

ECS DESIGN TEXTBOOK

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ECS COMPOSITES

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Table of Contents

| | |
|--|-----------|
| COMPANY OVERVIEW..... | 11 |
| COMPANY HISTORY | 11 |
| SMALL BUSINESS CLASSIFICATION | 11 |
| EQUAL EMPLOYMENT OPPORTUNITY | 11 |
| JOB SAFETY & THE ENVIRONMENT | 11 |
| FACILITY & LOCATION..... | 11 |
| TRANSPORTATION..... | 11 |
| CONTRACT MANAGEMENT | 11 |
| COMPUTER SYSTEMS..... | 12 |
| INTERNATIONAL SCOPE | 12 |
| CAPABILITIES OVERVIEW..... | 13 |
| MAKE-TO-ORDER | 13 |
| MANUFACTURING CAPABILITIES | 13 |
| PRODUCT FLEXIBILITY..... | 13 |
| ABILITY TO CUSTOMIZE..... | 13 |
| EXCEPTIONAL QUALITY..... | 13 |
| SUPERIOR PERFORMANCE..... | 14 |
| ECS PRODUCT DESIGN PHILOSOPHY | 15 |
| DESIGN OBJECTIVE..... | 15 |
| FEW LIMITATIONS | 15 |
| IMAGINATION..... | 15 |
| PERFORMANCE OBJECTIVE..... | 15 |
| COMPETITIVE PRICING..... | 15 |
| THE REAL ENVIRONMENT | 16 |
| MIL-STD-210C SUMMARY | 16 |
| 5.1 WORLDWIDE SURFACE ENVIRONMENT..... | 16 |
| 5.1.1 HIGH TEMPERATURE..... | 16 |
| 5.1.1.2 Frequency of Occurrence..... | 16 |
| 5.1.1.3 Long Term Extremes..... | 17 |
| 5.1.2 LOW TEMPERATURE..... | 17 |
| 5.1.2.2 Frequency of Occurrence..... | 17 |
| 5.1.2.3 Long Term Extremes..... | 17 |
| 5.1.3 HIGH ABSOLUTE HUMIDITY..... | 17 |
| 5.1.3.1 Highest Recorded..... | 17 |
| 5.1.3.2 Frequency of Occurrence..... | 17 |
| 5.1.3.3 Long Term Extremes..... | 18 |
| IDENTIFYING THE TARGETED ENVIRONMENT | 18 |
| MAKING A RISK ASSESSMENT | 18 |
| DOWNGRADED SPECIFICATIONS | 18 |
| The 1990 Persian Gulf Experience | 18 |
| Surface Temperature | 19 |
| Material Failures..... | 19 |

| | |
|--|-----------|
| Demand High Performance Requirements | 19 |
| COST VS. PERFORMANCE | 19 |
| EXTREME THINKING | 19 |
| Demand High Performance Requirements | 19 |
| SURVIVING THE NATURAL ENVIRONMENT | 20 |
| SURVIVING THE OUTER LIMITS OF THE ENVIRONMENT | 20 |
| Material Properties | 20 |
| Realistic Testing | 20 |
| SELECTING THE CORRECT CONTAINER MATERIAL | 20 |
| NON-REINFORCED THERMOPLASTICS | 20 |
| Interior Pressure | 21 |
| Yield Temperature | 21 |
| Moisture Failure | 21 |
| Reduced Performance Requirements | 21 |
| Avoiding Inadequate Manufacturing Processes | 21 |
| Advantages of Non-Reinforced Thermoplastics | 21 |
| Non-Reinforced Plastics | 22 |
| REINFORCED THERMOPLASTIC COMPOSITES | 22 |
| Reinforced Strength | 22 |
| Long Glass Fibers | 22 |
| Short Glass Fibers | 22 |
| Flow Form Compression Molding | 22 |
| Advanced Composites | 23 |
| Process Limitations | 23 |
| Chemical Resistance | 23 |
| Summary | 23 |
| ABOUT REINFORCED THERMOSET COMPOSITES | 23 |
| Thermoset Vs. Thermoplastic | 24 |
| Electrometric Compression Molding | 24 |
| Resin Selection | 24 |
| High Fiber Percentage | 24 |
| Elastomeric Plug Compression Molding | 24 |
| Comparing Molding Techniques | 25 |
| Advantages of Composites | 25 |
| Summary | 25 |
| Selecting a Supplier | 25 |
| ABOUT METALLIC MATERIALS | 26 |
| Design Flexibility | 26 |
| Chemically Active Metals | 26 |
| Oxidation | 26 |
| Non-Conductive Surfaces | 26 |
| Painting Required | 27 |
| Require Chemical Agent Resistive Coatings (CARC) | 27 |
| Denting | 27 |
| Summary | 27 |
| ABOUT LAMINATED MATERIALS | 27 |
| Attacked by Fungus | 28 |

| | |
|--|-----------|
| Labor Intensive | 28 |
| Performance Problems | 28 |
| Decontamination Problems | 28 |
| Summary | 28 |
| HERMETICALLY SEALED CONTAINERS | 29 |
| MOISTURE-VAPOR TRANSMISSION RATE | 29 |
| CLOSURE DESIGN AND GASKET SELECTION | 29 |
| HARDWARE SEALS AND GASKETS | 29 |
| AVOIDING DISSIMILAR METALS | 30 |
| AIR BREATHER VALVE SELECTION AND PERFORMANCE | 30 |
| CONTAINER STRENGTH | 30 |
| CLIMATIC EXTREMES | 30 |
| AIR VALVE DESIGN | 30 |
| AIR VALVE SIZE | 31 |
| INTERNAL PRESSURE DIFFERENTIALS | 31 |
| DISSIPATING PRESSURE CHANGES | 31 |
| CRACKING & RE-SEALING VALVES | 31 |
| AIR VALVE CYCLES | 32 |
| REDUCING BREATHING CYCLES | 32 |
| Unrealistic Requirements | 32 |
| Real World Protection | 32 |
| DISQUALIFYING CONTAINER MATERIALS | 32 |
| DESICCANT QUANTITY AND MAINTENANCE | 32 |
| INGRESS OF MOIST AIR | 33 |
| REDUCING BREATHING CYCLES | 33 |
| DESICCANT QUANTITY | 33 |
| DESICCANT MAINTENANCE | 33 |
| SURVIVING THE HUMAN ENVIRONMENT | 35 |
| TRANSPORTATION HAZARDS | 35 |
| Resistance to Transportation Hazards | 35 |
| FRAGILITY OF CONTAINED EQUIPMENT | 35 |
| Vibration | 35 |
| Shock Vs. Vibration | 36 |
| TRANSPORTATION METHODS | 36 |
| ON-ROAD VEHICLES | 36 |
| OFF-ROAD VEHICLES | 36 |
| RAILROAD | 37 |
| AIRCRAFT | 37 |
| SHIPS & BOATS | 37 |
| HANDLING HAZARDS | 38 |
| Rough Handling | 38 |
| Realistic Simulation | 38 |
| THE REAL WORLD OF MAN PORTABLE EQUIPMENT | 38 |
| Real World Abuse | 38 |
| DYNAMIC TESTING OF CONTAINERS | 39 |
| Testing Methods | 39 |
| CHARACTERISTICS OF CONTAINER MATERIALS | 40 |

| | |
|---|----|
| Compression Strength..... | 40 |
| Flexural Strength..... | 40 |
| Tensile Strength | 40 |
| Fungus Resistance..... | 40 |
| Water Vapor Transmission Rate | 40 |
| STRUCTURAL STRENGTH OF CONTAINERS | 40 |
| Free Fall Drop Test | 40 |
| Shock Pulse Test | 41 |
| Vibration Tests | 41 |
| Static Load Test / Concentrated Load Test | 41 |
| Loose Cargo Bounce Test | 41 |
| Handle Pull Test..... | 41 |
| Projectile Impact Test..... | 42 |
| ENVIRONMENTAL RESISTANCE OF CONTAINERS | 42 |
| Temperature Shock Test..... | 42 |
| High Temperature Test..... | 42 |
| Low Temperature Test..... | 42 |
| Altitude Cycle Test..... | 42 |
| Humidity Cycle Test | 42 |
| Salt Spray Test | 43 |
| Sand and Dust Resistance Test..... | 43 |
| Water Tests..... | 43 |
| ABOUT SHOCK AND VIBRATION PROTECTION | 43 |
| FORCES THAT DAMAGE EQUIPMENT..... | 43 |
| Basic Description of Shock Forces | 44 |
| Basic Description of Vibration and Vibrational Forces | 44 |
| Natural Frequency..... | 44 |
| Resonant Frequencies | 45 |
| ABSORBING SHOCK ENERGY | 45 |
| Structural Attenuation | 45 |
| Dynamic Attenuation | 45 |
| Damping of Shock Induced Motion..... | 46 |
| Shock Mounts | 46 |
| ABSORBING VIBRATIONAL ENERGY..... | 46 |
| Structural Attenuation | 47 |
| Dynamic Attenuation | 47 |
| Linkage of Shock and Vibration Attenuation..... | 47 |
| FOAM CUSHIONING MATERIALS..... | 47 |
| POLYETHYLENE FOAMS..... | 48 |
| Thermoplastic Material | 48 |
| Cushioning Characteristics | 48 |
| Temperature and Dynamics | 48 |
| Absorption Vs. Adsorption | 49 |
| Expansion and Contraction Problems..... | 49 |
| Chemical Characteristics | 49 |
| POLYURETHANE FOAMS | 50 |
| Thermoset Material..... | 50 |
| Cushioning Characteristics | 50 |

| | |
|---|-----------|
| Temperature and Dynamics | 51 |
| Expansion and Contraction | 51 |
| Chemical Characteristics | 51 |
| EXPANDED POLYSTYRENE FOAMS (EPS)..... | 51 |
| CWA CONTAMINATION & DECONTAMINATION | 52 |
| Decontamination Agents..... | 52 |
| DS2 and STB Resistance | 52 |
| CARC Paint | 52 |
| Ideal Materials | 52 |
| ESD/EMI/RFI/TEMPEST SHIELDING | 52 |
| Shielding Methods | 53 |
| Electromagnetic Waves..... | 53 |
| “E” and “H” Fields..... | 53 |
| Effective Shielding..... | 53 |
| EMI/RFI/TEMPEST Shielding..... | 54 |
| Aluminum Shields | 54 |
| Shielded Plastics | 54 |
| THERMOSET COMPOSITES..... | 54 |
| THERMOPLASTIC COMPOSITES..... | 55 |
| CONDUCTIVE THERMOPLASTIC COMPOSITES..... | 55 |
| NON-REINFORCED THERMOPLASTIC MATERIALS | 55 |
| CASE STYLES OLD & NEW | 56 |
| NON-OPERATING CASE STYLES | 56 |
| VALISE CASES | 56 |
| CARRYING CASES | 56 |
| COMMERCIAL TRANSIT CASES | 57 |
| HEAVY DUTY TRANSIT CASES | 58 |
| MILITARY TRANSIT CASES | 58 |
| OPERATING STYLE CASES | 59 |
| RIGID RACK-MOUNT CASES..... | 60 |
| VIBRATION ATTENUATED RACK-MOUNT CASES..... | 60 |
| SHOCK & VIBRATION ATTENUATED RACKMOUNT CASES..... | 61 |
| COMBINATION CASES | 62 |
| PANEL MOUNT CASES | 63 |
| FOAM SUSPENSION OPERATING CASES | 64 |
| FINISHES FOR CONTAINERS & HARDWARE | 65 |
| EXTERIOR CONTAINER FINISHES | 65 |
| Container Hardware Finishes..... | 65 |
| Permanence of Finishes | 65 |
| Pigmented Plastic Materials..... | 65 |
| PLATED FINISHES & CONVERSION COATINGS | 66 |
| Aluminum Finishes..... | 66 |
| MIL SPEC Finishes | 66 |
| PAINTS..... | 66 |
| CARC Paint | 67 |
| Powder Coating..... | 67 |

| | |
|---|-----------|
| GEL COATS FOR FIBERGLASS PARTS..... | 67 |
| Gel Coat Application..... | 67 |
| Gel Coat Bonding | 68 |
| Gel Coat Unnecessary..... | 68 |
| Compression Molding Preferred..... | 68 |
| MANUFACTURING METHODS FOR CONTAINERS..... | 69 |
| MOLDING METHODS FOR CONTAINERS..... | 69 |
| CLOSED TOOL METHODS | 69 |
| Elastomeric Compression Molding..... | 69 |
| Reinforcement Materials..... | 69 |
| Repeatability | 69 |
| Resin Application..... | 70 |
| Closing the Mold..... | 70 |
| Uniform Pressure | 70 |
| High Fiber Percentage..... | 70 |
| Curing the Part | 70 |
| Flow Form Compression Molding..... | 70 |
| High Pressure Molding | 71 |
| Materials Described | 71 |
| Material Preparation..... | 71 |
| Placing the Material | 71 |
| Closing the Mold..... | 71 |
| Glass Fiber Distribution..... | 72 |
| Removing the Part..... | 72 |
| Molded-In Features..... | 72 |
| Matched Metal Molding with Pre-forms | 72 |
| Pre-Form Making..... | 72 |
| Pre-Form Drying..... | 73 |
| Molding Process..... | 73 |
| Curing the Part | 73 |
| Low Fiber Percentage | 73 |
| Process Inconsistencies..... | 73 |
| Structural Weaknesses..... | 74 |
| Process Comparisons | 74 |
| Matched Metal Molding with Sheet Molding Compound | 74 |
| Materials Described | 74 |
| Placing the Material | 75 |
| Closing the Mold..... | 75 |
| Glass Fiber Distribution..... | 75 |
| Curing the Part | 75 |
| Process Comparisons | 75 |
| Structural Weaknesses..... | 76 |
| Matched Metal Molding with Bulk Molding Compound..... | 76 |
| Placing the Material | 76 |
| Closing the Mold..... | 76 |
| Glass Fiber Distribution..... | 76 |
| Curing the Part | 77 |

| | |
|--|----|
| Process Comparisons | 77 |
| Structural Weaknesses..... | 77 |
| Resin Transfer Molding | 77 |
| Required Equipment | 77 |
| Surface Preparation..... | 77 |
| Placing the Material | 78 |
| Closing the Mold..... | 78 |
| Injecting the Resin | 78 |
| Process Comparisons | 78 |
| Structural Weaknesses..... | 78 |
| Molding of Pre-Impregnated Thermoset & Thermoplastic Materials | 79 |
| SMC Similarities..... | 79 |
| Process Comparisons | 79 |
| Thermoset Materials | 79 |
| Thermoplastic Materials | 79 |
| Cold Molding..... | 80 |
| Low Cost Molds..... | 80 |
| Mold Preparation | 80 |
| Room Temperature Molds | 80 |
| Curing the Part | 81 |
| Process Comparisons | 81 |
| OPEN TOOL METHODS | 81 |
| Hand Lay-Up Fiberglass Molding | 81 |
| Mold Preparation | 81 |
| Material Placement | 82 |
| Curing the Part | 82 |
| Process Comparisons | 82 |
| Structural Weaknesses..... | 82 |
| Spray-Up Fiberglass Molding..... | 83 |
| Mold Preparation | 83 |
| Material Placement | 83 |
| Curing the Part | 83 |
| Process Comparisons | 83 |
| Structural Weaknesses..... | 83 |
| Vacuum Bag Molding | 84 |
| Mold Preparation | 84 |
| Material Placement | 84 |
| Applying the Vacuum Bag | 84 |
| Curing the Part Without Heat..... | 85 |
| Curing the Part with Heat | 85 |
| Process Comparisons | 85 |
| Structural weaknesses..... | 85 |
| MOLDING METHODS FOR NON-REINFORCED THERMOPLASTICS | 86 |
| Injection Molding..... | 86 |
| Mold Design..... | 86 |
| High Pressure Molding | 86 |
| Materials Described | 87 |
| Closing the Mold..... | 87 |

| | |
|--|----|
| Clamping the Mold | 87 |
| Injecting the Material | 87 |
| Glass Fiber Distribution | 87 |
| Removing the Part | 88 |
| Molded-In Features | 88 |
| Process Comparisons | 88 |
| Structural Weaknesses | 88 |
| Thermoforming | 88 |
| Basic Thermoforming | 89 |
| Selecting the Thermoplastic Material | 89 |
| Preparing the Thermoplastic Sheet | 89 |
| Heating the Thermoplastic Sheet | 89 |
| Forming the Part | 89 |
| Removing the Formed Part | 90 |
| Process Comparisons | 90 |
| Structural Weaknesses | 90 |
| Summary | 90 |
| Pressure Forming | 90 |
| Selecting the Thermoplastic Material | 91 |
| Preparing the Thermoplastic Sheet | 91 |
| Heating the Thermoplastic Sheet | 91 |
| Stretching the Sheet | 91 |
| Forming the Part | 91 |
| Removing the Formed Part | 92 |
| Process Comparisons | 92 |
| Structural Weaknesses | 92 |
| Rotational Molding | 92 |
| Required Equipment | 93 |
| Materials Described | 93 |
| Tooling Described | 93 |
| Molding the Part | 93 |
| Process Comparisons | 94 |
| Structural Weaknesses | 94 |
| Summary | 94 |
| Blow Molding | 94 |
| Blow Molding Techniques | 94 |
| Mold Design | 95 |
| Low Pressure Process | 95 |
| Materials | 95 |
| Equipment | 95 |
| Molding the Part | 95 |
| Process Comparisons | 96 |
| METAL FORMING | 96 |
| Aluminum Characteristics | 96 |
| Deep Drawing | 96 |
| Required Equipment | 97 |
| Tooling Description | 97 |
| Preparing the Aluminum Sheet | 97 |

| | |
|---|----|
| Placing the Material | 97 |
| Forming the Part | 98 |
| Multiple Stage Drawing..... | 98 |
| Secondary Operations | 98 |
| Process Comparisons | 98 |
| Fabrication | 98 |
| Modular Assembly | 99 |
| FABRICATION OF LAMINATED CONTAINERS | 99 |

COMPANY OVERVIEW

COMPANY HISTORY

ECS was founded in 1954 in Oakland, California, USA to manufacture wooden shipping containers. In 1964, the company relocated to Grants Pass, Oregon, USA where it evolved into a major supplier of reusable packaging for sensitive electronic equipment. Expansion of its compression molding capacity for container applications led to the custom molding of thermoplastic and thermoset composite parts. Thermoforming and pressure molding of non-reinforced plastic materials has added versatility to the company. Expansion into the rotational molding of thermoplastic materials has rounded out the transformation of the company from its wooden box origins.

SMALL BUSINESS CLASSIFICATION

ECS is classified as a small business. The company is located in a substantial labor surplus area. The local work force is of high quality and is important to the success and growth of the company.

EQUAL EMPLOYMENT OPPORTUNITY

ECS is an equal opportunity employer and complies with US Federal and State of Oregon labor laws. Additionally, the company is proud to maintain an Affirmative Action Program that has been approved by the United States Department of Labor and that is periodically audited for compliance.

JOB SAFETY & THE ENVIRONMENT

The company is in strict compliance with Oregon State Department of Environmental Quality (DEQ) and US Federal Environmental Protection Agency (EPA) regulations. And, the company has an enviable record of job related safety.

FACILITY & LOCATION

The facility includes 80,000 square feet of modern, concrete tilt-up factory and office space which is located on a ten acre light industrial site. The company is located in the Rogue River Valley of Southwestern Oregon, famous for its runs of salmon, steelhead and the adventure of whitewater rivers. The area is surrounded by the beauty of evergreen covered mountainous terrain and pristine wilderness areas.

TRANSPORTATION

ECS is located along Interstate Highway 5 (I-5) in Southwestern Oregon. The interstate highway system provides many surface freight carriers for the shipment of ECS products throughout the United States and Canada. The area is also serviced by major airlines, UPS blue label and Federal Express services from an excellent airport in Medford, Oregon, approximately twenty-five miles from ECS.

CONTRACT MANAGEMENT

ECS maintains a full contract management department. The company utilizes a sophisticated cost accounting system to record and analyze every job related expense, including labor by task, by lot, and by work station. This cost data is then rolled into learning curve altered labor estimates for

quotation purposes. The ECS manufacturing management system utilizes IBM MAPICS software to provide detailed material cost data and the ability to fully document support contract cost estimates. ECS regularly participates in fact finding, quotation analysis and negotiations of contracts which are subject to the requirements of the US Federal Acquisition Regulations (FAR). The contract management department is also responsible for the cost management of major fixed price contracts and developmental contracts.

COMPUTER SYSTEMS

ECS uses sophisticated data management systems. The company utilizes an installed network of personal computers and its mainframe system to manage the manufacturing process, to design its products, and to communicate with its customers. ECS is also a sophisticated Internet user, with a comprehensive web site and support capabilities for secure, on-line e-commerce.

INTERNATIONAL SCOPE

ECS products are shipped to a blue ribbon group of customers in the United States and around the world. Domestic USA sales are handled thru direct ECS field engineers, sales personnel, and sales representatives. ECS products are sold internationally thru a network of representatives located in the Americas, Europe, Asia, and the Mid-East. The company has licensed its composite molding technology to a French partner, Constructions Mechanique de Normandie (CMN) in Cherbourg, France. The French company designs and manufactures complete container assemblies and completes final assembly, and delivers containers and enclosures to European markets.

CAPABILITIES OVERVIEW

MAKE-TO-ORDER

ECS Composites has evolved as a sophisticated make-to-order manufacturer of reusable containers and enclosures, as a custom molder of composite parts and as a molder of thermoplastic materials for diverse applications. Electronic equipment of all kinds comprise the most prominent applications for the containers and enclosures manufactured by the company. Custom compression molded composite parts find applications in a broad range of uses including automotive, heavy truck, commercial aircraft and military hardware. Molded plastic parts are used in a variety of commercial and industrial applications.

MANUFACTURING CAPABILITIES

The company stresses its capabilities and responds to each new application by first determining if it fits within the range of those capabilities. Coupled with standard products and stock lines of transit cases and 19-inch rackmount electronic enclosures, the capabilities focus of the company has opened a world of additional manufacturing possibilities. The resident capabilities of the company allow the manufacture of many products that are not currently manufactured for its present customers. These capabilities include the compression molding of crushed-core honeycomb composite structures, sheet molding compound (SMC), and bulk molding compound (BMC); the manufacture of drawn and fabricated aluminum containers and enclosures; and the manufacture of a variety of metal parts. ECS' innovative tooling for compression molding also constitutes a product line of the company.

PRODUCT FLEXIBILITY

In support of the make-to-order nature of the business, ECS has implemented management systems, engineering capabilities and computerized communication facilities that allow the manufacture of a broad variety of products for a diverse group of customers, both domestic USA and foreign. These installed systems provide ECS with the flexibility to respond to changes in products, delivery schedules and/or customer needs in a real-time environment.

ABILITY TO CUSTOMIZE

ECS maintains a large number of standard designs and products, and custom products are designs and manufactures for applications that cannot be matched to standard products. Computer Aided Design and Solid Modeling of customized products supports every unique application.

EXCEPTIONAL QUALITY

ECS maintains exceptionally high standards of quality for all of its products. The MIL-I-45208 Quality Assurance system insures that every product meets the highest dimensional and appearance standards. ECS utilizes statistical process control (SPC) to optimize its manufacturing processes, and is a certified SPC supplier to major US aerospace companies. The ECS quality system and the professionalism of its personnel have been highly complimented by government, military and commercial customers. ECS is the recipient of the highly prized Star Supplier Award from Lockheed Corporation.

SUPERIOR PERFORMANCE

ECS cases and 19-inch rackmount electronic enclosures utilize the most durable and highest quality materials available anywhere. Compression molded composite parts utilize innovative glass fiber materials which are molded in creatively designed tooling manufactured by ECS. Rotationally molded polyethylene containers are molded in ECS designed and manufactured tooling. The end result of our effort is the design, manufacture and delivery of products that demonstrate consistently superior performance.

ECS PRODUCT DESIGN PHILOSOPHY

DESIGN OBJECTIVE

The ECS design objective is focused...

- Analyze actual requirements of each application.
- Design the optimum product for the application.
- Insure that the new product can be manufactured at consistently high quality.

It is a simple objective to state. However, constant attention is provided by a positively motivated workforce to insure that every customer is satisfied and that every design solution is the optimum that can be achieved.

FEW LIMITATIONS

ECS begins the design process with very few natural limitations. Almost any type or style of container or enclosure, and molded composite or plastic part, can be fabricated by the manufacturing departments at ECS, together with the support of ECS' specialty vendors, who are partners in the manufacturing process. ECS' product design approach is similar to an immense assortment of LEGO parts... the number of potential combinations of our standard, or custom, parts and pieces is nearly infinite. Spanning the range from metal forming to compression molding and rotational molding, to foam fabrication and plastic fabrication, to shock mounting and structural damping, to welding and ultrasonic bonding, to conductive EMI/RFI shielding materials and powder coating... ECS has amazing design diversity... and, as a result, ECS has few design product limitations.

IMAGINATION

The imaginative mind of ECS continues to conceive creative design solutions for diverse application problems presented by our customers. This capabilities manual stresses the broad range of product designs that have already been manufactured by the company. Our creative imaginations will determine the shape of products manufactured tomorrow.

PERFORMANCE OBJECTIVE

ECS supports the concept of longevity of service for manufactured products. We are opposed to planned obsolescence. The container, enclosure or custom molded part must perform its assigned role for the foreseeable life of the product with which it is associated. Nothing less is acceptable to ECS.

COMPETITIVE PRICING

We at ECS believe that every customer and every end user of a container, enclosure or custom molded part should demand and receive value for his/her expenditure. We also believe that those who specify, manufacture or buy inferior materials or inadequate product designs simply to lower the price of their resulting end products, should be held responsible for the failures of those products in use. At ECS, high quality products are priced competitively, but we refuse to be cheap or cheapened.

THE REAL ENVIRONMENT

MIL-STD-210C SUMMARY

The United States Department of Defense Specification, titled Climatic Information to Determine Design and Test Requirements for Military Systems and Equipment, is an excellent manual of predictable, worldwide, environmental and climatic conditions. The following MIL-STD-210 paragraphs must be seriously considered by designers and specifiers of containers, transit cases, electronic enclosures and other parts or equipment that will be exposed to the hazards of the earth's real environment.

5.1 WORLDWIDE SURFACE ENVIRONMENT

The data in this section is based on surface weather observations over land areas. Data is provided for the most extreme ever recorded values that occur for specified frequencies-of-occurrence for the most severe month and long term climatic extremes that would be equaled or exceeded at least once during 10, 30 or 60 years of exposure.

More extreme climatic values should be considered for equipment whose failure to operate is life threatening, or for material that would be rendered useless or dangerous after a one-time exposure.

5.1.1 HIGH TEMPERATURE

Temperatures discussed in this section represent temperatures of the free air in the shade about 1.5 Meters above the ground. The ground surface will attain temperatures 15°C to 30°C higher than that of the free air, depending upon radiation, conduction, wind, and turbulence.

The temperature attained by military equipment exposed to high temperatures will vary greatly with the physical properties of the equipment affecting heat transfer and capacity, and with the type of exposure. (Probably the worst exposure is that of equipment placed on the ground in direct sunshine.) The equipment temperature will also be dependent on solar radiation reflected to it from the ground, long wave radiation from the heated ground, long wave radiation to the cold sky, scattered radiation from the sky and nearby clouds, the vertical temperature distribution in the free air surrounding the equipment, and total ventilation from wind and turbulence.

5.1.1.2 Frequency of Occurrence

The hottest area of the world lies in the interior of northern Africa eastward to India. The hottest part of this area is the Sahara desert, which qualifies as the worst part of the world for high temperature. The 1%, 5%, and 10% temperatures (i.e. temperatures that occur that percentage of the time) are 49°C, 46°C, and 45°C, respectively.

Hot extremes are part of a well pronounced daily cycle. The daily maximum lasts only a couple of hours. However, it is accompanied by intense solar radiation that causes equipment to attain temperatures considerably higher than free-air values.

If military equipment is to be designed to operate in a 1% temperature any place in the world during the warmest month of the year, then it must be designed for a daily cycle in which the air temperature attains a maximum of at least 49°C at a height of 1.5 Meters above the ground.

5.1.1.3 Long Term Extremes

High temperatures that would be expected to occur at least once during 10, 30, and 60 years in the hottest part of the world are 53°C, 54°C, and 55°C, respectively.

5.1.2 LOW TEMPERATURE

Low temperature extremes occur from the optimum combination of several meteorological elements. Long absence of solar radiation, a snow cover, and calm air are the most essential requirements, with the ultimate fall in temperature dependent upon the duration of these conditions. Since these conditions can exist for extended periods at high-latitude continental areas, there can be much longer durations of cold than high temperatures.

5.1.2.2 Frequency of Occurrence

The coldest areas of the world, excluding Antarctica, are the central part of the Greenland ice cap (2,500m to 3,000m elevation) and Siberia between 62° and 68° North, and 125° to 145° East (less than 800m elevation). The 1%, 5%, 10% and 20% temperatures in these areas are -60°C, -56°C, -53°C, and -51°C, respectively. These temperatures will also be encountered during other months and in other high latitude locations in the northern hemisphere, but less frequently.

5.1.2.3 Long Term Extremes

Low temperatures that would be expected to occur at least once during 10, 30, and 60 years in the coldest area of the world are -65°C, -67°C, and -69°C.

5.1.3 HIGH ABSOLUTE HUMIDITY

Absolute humidity is the mass (i.e. weight) of water vapor in a specified volume of air. It is generally specified in grams/cubic meter or parts of water vapor per million parts of dry air. The dew point is the temperature at which condensation will occur if the air is cooled at constant atmospheric pressure. The dew point is used to calculate the absolute humidity. Since the amount of water vapor that the air can hold increases with temperature, areas with the highest absolute humidities are hot locations (usually at the edge of a desert) adjacent to very warm bodies of water.

5.1.3.1 Highest Recorded

The highest accepted dew point observation is 93° F recorded in July (exact date unknown) at Sharjar, Arabia, on the shore of the Persian Gulf. This corresponds to a mixing ratio of 35 x 10 parts per million.

5.1.3.2 Frequency of Occurrence

The highest dew points in the world were recorded along the narrow coastal deserts of the Red Sea, Gulf of Aden, and the Persian Gulf eastward to the northern Arabian Sea. In this area, Abadan, Iran was found to have the highest dew point extremes are 30°C, 28°C, and 28°C, respectively.

Although Abadan has the highest 1% extreme, extremes for higher percents are found in regions where the dew points are somewhat lower but more nearly constant. The 5%, 10% and 20% dew point extremes are 86°F, 84°F and 83°F, respectively.

5.1.3.3 Long Term Extremes

The long term extreme will be a repetition of a daily cycle typical of a location experiencing high absolute humidities for extended periods of time. Though this location will not experience the high 1% value of the coastal desert, it will experience periods of sustained high dew points only slightly lower than the 1% value.

Long periods with absolute humidities were found at Belize City, Belize during August. The dew points range between 25°C and 28°C for ambient temperatures between 27°C and 30°C. Such conditions are found in coastal, moist tropical locations and are approximately duplicated for a month. Adjacent months will experience only slightly less humid extremes.

IDENTIFYING THE TARGETED ENVIRONMENT

Spend a few summer months in the Saudi Arabian desert or winter months in the arctic wilderness. Here both man and materiel are tested to the limits of their endurance. But are such tests a reasonable way to establish the performance criteria for containers, enclosures and custom molded composite parts? Is it realistic to design a container, enclosure or composite part for reliable operation in a targeted environment, like the United States or Central Europe, when the probability of use in an extreme environment may reasonably be expected to occur during the effective life of the product?

MAKING A RISK ASSESSMENT

The answers to these questions are complex and should not be simplified. The questions entail evaluations of risk. Containers and enclosures are expected to protect valuable equipment from the natural environment and from the hazards of man. The physical survival of men and women (i.e. the lives of these people), who depend on the use of that enclosed equipment, may depend on the survival of the equipment, which in turn depends on the survival of the container or enclosure. Or, at a lower level of exposure, the financial success of a job related objective may be jeopardized by the failure of a container and its equipment. Determining what is at stake is as important as correctly evaluating the probability of exposure to damaging or destructive environments during the expected life of the equipment.

DOWNGRADED SPECIFICATIONS

Qualification testing and product performance testing requirements for reusable containers and enclosures were systematically reduced in the United States during the 1980's and early 1990's. Considering the adverse effects of extreme natural environment examples of Britain's winter sea war in the Falkland Islands and United States involvement in the tropics of Panama and in the Saudi desert, a rational assessment of performance requirements should result in higher, not lower, testing limits. Instead, key military specifications, such as MIL-C-4150 have had temperature testing requirements reduced from a range of -65°F to +160°F down to -20°F to +140°F.

The 1990 Persian Gulf Experience

In 1990, prior to the deployment of US. Military forces to the Persian Gulf in Operation Desert Shield and Desert Storm, in effect, any material that could pass rough handling and drop testing in a range of

-28°C to +60°C was considered to be fully capable of performing in the Saudi Arabian desert or on an arctic expedition. This presumption was, and is, false. Daytime temperatures in the shade in Saudi Arabia commonly reach 49°C, ground surface temperatures reach 93°C, and the temperature gain (i.e. solar gain) experienced by objects exposed to the sun is amplified by the reflection of solar energy from the ground.

Surface Temperature

Military containers and enclosures in these environments will be placed on the ground, which may be as hot as 93°C, will be showered with intense solar radiation, and will be further heated by the reflection of heat from surrounding ground areas. Within a 24 hour daily cycle, these containers will drop to nighttime temperatures of 32°C to 38°C in the presence of highly humidified air. Worse yet, these containers may be alternately stored and moved from temperature controlled shelters to outside exposure in intense heat and humidity.

Material Failures

Under conditions of intense heat, daily temperature cycling, and dripping humidity, inadequate container materials will fail to provide protection for enclosed equipment. And metallic containers, which absorb and retain immense amounts of solar heat, will present an obvious infrared image of detectability. At arctic temperatures, low temperature failures of inadequate materials can cause the failure of important missions, too.

Demand High Performance Requirements

Reduced testing requirements for containers and enclosures cannot be condoned. Military hardware, which is stored for future use, can be deployed anywhere in the world. Such equipment must be designed, tested and qualified for use anywhere.

COST VS. PERFORMANCE

It is easier and less expensive to design for the relatively benign environments of the Continental United States or for Central Europe than for the extreme environments of the Mid-East or arctic. However, if the product being designed is intended for military use, it is unrealistic to do so. The world is now a small globe, with regional and isolated points of conflict that have no respect for climatic preference. Nations of the world are on an air transport fast track, both militarily and industrially, to expose man and his equipment to extreme environmental exposure. The higher cost of proper environmental preparedness of essential equipment should never be confused with the lower cost and lower protection required by benign environmental exposure.

EXTREME THINKING

The real environment cannot be changed by the wishful thinking of man. The natural environment must be met at its extremes, or its extremes will defeat the inadequately prepared man.

Demand High Performance Requirements

Reduced testing requirements for containers and enclosures cannot be condoned. Military hardware, which is stored for future use, can be deployed anywhere in the world. Such equipment must be designed, tested and qualified for use anywhere.

SURVIVING THE NATURAL ENVIRONMENT

SURVIVING THE OUTER LIMITS OF THE ENVIRONMENT

MIL-STD-210 is a reservoir of information about the world's natural environment and the frequency with which extreme conditions occur. Using this specification as a design guide, it is possible to specify competitively priced materials and reusable containers manufactured from those materials that will survive the extremes. Such materials are readily available, and are capable of performing under the worst conditions presented by man and the environment.

Material Properties

The key to survivability over a broad range of climatic and handling conditions is a combination of impact resistance at extreme temperatures, mechanical strength (compressive, flexural, and tensile) at those extremes, inherent toughness, and excellent chemical & solvent resistance. The survivability of the container or enclosure is a function of the natural properties of the materials from which it is manufactured. If the raw materials yield at the extremes, then the container must be expected to fail, also.

Realistic Testing

As a minimum requirement, containers, cases, enclosures and structural composite parts that may be exposed to arctic chill and/or solar gain desert temperatures, should be tested at temperatures that equal the temperatures of field use. The testing concept is simple to understand: demand rough handling tests that simulate the real world. A military equipment user (who may be dug-in in a desert battlefield or manning a post in the arctic) will not be enjoying the comfort of a laboratory or thermostatically controlled bunker. To him, or her, only one thing counts... will it work when it's needed?

SELECTING THE CORRECT CONTAINER MATERIAL

Commonly used container and enclosure materials are available in five basic families. A comparative list of typical material properties can be referenced in these Internet Pages. The most commonly used materials are:

- Non-reinforced thermoplastics
- Reinforced thermoplastic composites
- Reinforced thermoset composites
- Metallics
- Laminated Materials

NON-REINFORCED THERMOPLASTICS

At moderate temperatures, non-reinforced thermoplastics are suitable for a wide variety of applications. At high temperature, however, materials such as polyethylene and ABS, may reach a yield temperature (a failure point) which results from the combination of the actual temperature of the material (including the solar gain) and the build-up of pressure inside the container. With the occurrence of these conditions, internal pressure, which is never fully dissipated by an automatic air breather valve (discussed in the next section), may cause damage to the container.

Interior Pressure

It is surprising that residual pressure of 0.5 PSI can cause serious container failures at high temperature, but it is easier to understand when one calculates the total applied force on the inside of a 20" x 20" x 20" container. Internal air pressure of 0.5 PSI will cause 200 pounds of force to be uniformly applied against each interior surface of the container (i.e. an area 20" x 20" times the pressures of 0.5 pounds per square inch = 200 Lbs.). At a residual pressure of 1.0 PSI, the internal force will be 400 pounds on each surface. If the case or enclosure also contains closed cell polyethylene foam as a cushioning material, trapped cells of air in the foam expand as the temperature rises and the foam applies additional force against the interior walls of the container.

Yield Temperature

If inadequate non-reinforced thermoplastic materials are chosen for reusable container applications and they reach their yield temperatures, the internally applied force may be sufficient to cause permanent distortion, because the thermoplastic material stretches. Similar results may occur when containers made from these materials are stacked for storage or used in a stacked configuration at high temperature and in sunlit locations. Distortion and sagging may result from the loss of the mechanical rigidity of their plastic materials under the weight of the stacked containers and with the internally applied forces. This can result in inoperable or dangerous deployments of military hardware.

Moisture Failure

If the container designer chooses an air breather valve with a lower pressure setting (cracking pressure) as a means of reducing residual internal pressure and distortion, the valve will breathe more frequently and will cause a more rapid build-up of humidity and condensation inside the container. Since these containers are intended to be Method II (hermetically sealed) packages per MIL-P-116 (Methods of Packaging and Preservation), the accumulation of moisture, which results from down-grading the performance of the air valve, defeats the intended purpose of the container. It is not a suitable fix.

Reduced Performance Requirements

Reductions in the requirements for broad temperature performance of container materials have allowed expanded use of non-reinforced thermoplastic materials. These changes in requirements, however, invite failures of critical equipment during times of crisis if design considerations associated with these materials are not given careful attention.

Avoiding Inadequate Manufacturing Processes

Non-reinforced Thermoplastic materials are most commonly molded into containers using thermoforming processes, rotational molding, and injection molding methods. Each of these processes offers its own advantages and/or disadvantages in terms of the design of the product. However, special attention must be given to the unique design requirements of these materials in order to overcome the heat distortion performance and low temperature impact strength characteristics that are displayed by many thermoplastic raw materials.

Advantages of Non-Reinforced Thermoplastics

Thermoplastic Materials generally exhibit good resistance to ultra-violet radiation but this resistance can vary with differences in material types, additives and color. These materials are resistant to salt, dust & water, to solvents and cleaners, to fuels and petroleum products, and they are normally fungus

resistant. These materials are pigmented throughout and therefore do not need to be painted, as do metallic containers. Flammability and smoke generation characteristics of thermoplastics are specific to individual materials and should be evaluated prior to selection for use on individual applications.

Non-Reinforced Plastics

In summary, non-reinforced thermoplastic materials have many applications in commercial and industrial containers and enclosures. These materials are usable in military applications where performance extremes do not exceed the inherent characteristics of the materials.

REINFORCED THERMOPLASTIC COMPOSITES

Glass fiber reinforced thermoplastic materials overcome all of the performance limitations of their non-reinforced counterparts. The addition of glass fibers, which are available in a variety of lengths and types, provides substantial increases in tensile strength and impact resistance together with excellent high temperature and low temperature performance characteristics.

Reinforced Strength

Increased mechanical, temperature resistance and impact performance characteristics of these materials are directly related to the amount of glass fibers in the composite and to the length of those fibers in the finished part. As the length of the fibers increases, up to continuous fiber length, the thermoplastic resin is able to more effectively bond onto each fiber in the composite structure, and the strength of the composite part increases. As the number of fibers in the cross section of material increases, the composite structure is three dimensionally strengthened by the added fiber bonds and by the increased overlapping of the matrix of multi-directional reinforcements.

Long Glass Fibers

In essence, a glass fiber reinforced composite material can be compared to the classic game of tug-of-war. As the length of the rope is increased, more hands are able to grasp it. In the case of composite materials, long fibers which radiate in all directions are grasped by the adhesive bonds of the plastic substrate. This bonding to long strand reinforcements multiplies the strength and performance characteristics of the molded composite part.

Short Glass Fibers

Manufacturing techniques also affect the length of glass fibers that can be achieved. The injection molding process uses short glass fibers (milled fibers) which are unavoidably sheared into shorter lengths during the molding process. The resulting short fibers, which are from one-eighth to one-quarter of an inch in length, provide improved stiffness for the molded part. However, the stratification of the glass fibers generally reduces the impact strength of the base material. Tensile strengths are only slightly improved compared to non-reinforced materials.

Flow Form Compression Molding

The compression molding process allows the use of long fiber and continuous fiber reinforcements in thermoplastic composites. This molding process approaches the speed and design flexibility of the injection molding process, but the resulting parts are tougher, have higher impact strength, and substantially outperform other thermoplastic materials and short fiber composites at all temperatures.

Advanced Composites

Very high temperature thermoplastic composites with operating capabilities in excess of 315°C are only moldable using the flow form compression molding technique, which is the process employed by ECS Composites. This process has also been successfully used for molding highly conductive, high temperature composite moldings from graphite reinforced thermoplastic materials.

Process Limitations

Because long strand glass fibers, which may be used to reinforce thermoplastic sheet materials, change the elasticity of heated sheet, it is not possible to thermoform such materials. And, since rotationally molded parts are made from a finely ground powdered raw material, it is not possible to use glass fibers for the reinforcement of parts molded by this method, either.

Chemical Resistance

Most thermoplastic composite materials exhibit excellent resistance to ultra-violet radiation, to salt, to dust, to water and humidity, to solvents and cleaners, and to fuels and petroleum products. They are not hygroscopic nor do they exhibit a hydrolytic stability problem. They are not nutrients for fungi. They are resistant to DS2 and super tropical bleach (STB) decontamination agents and therefore do not need to be protected with chemical agent resistant coatings (CARC), as do metallic containers. These composite materials are pigmented throughout and therefore do not need to be painted to achieve the desired color.

Summary

In summary, reinforced thermoplastic composites demonstrate ideal physical, chemical resistance and electrical properties for many types of military, commercial and industrial containers and enclosures, and compression molded composite parts. These materials are excellent for military applications where durability is required from -53°C to +74°C. Many of these materials will perform satisfactorily at temperatures that are well in excess of these extremes. They are ideal substitutes for non-reinforced thermoplastic materials where higher levels of performance are required. They are excellent replacement materials for many metal parts, and they eliminate the need for painted finishes which are required on most metallic products. And, they are capable of being manufactured at high rates of production with full dimensional interchangeability.

ABOUT REINFORCED THERMOSET COMPOSITES

Reinforced thermoset composite materials are most commonly manufactured using glass fiber and polyester resins. Alternative methods include graphite and polyester reinforcing materials and a variety of other resins, most notably epoxies. But, in order to focus on the selection of container and enclosure materials that will survive the natural environment, it is most practical to concentrate on a few of the many variations of glass reinforced polyester composites.

Thermoset Vs. Thermoplastic

Glass reinforced thermoset composites are distinctly different than their thermoplastic cousins. Thermoset resins (i.e. polyesters and epoxies) chemically change from liquid resins into hardened polymers as they are being molded. The curing process causes the resin to permanently alter its physical and chemical properties. When fully cured, these materials cannot be remelted or re-molded. Thermoplastic Materials, however, are capable of being melted, and remelted repeatedly. The permanent curing of thermoset composites, and their refusal to be remelted, are the underlying reasons for the higher performance characteristics of thermoset composites versus thermoplastic composites and much higher characteristics than non-reinforced thermoplastics.

Electrometric Compression Molding

Compression molded, glass fiber reinforced, isophthalic polyester composites, (at ECS we say “FRP”), offer excellent physical and chemical characteristics over a very broad temperature range. The liquid resin is cured at over 149°C, and parts are capable of being removed from the compression molding tools at over 104°C. These materials easily handle the most extreme temperatures of nature.

Resin Selection

ECS has standardized on the use of isophthalic polyester resins, despite higher prices than orthophthalic polyesters, because this family of resins was developed to achieve excellent chemical resistance. An orthophthalic polyester composite may look the same, feel the same, and be priced lower than an isophthalic polyester product, but it will not perform adequately at the extremes. The ECS resins inherently resist acids, alkalis, solvents, fuel oils and a host of other debilitating chemical substances. Once cured, the ECS thermoset composite is submersible in standard decontamination agents, DS2 and supertropical bleach (STB), indefinitely. It will not rust or oxidize. It is not a nutrient for fungi. It is as close to being impregnable as any container material ever marketed.

High Fiber Percentage

The ECS elastomeric plug assisted compression molding process causes the male half of the mold to expand against all of the interior surfaces of the polished aluminum female mold half. This process enables ECS to consistently achieve extremely high levels of glass fiber reinforcement in its molded parts. This molding technique is vastly superior to matched-metal molding and hand lay-up processes because it achieves 65% to 80% glass fiber content in the finished laminate. By comparison, the hand lay-up process is lucky to achieve 30% glass content and the matched metal molding technique is unable to apply pressure on the side walls of the mold, so its parts have variable glass contents. With a glass fiber content of 60% or less, these hand lay-up and matched metal molded fiberglass parts simply lack sufficient strength to meet rough handling and impact testing at ambient temperature. And, at the temperature extremes of -51°C to +74°C they are miserable failures.

Elastomeric Plug Compression Molding

Elastomeric plug assisted compression molded FRP parts from ECS are readily identifiable by their slightly textured interior surfaces. The molding process compresses layers of glass fiber together until the glass fibers resist further compression at an applied pressure of 50 PSI. At that pressure, the layers of fiberglass materials are compressed to approximately one fourth of their naturally lofted thickness,

and all of the remaining space in the composite is filled by the isophthalic polyester resin. The polyester resin chemically bonds to each of the hundreds of thousands of long and continuous glass fibers, and it structurally encases these laminated fibers within its chemically resistant shell. There is no substitute for this molding method, or for the tremendous strength to weight ratio of the composite parts that are manufactured using it.

Comparing Molding Techniques

Thermoset composite parts that display smooth surfaces inside and out have not been molded with the ECS elastomeric compression molding technique. Parts with smooth interior surfaces will display reduced glass fiber content on the vertical walls because it is physically impossible for smooth surfaced matched metal molds to press against the interior side walls of the tool. Without compression, the glass fiber materials in the tool cannot be sufficiently compacted, and all of the extra space around each fiber in the composite will be saturated with unwanted polyester resin. Worse yet, containers can be matched metal molded using sheet molding compound (SMC) or bulk molding compound (BMC), and the resulting parts will be reinforced with an inadequate quantity of short glass fibers and an excessive percentage of inorganic fillers such as clay and chalk. SMC and BMC molded parts may be smooth and visually attractive, but they are physically inferior to unsuitable for use in reusable container applications.

Advantages of Composites

Compared to other competing materials, thermoset composites have a number of other advantages. The textured interiors of ECS composite parts provide increased surface area for the absorption of energy from the heated air which is inside the case. The improved energy absorption of the textured surface, compared with smooth surfaced materials, allows the efficient dissipation of heat from the inside of the case or enclosure. Test data demonstrates that a thermoset composite container or enclosure, with a textured interior surface, dissipates heat as efficiently as a painted aluminum case or enclosure of the same surface area. Yet the lower specific heat index of the ECS composite, compared to aluminum, provides a lower, total energy accumulation within the cross section of the container and a lower infra-red signature than its aluminum counterpart. And, the ECS product does not need to be anodized, plated or painted.

Summary

In summary, highly reinforced thermoset composites demonstrate excellent physical and chemical properties and are ideally suited for the most rigorous container and enclosure applications. These materials are available in effective flame retarded types, they will operate at extreme temperatures without sagging or distortion, and they are resistant to projectile impact. They do not need to be painted, coated or CARCized. They are capable of being effectively EMI/RFI shielded. They have lower detectability and higher survivability than any other container material. They are, in short, one of the most dependable container materials.

Selecting a Supplier

All manufacturers of polyester composite products have a selection of hundreds of blends of resins, hundreds of types and styles of glass fiber reinforcements, and approximately ten different molding methods available for their use. This immense range of potential combinations mandates that an experienced and respected manufacturer of composite products be selected for every application. ECS is that company.

ABOUT METALLIC MATERIALS

Aluminum Alloys have become the primary non-ferrous metals used to fabricate metallic containers and enclosures. Steel, a ferrous metal, was the predominate choice until the 1960's.

Design Flexibility

Aluminum is currently deep drawn into rectangular container shapes and it is sheared, punched, formed, cast and welded into a variety of container and enclosure shapes. The fabricating flexibility of these materials allows a broad range of products to be manufactured, and the ability to spot weld and heliarc weld further broadens their design flexibility.

Chemically Active Metals

Aluminum, however, has inherent strengths and weaknesses that result from the inalterable characteristics of the aluminum atom. As an element, aluminum (Al) is classified as a moderately active metal. On the atomic scale of chemical activity, it is less active, and therefore less volatile, than magnesium (Mg), but it is considerably more active than iron (Fe). This characteristic alone accounts for important features of aluminum alloys that need to be seriously considered when designing containers and enclosures.

Oxidation

Aluminum oxidizes rapidly in the presence of oxygen, and the resulting aluminum oxide coating is non-conductive. This is both an advantage and a disadvantage to the container designer. Aluminum oxide can be a protective coating for the surface of aluminum parts when properly applied using an anodizing process. However, the protective coating is rarely greater than a few ten thousandths of an inch thick, it is easily scratched from the surface of the part, and exposed aluminum surfaces begin to immediately corrode in the presence of salt spray and air. Specialized coatings such as hard anodize, duranodic finishes and nickel plating are available, but they are expensive and are subject to scratching and damage due to normal rough handling and field use of the containers and enclosures.

Non-Conductive Surfaces

The natural build-up of non-conductive aluminum oxide on the surface of aluminum parts is a severe disadvantage in applications where conductivity is mandatory. The most notable examples are EMI/RFI shielded enclosures and housings which require uninterrupted, low resistance interfaces between mating equipment panels, connectors, seals, gaskets and the container or enclosure surfaces. These aluminum parts are commonly finished with a chemical conversion coating, such as alodine, or are plated with nickel. However, such coatings are not durable and are subject to deterioration or removal during normal use of the equipment. Once removed, the exposed aluminum surface begins the predictable process of oxidation in the presence of air, and the previously conductive surface becomes non-conductive. Non-conductive interfaces effectively create antennas that broadcast the very EMI/RFI radiation that is intended to be contained or suppressed by the container, enclosure or housing. Alas, the very nature of aluminum is both an ally (internal conductivity) and an enemy (surface resistivity).

Painting Required

Aluminum is further hampered by its need for painted finishes. A glossy, metallic finish may be beautiful to the buyer of a valise or suitcase, but industrial and military applications typically require painted finishes. For the military, there is no alternative for the use of chemical agent resistive coatings CARC on all exterior surfaces of aluminum containers and enclosures or aluminum parts of non-metallic containers. CARC is needed to provide resistance to DS2 and supertropical bleach (STB) decontamination agents that are used for clean up in the event of nuclear, biological or chemical NBC agent exposure. DS2 is a moderately alkaline, soapy solution and STB is a hydrochloric acid solution, and both attack unprotected aluminum surfaces.

Require Chemical Agent Resistive Coatings (CARC)

CARC paint finishes are notorious for their poor bond strength to aluminum and other metallic surfaces. The traditionally poor bonding properties of these finishes have been further degraded as environmental restrictions have forced the use of paints which do not contain volatile, organic compounds. The aluminum container manufacturer and end users of those containers are caught between the proverbial rock-and-a-hard-place...CARC finishes are mandatory to protect metallic surfaces, but these same CARC finishes inherently flake off, chip off and scrape off the very surfaces they are intended to protect.

Denting

Aluminum is also subject to denting and distortion during normal use. It is a curious fact that military specifications have traditionally allowed the denting of aluminum case corners during drop testing and rough handling testing. Denting has also been allowed to occur during instrumented drop tests that are intended to demonstrate the shock attenuation capabilities of a container and its cushion system or shock mount system. The crushing of a corner during drop tests contributes to the energy absorption of the container, and reduces the shock that is transmitted to the enclosed equipment. Unfortunately, this advantage can only be gained once, and that is not suitable for reusable containers that are intended to be deployed for many years.

Summary

In summary, unlike reinforced thermoplastic composites and reinforced thermoset composites, aluminum needs a variety of special treatments to be truly suitable for use in extreme environments. The natural characteristics of this metal cause it to retain higher levels of energy, to be more highly detectable, and subject to corrosion compared to composite substitutes. Aluminum, however, continues to be used for many applications because of its design freedom and manufacturing flexibility.

ABOUT LAMINATED MATERIALS

Over the past twenty years, various containers and enclosures have been fabricated from a variety of laminated sheet materials. These materials have been as basic as vinyl clad plywood and as sophisticated as crushed core honeycomb composite panels. This technique persists because products manufactured by this method are essentially free from the cost of dedicated tooling which is normal to all of the other molding, forming and deep drawing methods of container manufacture. The process, however, has weaknesses which are inseparable from its tooling economy.

Attacked by Fungus

Laminated sheet materials, which include wooden cores such as plywood, are subject to attack by a variety of fungi and microorganisms which rend such containers useless in short order. At the least, containers and enclosures that may be deployed in tropical or high humidity conditions, anywhere in the world, should not be manufactured from wooden core materials.

The Method II (hermetically sealed) purpose of US Military specification MIL-P-116 (Methods of Packaging and Preservation) cannot be reliably accomplished using materials that are subject to organic deterioration. The mechanical strength of such containers is rapidly diminished by hungry little enemies that await the arrival of organically nutritious materials.

Labor Intensive

The construction of containers using laminated sheet materials, despite its tooling economy, is very labor intensive. The process requires that the container or enclosure be constructed from many individual panels in addition to a variety of aluminum extrusions, rivets, metal brackets and other devices. The assembly time needed to manufacture such a product is far greater than the time needed to manufacture a compression molded composite part in a dedicated tool.

Performance Problems

Manufacturing time is a small problem compared to the performance failures of laminated containers. Each of the hundreds of bits and pieces that are assembled into such a container is a potential source of leakage. All of the joints at all of the extrusions, all of the corners, every edge and recessed plate used for the mounting of hardware are potential points of ingress of moisture, contaminants, dust, and salt spray. Even if the laminated container passes acceptance testing at the time of manufacture, it will not maintain the reliability or integrity of containers manufactured by any of the previous methods or from any of the previously mentioned materials. Such products are simply inferior to their plastic, composite and metallic counterparts.

Decontamination Problems

The decontamination of laminated containers is nightmarish. NBC contaminants (nuclear, biological and chemical agents) wick under and into all of the joints between the assemblage of container parts. It is essentially impossible to remove the contaminants from all of the nooks and crannies of such container designs. These products generally fail to shed water from all of their surfaces, thereby providing collection points for moisture, dust and dirt, and contaminants. Such designs should not be allowed in a battlefield environment. Due to the construction of laminated containers, they are unable to withstand the abuses of rough handling without inducing leakage points at rivets, extrusions and/or metal hardware items. These cases may be suitable for commercial products such as audio equipment, but they are incapable of providing long term reliability for field portable and man portable military equipment.

Summary

In summary, laminated containers have found many applications in commercial uses where the excessive weight of the container is not a problem for field portability and where the container is not intended to provide hermetically sealed protection for the enclosed equipment. In the real world of extreme environments, however, such materials are not capable of providing dependable protection for enclosed equipment.

HERMETICALLY SEALED CONTAINERS

If the container or enclosure is expected to protect its enclosed equipment from the natural environment, it must be capable of maintaining an air tight seal. In other words, it must be designed and manufactured to be hermetically sealed. There simply is no substitute for this requirement. There are, however, a number of individual design and material selection factors that affect the long term effectiveness of a container's seal.

MOISTURE-VAPOR TRANSMISSION RATE

The primary barrier to the entry of liquid water or water-vapor into the container is composed of the walls of the container. The material from which the container shells are manufactured must have substantial resistance to the passage of water and water-vapor if the container is to stay dry inside. Metals are impervious to moisture and to the passage of water-vapor, and they are the best moisture barrier materials. Non-reinforced Thermoplastic materials, thermoplastic composite materials, and thermoset composite materials are impervious to moisture and demonstrate excellent resistance to the passage of water-vapor. Most composition materials and wood core materials are incapable of adequately resisting the passage of water-vapor and are not useful for the manufacture of hermetically sealed containers. The verification of a minimal water-vapor transmission rate, in conformance with MIL-STD-101 Method 3030, should be a mandatory design requirement for any reusable container or enclosure.

CLOSURE DESIGN AND GASKET SELECTION

The second most important point of resistance to the entry of moisture is the gasketed closure of the container or enclosure. The gasketed closure joint must be capable of retaining an effective hermetic seal after repeated openings and closings of the container. The joint between the lid and body of the container must utilize a gasket material that is impervious to the chemicals, solvents, decontamination agents, salt water, sand, dust and other agents that the container will be exposed to during its useful life. The gasket must also resist permanent deformation (i.e. compression set) as a result of being repeatedly compressed by the container closure and being stored or used for long periods of time over a broad temperature range. The closure design must not compress the gasket more than 30% of its non-compressed thickness when the container latches are fully engaged, or the compression set of the gasket will be increased. Tubular shapes, chevron shapes (i.e. a folding "V" shape), and certain solid shapes are the most effective gasket designs. Foam gaskets, such as closed cell neoprene and silicone, are more likely to flatten due to the loss of cellular air capacity which results from long term compression of the gasket material.

HARDWARE SEALS AND GASKETS

The third area of possible moisture entry into the container is found at hardware attachment points, connector holes, and other openings thru the walls of the container. Each of these holes or openings must be effectively sealed. To the extent that the container can be designed with fewer holes and openings, this gasketing task is simplified. Like the requirement for closure gaskets, all of the seals and gaskets around holes and openings thru the container walls must provide long term resistance to the chemicals and compounds found in the natural and man-made environments.

AVOIDING DISSIMILAR METALS

Finally, long term resistance to the entry of moisture can be adversely affected by the adjacent use of dissimilar metals. When dissimilar metals are in close contact with each other and are exposed to an electrolyte such as salt water, the metals begin to chemically consume each other in an electrolytic reaction. The long term result of this process is the physical destruction of one or both of the adjacent metals. When this problem is allowed to occur in a reusable container or enclosure design, the chemical destruction of fasteners, hardware and other critical components of the container will eventually result in the ingress of moisture. Therefore, the container designer must avoid the use of dissimilar metals and/or improperly plated or finished metal parts when creating the new product.

AIR BREATHER VALVE SELECTION AND PERFORMANCE

The selection of an appropriate air breather valve is a critical decision point in the design of any hermetically sealed container. The air valve must perform the dual purpose of protecting the container from excessive internal air pressure or vacuum and it must prevent excessive build-up of moisture inside the container. The air valve is an important part of the protective systems used to achieve Method II (hermetically sealed) packaging protection in accord with US Military Specification MIL-P-116 (Methods of Packaging and Preservation).

CONTAINER STRENGTH

The choice of an air valve is directly related to the structural strength of the container at the extreme variations in temperature and humidity that the container will witness during its deployments throughout its normal life expectancy. Anything less than a comprehensive review of temperature extremes, humidity extremes, and yield points of the container materials at those extremes constitutes the taking of a gamble on the performance of the container and the survivability of the contained equipment.

CLIMATIC EXTREMES

For a normal reusable container or enclosure, with a design life of ten years and a military application, it is mandatory to assume that the container will be deployed at some time in the most extreme climatic conditions the world has to offer. The design of this product must not be subject to a statistical game of evaluating cost versus performance in a lesser set of climatic extremes. The decision to design a container or enclosure for effective performance in Central Europe, while ignoring the potential deployment of that same container or enclosure in the Saudi Arabian desert or a Sub-Arctic location, is tantamount to guaranteeing failure at those extremes. Mistakes in design judgment of this type can be lethal. Such decisions can literally cause the failure of equipment, missions and the death of military personnel. It is comparable to the age-old story about the loss of the nail, that caused the loss of the shoe, that caused the loss of the horse, that caused the loss of the king, that ultimately caused the loss of the kingdom.

AIR VALVE DESIGN

An automatic air breather valve has a pair of calibrated springs which keep the valve closed. One spring holds the intake port closed and the second spring holds the exhaust port closed. Each of the sealed

ports acts independently from the other. It is therefore possible to select air valves which have different sealing settings in the pressure and vacuum directions.

AIR VALVE SIZE

Air breather valves are also available in a variety of port diameters. As the diameters of the air valve ports increase, the valve is able to pass an increasing volume of air at the same pressure differential. It is therefore possible to select a valve that has an adequate rate of air flow to effectively dissipate rapid changes in internal vacuum or pressure in containers of different cubic volume. Such rapid changes in internal pressure most commonly result from rapid changes in altitude or pressurization of cargo aircraft.

INTERNAL PRESSURE DIFFERENTIALS

A change in temperature of approximately 17°C will result in an internal pressure change, in a sealed container or enclosure, of 1.1 PSI. An altitude change of 9,143m (30,000 Ft), rising from sea level, causes a change in atmospheric pressure. The pressure differential experienced by a sealed container during a 30,000 foot elevation change is approximately 10 PSI. The pressure change is greater for each thousand feet of elevation when the aircraft is closer to sea level because of the greater density of the air near sea level. However, the average pressure change from sea level to 30,000 feet in an unpressurized aircraft, or when the aircraft is uniformly pressurized to the equivalent of 30,000 feet, is 0.33 PSI/1000 Ft.

DISSIPATING PRESSURE CHANGES

Pressure changes in the container, either vacuum or compression, must be reduced by the functioning of the air breather valve. However, the air valve does maintain residual pressure or vacuum inside the container or enclosure at the end of each breathing cycle. In order for the container to constantly maintain an internal pressure that would be equal to the external atmospheric pressure where it is located, the container would need to have an open hole in it. By definition, it is not possible for a container to be hermetically sealed container if the container has a hole in it. Since residual pressure or vacuum is normal, it is important to understand the effect of that residual pressure or on the accumulation of moisture inside the container or enclosure. And, it is important to realize the effect of residual pressure on the structural characteristics of the container material.

CRACKING & RE-SEALING VALVES

Air valves open and re-seal. That is their purpose. When the valve is open and allowing the flow of air either in or out of the container, it will finish the cycle by re-sealing at an interior container air pressure that is overcome by the strength of the spring in the valve. This pressure is known as the re-sealing pressure, and is the normal pressure rating used to describe the valve. The pressure required to open the valve is known as the cracking pressure, and it is typically higher than the re-sealing pressure of the valve. The cracking pressure is greater than the re-sealing pressure due to the slight adherence of the elastomeric gasket to the valve port and due to frictional forces within the valve that must be overcome by the pressure differential which exists between the inside and the outside of the container. In essence, air breather valves open at higher pressure and vacuum differentials than their rated re-sealing pressures. Therefore, the container must be strong enough, at all temperature extremes, to tolerate these pressure differentials without structural damage to the container.

AIR VALVE CYCLES

Hermetically Sealed containers with air valves inhale air and exhale air. These containers exhale as the temperature increases, the altitude increases and/or the atmospheric pressure decreases. They inhale as the temperature decreases, the altitude decreases and/or the atmospheric pressure increases. The nature of this cycle of inhaling and exhaling air, causes the container to accumulate moisture, first in the form of water-vapor, and then in the form of condensation (liquid droplets). The more frequently the container breathes, the more rapidly it accumulates moisture.

REDUCING BREATHING CYCLES

The air breather valve should reduce the frequency of breathing cycles if it has cracking pressures that are high enough to resist most of the pressure differentials that occur during the normal life of the container or enclosure. If the container material is strong at all temperatures, it is possible to select an air valve with higher cracking pressures. If the container material is weakened by high or low temperature extremes, the valve must have lower cracking pressures, and it will open more frequently during the life of the container.

Unrealistic Requirements

When designing a container for the relatively benign environments of the United States or Central Europe, it is safe to conclude that lower reseal pressures are adequate to limit breathing cycles to less than ten per year, assuming that the container is in storage, is never moved, is never cycled from daylight (solar gain) to darkness and has an adequate charge of desiccant to absorb accumulated moisture vapor.

Real World Protection

In user environments that experience climatic extremes, higher vacuum re-seal pressures may be required in order to prevent more frequent container breathing cycles and to protect the enclosed equipment from long term moisture damage. In lieu of higher valve reseal pressures, more frequent reactivation of desiccant may be required.

DISQUALIFYING CONTAINER MATERIALS

Any container material that is incapable of tolerating such pressures at the temperature extremes, solar heat gain and humidity levels specified in MIL-STD-210C should be disqualified from use on military applications. Every reusable, hermetically sealed container or enclosure should be tested or certified for satisfactory performance under these conditions.

DESICCANT QUANTITY AND MAINTENANCE

Desiccant is used to absorb moisture vapor that may enter a hermetically sealed container. The most commonly specified desiccant material is aluminum silicate clay, which is a dimensionally stable, chemically inert, granular material that has microscopic pores that attract, absorb and retain moisture. This granular material is normally contained in cloth or composition sacks of different capacities and is stored inside the sealed container in desiccant storage compartments. Desiccant is installed in the container in an oven baked, absolutely dry condition, and it is able to absorb substantial moisture from the air inside the container prior to being replaced or re-activated. The requirements for desiccant usage and replacement are controlled by the container design and the environments to which the container is exposed.

INGRESS OF MOIST AIR

Even the most effectively designed, hermetically sealed container will experience an occasional opening and closing of the air breather valve during long term storage. When the opening of the valve results in the ingress of outside air into the container, that outside air carries water-vapor into the container. If outside air is repeatedly breathed into the stored container, the relative humidity level inside the container will eventually get high enough to reach the point of condensation, and beads of liquid moisture will appear on the inside of the container and on the enclosed equipment.

REDUCING BREATHING CYCLES

To prevent internal condensation, it is important to design a reusable container using materials that maintain structural strength at the extreme temperatures of the natural environment. Such materials allow the use of an air breather valve with higher cracking pressures, which in turn reduces the frequency of container breathing cycles and therefore reduces the ingress of moist air into the container. If the container material yields (i.e. stretches and/or fails) at high temperature due to the internal container pressure which is retained by a breather valve with higher cracking pressure, then the air breather valve must be replaced with a substitute that has lower cracking pressures. Such reduced cracking pressures automatically result in more frequent breathing cycles and in the increased entry of moist air into the container.

DESICCANT QUANTITY

The cubic volume of air inside the hermetically sealed container is the primary determinant of the volume of desiccant that is required for long term storage. As the internal volume of air (i.e. total inside container volume less the volume of the contained items) increases, the cubic volume of moist air that is breathed into the container during each breathing cycle will increase also. Therefore, the weight of water-vapor that is enclosed within the sealed container will increase as the cubic volume of the container increases. Aluminum silicate clay desiccant has a fixed capacity to retain moisture per cubic volume of desiccant. As a result, the volume of desiccant must increase as the cubic volume of the container increases. Selection of an ideal desiccant quantity and storage compartments for that desiccant should be made in consultation with the ECS Application Engineering Department.

DESICCANT MAINTENANCE

Each reusable, hermetically sealed container or enclosure should be equipped with a humidity indicator that is capable of measuring the relative humidity of the air inside the container. Such indicators are installed thru the wall of the container and are capable of being read from outside. As the desiccant granules continue to absorb water-vapor from the air inside the container, the desiccant will gradually reach a saturation point at which it is unable to absorb more water. As that saturation point is being approached, the residual relative humidity of the air inside the container will increase, and that increase in moist air must be monitored by regularly viewing the humidity indicator window. If the enclosed equipment cannot tolerate relative humidity levels above a specified percentage, or if the likely dew-point inside the container will be reached at that relative humidity level, the desiccant must be changed. This requires the opening of the container, removal of the saturated desiccant, and the supply of bags of fresh, dry desiccant. The saturated desiccant is generally capable of being oven baked and reused. As the frequency of breather valve cycles increases, it is evident that the cost and inconvenience of

desiccant replacement also increases. This expenditure of time and money is one more reason for the specification of container materials that will resist the temperature extremes of the natural environment and allow the use of air breather valves with higher cracking pressures.

SURVIVING THE HUMAN ENVIRONMENT

TRANSPORTATION HAZARDS

Man's environment adds one more degree of complexity to the natural environment, which represents the first challenge to the design of hermetically sealed containers and enclosures. Man persists in moving himself/herself and his/her possessions from continent to continent, from one tactical location to the next, and from one isolated climatic extreme to the next. The modes of transportation used for this endless movement of man and material constitute serious hazards for packaged items. However, knowledge of these hazards provides the container designer with a focus for the practical design of reusable containers and enclosures.

Resistance to Transportation Hazards

Emphasis needs to be placed on the term reusable containers and enclosures in the context of transportation hazards. The term reusable infers that the container or enclosure will survive long term handling, transportation and actual use and will continue to function properly. Effective design principles for reusable packaging are necessarily different than those applied to non-reusable, single-trip, packaging. The reusable package is commonly expected to provide complete protection, including shock and vibration attenuation, isolation from the natural environment, immunity from shipment and handling abuses, and shielding from a broad electro-magnetic spectrum for up to ten years. The design process starts with an evaluation of the product to be packaged and the shipment environment it will witness during its useful lifetime.

FRAGILITY OF CONTAINED EQUIPMENT

It is essential to know the fragility of the equipment when designing for transportation hazards. Fragility is a measurement of the shock and/or vibration level at which physical or functional damage occurs. By way of comparison, it is significantly easier to design the ideal container for an ingot of gold than for a gold plated satellite. Both are valuable, but they represent different types of fragilities. The structural integrity (i.e. fragility) of the product is the primary determinant of the size of the container, because the shock isolating system needs to provide greater motion for shock mitigation as the fragility of the product increases. Greater fragility thus equates to larger container size and cost.

Vibration

Sensitivity to vibration is another crucial design consideration. Everything has at least one natural frequency of vibration, and most assembled products have a number of natural frequencies which are associated with various parts of the assembly. It is possible to damage a product by exposing it to externally generated vibrational forces which coincide with one or more of the natural frequencies of vibration of the product. Under such circumstances, the forcing vibration may cause the product, or a component of the product, to resonate and to gyrate excessively, causing damage or destruction. If the product is known to have a natural frequency, or a harmonic frequency, that is near the forcing frequencies of the methods of transportation to be used, the container must be equipped with an effective vibration absorption system to isolate those potentially damaging frequencies before they reach the equipment.

Shock Vs. Vibration

Shock attenuation and the natural vibration characteristics of the shock mount system are directly related, so it is important to individually consider the shock and vibration fragility of a product when designing its reusable container. The structural damping (i.e. the ability to absorb vibrational energy) characteristics of composite container materials, together with properly selected shock mitigation systems, offer extremely efficient protection options for the container designer.

TRANSPORTATION METHODS

Though every transportation method may have unique handling hazards associated with it, it is important to consider transportation hazards separately from handling hazards, which are discussed in a later section. In this context, one must assume that the container or enclosure is already attached to or located within the transportation device (truck, train, aircraft, etc.).

ON-ROAD VEHICLES

Wheeled vehicles, traveling along paved roads and highways impart a variety of impacts and vibrational forces to their contained loads. To understand the normal forces that are encountered by the suspension system of a vehicle on American roads, the Bendix road test track provides accelerated exposure to hazards from potholes to frame torquing twists. The responsiveness of the vehicle's suspension system will determine what types and levels of vibration and shock forces are transferred to the enclosed containers. Such forces include high amplitude, low frequency vibration; structural shock from dock impact to vehicle crashes; and the bouncing and impacting of containers inside the vehicle. The size and weight of the vehicle will also determine the forces that will be imparted to the load that is carried by the vehicle. A properly designed container or enclosure will provide a durable physical envelope together with balanced shock and vibration attenuation which is tuned to the shock and vibrational fragilities of the enclosed equipment.

OFF-ROAD VEHICLES

Off-road travel brings an additional set of hazards to the on-road environment. These hazards are normally in addition to the on-road hazards, because off-road vehicles will generally use paved roads and highways, also. Such vehicles are generally smaller, have more rigid suspensions, travel over much rougher terrain, and impart significantly higher levels of shock and vibrational forces to their contents than on-road vehicles. The Munson road test is an accelerated assault on the structural integrity of off-road military vehicles and enclosed equipment, and it imparts the types and levels of forces that will be encountered in off-road travel. It is not uncommon for off-road vehicles to crash, and for their contents to be bounced around the inside of the vehicle or scattered across the crash site. In off-road applications, it is more common for containers and enclosures to be mechanically attached to the vehicle, and to therefore sustain the full structural impacts and vibration forces that are transferred by the vehicle's suspension system. For such applications, it is mandatory that containers and/or enclosures be designed for exceptional durability under high stress, to have structurally sound attachment hardware, and to be able to mitigate crushing levels of impact, shock and vibration forces. If the average value of a reusable container is approximately 3-5% the value of its enclosed equipment, it is a low cost form of insurance for off-road protection of its enclosed cargo. It should never be under-designed or cheapened at the expense of its performance. It provides low cost survivability for the equipment, the satisfactory completion of the mission, and the effective utilization of the manpower assigned to the task.

RAILROAD

Reusable Containers and enclosures are occasionally shipped via railroad, and it is important to understand the unique shock and vibration environment of this method of transportation. However, rail shipment is generally used for heavy and/or bulky containers and equipment that rarely qualify as man-portable equipment. When this method of shipment is encountered, containers and enclosures are exposed to nearly continuous vibration forces at moderate to higher frequencies, but at lower amplitudes than on-road vehicles. Vibration can be sustained enough and substantial enough to physically move and/or rotate poorly secured items through many complete cycles during a trans-continental journey, causing external damage, paint loss, and other physical injury.

Shock loads, on the other hand, are primarily associated with the “humping” impacts encountered during the coupling of train cars, and during the acceleration or braking of the train, which cause a chain reaction of impacts from the couplings and suspensions of one rail car to the next. These impacts are transferred to the contained cargo and must be mitigated by the shock isolation characteristics of the containers and enclosures. With the possible exception of increased structural strength, a container or enclosure which has been designed for on-road transportation should be expected to be satisfactory for rail transport.

AIRCRAFT

Aircraft transportation imparts the highest vibration frequencies and at the lowest amplitudes of any common form of shipment. These vibration forces are not normally a hazard to electronic equipment or other material. If given a choice of transportation method, air shipment would be preferred for its speed and for its relative safety and minimal exposure to shock and vibration forces. However, it is important to consider the effects of rapid pressurization and/or de-pressurization of cargo aircraft and the structural responses of reusable, hermetically sealed containers and enclosures that experience these pressure changes. This transportation method does force a review of structural strength issues and air breather valve selection which were highlighted in previous sections.

SHIPS & BOATS

As a transportation method, the ship borne environment has increasingly been converted to containerization. This method utilizes containers which are typically constructed in twenty or forty foot truck trailer lengths and which are capable of enclosing large volumes of materiel when stowed in the hold of the ship or secured to the deck of sea-going freighters. Upon arrival at the destination port, these containers are secured to the frame of a trailer, and are commonly used for final delivery of the enclosed products. This method of shipment does not represent substantial hazards for equipment that is being shipped inside hermetically sealed containers or enclosures. At the extreme, ship-borne transportation can impart low frequency vibration forces and impact loads which are similar to the hazards of railroad transportation. However, ships encounter a wide variety of temperature extremes and humidity levels as they travel the globe, and these extremes are the source of potential moisture damage if containerized freight is inadequately packaged, or if the container is not capable of being effectively sealed.

HANDLING HAZARDS

The hazards of transportation should never be confused with the hazards of handling freight that is being shipped. When one speaks of transportability, one must assume that the item that is being shipped is already safely stowed on the transport vehicle (truck, train, aircraft, etc.). However, the handling of freight before and after shipment is frequently more hazardous than the dangers of the trip itself. It is during the handling of freight using manual or mechanized methods that reusable containers and enclosures frequently witness their most severe abuse. These are the opportunities for drops from truck beds, parked aircraft, and fork-lifted pallets. These are the times for fork-lift blade penetration of containers, for the crushing of containers by mechanized equipment, and the inevitable breakage of slings used to hoist containerized freight from the hold of a ship.

Rough Handling

Within sensible limits (protection from fork-lift penetration generally being considered unreasonable), reusable containers and enclosures must be expected to endure substantial rough handling. This is a reasonable demand, because rough handling is normal at the origination and destination points of every method of transportation, worldwide. During a normal ten year life expectancy, virtually every reusable container or enclosure will be dropped, dragged, impacted, and stacked unreasonably in addition to enduring natural environmental hazards, the pitfalls of man-handling and man's environment of chemicals, solvents, fuels, etc..

Realistic Simulation

Any container testing sequence that fails to effectively simulate rough handling at a variety of realistic environmental extremes during qualification evaluation invites the acceptance, purchase and use of reusable containers that are statistically likely to be damaged during their lifetimes. There is no justification for design compromise if longevity of service is to be achieved.

THE REAL WORLD OF MAN PORTABLE EQUIPMENT

The concept of transportability should never be confused with the concept of man-portability. And, man-portability must be considered as an incremental jump in hazard level compared to the hazards of handling. Transportability assumes safe stowage in the vehicle, handling generally assumes adequately trained personnel and suitable equipment, but man-portability assumes the gamut of the worst imaginable circumstances for man and his/her equipment. This is the real test, because this is where the container or enclosure and its important cargo are actually used. If the equipment survived all of the hazards up to its deployment and use, but fails in the real world of man-portability, it is still a failure. There is just simply no compromise at the point of use. Man-portability is the final test.

Real World Abuse

Despite the best training and instruction, crisis situations and other urgent circumstances cause the users of field portable equipment to abuse it. Therefore, field portable equipment must tolerate abuse. It's not just a good idea, it is mandatory.

Military containers are not gently carried by their handles and neatly placed in their respective positions in a vehicle. They are more likely to be swung by one or two handles from the ground onto the bed of a half-track or HMMWV...real operating loads on those handles exceeding 100 pounds each.

Containers and electronic enclosures for commercial and industrial applications are not used like designer-label luggage. They are tossed into the trunks of vehicles, bumped and dragged from one user site to the next, and occasionally rolled out of the vehicles in which they are carried.

In the real world, containers and electronic enclosures are not dropped onto two inches of plywood over concrete... they are dropped into mud, onto rocks, onto airport tarmacs, off of moving vehicles, and are involved in crashes of cars, trucks and trailers. They are even the targets of enemy fire.

Tactical military engagements in the 21st century are not set-piece, strategic emplacements of men and materiel. When a tactical military force (complete with equipment, armaments, electronics and personnel), is engaged in battle, the shifting of offensive and defensive conditions can mandate an immediate advance or withdrawal from the present position. When it's time to leave, there's no time for niceties. Cases, containers, electronics, ammo, artillery shells, vans, vehicles and every essential piece of equipment gets moved fast or gets left behind.

If it's a military container or enclosure, it's likely to be used for anything. It will be a chair, a stool, a sled, a shield, a shelf... anything that suits the purpose or the needs of the user. Dragged across the deck, dragged across the runway, or dragged thru the jungle... the container will see many unexpected uses. It needs to be designed with that expectation. And when the choice is made, nothing will survive such adverse conditions as effectively as glass fiber reinforced thermoplastic composites and glass fiber reinforced thermoset composite materials.

DYNAMIC TESTING OF CONTAINERS

The testing of containers and enclosures is intended to simulate real-life conditions that will be faced during the effective life of the container and its enclosed equipment. Simulation necessitates that those real-life hazards are known, that they are capable of being repeated in a laboratory environment, and that the results of the testing are verifiable with the results of actual field trials conducted under real-life conditions. None of these prerequisites should be negotiable or compromised in order to allow the use of materials that are known to fail under real-life conditions. If the testing is not representative of real-life conditions, then those products that have been qualified to lesser test conditions are far more likely to fail during use.

Testing Methods

Following is a listing of the most relevant tests that are suitable for rigid, reusable containers and enclosures. All of these tests should be conducted at the environmental extremes to which the equipment will be subjected during a prolonged lifetime in an uncertain world. MIL-STD-210C is an excellent resource for data concerning naturally occurring environmental conditions.

CHARACTERISTICS OF CONTAINER MATERIALS

Compression Strength

The compressive strength test (FED-STD-101 Method 2012) (ASTM D695) measures the ability of a container material to resist buckling or deforming under the weight of a stacked load. Composite Materials have excellent compressive strength at a broad range of temperatures. Non-reinforced thermoplastics demonstrate lower compression strength, but proper consideration for the design characteristics of these materials may allow them to be useful for many applications.

Flexural Strength

The flexural strength test (FED-STD-101 Method 2019) (ASTM D790) measures the resistance of a container material to be distorted or bent when force is applied to it. This test helps to explain why materials used to manufacture non-reinforced thermoplastic containers must be carefully selected and designed for these applications. By comparison, very high flexural strength is a key advantage of composite materials at all temperatures.

Tensile Strength

The tensile strength test (FED-STD-101 Method 2040) (ASTM D638) measures the stretch resistance of a container material. Unlike composite and metallic materials, which have excellent tensile strength over a broad temperature range, the tensile strength of non-reinforced thermoplastics is measured as the temperature at which the material stretches when exposed to a specified tensile force. This temperature is known as the yield point of the material. The tensile strengths of composites and metallics are generally higher than for non-reinforced thermoplastics.

Fungus Resistance

The fungus resistance test (FED-STD-101 Method 3020) (MIL-STD-810 Method 508-1) measures the ability of fungi to thrive on nutrients that may be available from within the container materials themselves. Most thermoplastics, composites and metallics are fungus inert, but some reusable containers made from laminated materials are capable of being digested by common fungi.

Water Vapor Transmission Rate

The water vapor transmission rate test (FED-STD-101 Method 3030) measures the ability of water vapor to pass thru the wall of the container when the air inside of the container has a low relative humidity and the outside air has a high moisture content. Metallic materials are impermeable to moisture, and most composites and thermoplastics demonstrate essentially zero moisture transmissibility.

STRUCTURAL STRENGTH OF CONTAINERS

Free Fall Drop Test

The free fall drop test (FED-STD-101 Method 5007) (MIL-STD-810 Method 516-2) measures the ability of the container to withstand impacts onto hard surfaces, such as concrete or steel, or onto compacted soil or plywood surfaces. Drop testing is the most common method of testing the durability and rough handling resistance of reusable containers. This testing method also provides great insight into the effectiveness of shock and vibration attenuation systems that may be part of the design of the container or enclosure.

However, drop testing methods no longer include tumble testing techniques which cause the container to impact onto pointed objects that simulate rocks. Drop testing should be conducted at temperatures of -53°C , $+21^{\circ}\text{C}$ and $+74^{\circ}\text{C}$ in order to accurately simulate real-world environmental extremes.

Shock Pulse Test

The shock pulse test (MIL-STD-810 Method 516-1) should not be confused with drop testing nor used as a replacement for drop testing. Shock pulse testing is conducted on a hydraulically actuated table, with the test container firmly attached to the surface of the table. Shock pulses, of specified magnitudes and durations, are imparted to the test subject to evaluate the effect. Rarely do shock pulse tests simulate the real-life environment of a container or enclosure, unless that container or enclosure is intended to be attached to a ship, a vehicle or some other larger object.

Vibration Tests

(MIL-STD-810 Method 514-10) are primarily designed to evaluate the effectiveness of shock and vibration isolation systems that are a part of the container or enclosure system. Due to the variation in vibration attenuation characteristics that may be affected by temperature extremes, it is recommended that vibration tests be conducted at temperature extremes, though the build-up of frictional energy within the shock mounts during testing may more likely result in failure at high temperatures than at low temperatures.

Static Load Test / Concentrated Load Test

(FED-STD-101 Method 5016) / (MIL-T-4734 Method 4.6.2.2) The static load test or the concentrated load test measures the ability of the container material and container design to resist deformation and failure when heavy materials are stacked on top of the container. These tests should be conducted at -53°C , $+21^{\circ}\text{C}$ and $+74^{\circ}\text{C}$ to demonstrate the changes in stacking strength that result from temperature changes. Composites and metallics have excellent stacking strength at all temperatures, but the strength of non-reinforced thermoplastics degrades rapidly at elevated temperatures. This is a key reason to avoid the use of non-reinforced thermoplastics in desert environments.

Loose Cargo Bounce Test

The loose cargo bounce test (MIL-STD-810 Method 514-11) evaluates the durability of a container that is allowed to bounce loosely around the inside of a truck presumed to be traveling over a variety of road surfaces. This is an excellent method to evaluate the abrasion resistance of the container and the effectiveness of the attachment of external hardware. This test clearly demonstrates the predictable loss of paint on metallic containers and supports the use of fully pigmented materials such as composites and thermoplastics which have no paint to abrade.

Handle Pull Test

(MIL-C-4150 Paragraph 4.5.3.6) provides an excellent method of evaluating the ability of the container or enclosure to resist jerking loads applied to the handles. The test case is suspended above the ground on a quick release mechanism. One end of the rope is attached to a handle on the container and the other end of the rope is attached overhead to a structurally secure object. Slack length is left in the rope,

but the rope is too short to allow the container to hit the ground. When the container is released, the entire force of the dropping case is absorbed by the handle.

Projectile Impact Test

The projectile impact test (MIL-T-4734 Paragraph 4.6.2.3) is an excellent method to determine the ability of the container to resist the concentrated impact of a blunt projectile. A twelve inch long, one inch diameter steel rod is allowed to free-fall eight feet down a tube until it impacts the surface of the container or enclosure. Though MIL-T-4734 is no longer in active use, this testing method continues to be an effective way to determine the ability of a container to resist penetration by rocks and blunt objects. Composite container materials demonstrate excellent projectile resistance, and can even resist penetration by round-nosed, jacketed, handgun bullets fired at close range.

ENVIRONMENTAL RESISTANCE OF CONTAINERS

Temperature Shock Test

The temperature shock test (MIL-STD-810 Method 503-1) is designed to evaluate the ability of a container or enclosure to tolerate exposure to rapid changes in temperature. Hermetically Sealed, non-reinforced thermoplastic containers demonstrate serious structural deficiencies when cycled through substantial changes in temperature. Composite and metallic containers possess the structural integrity, over a broad temperature range, to resist permanent deformation during temperature shock testing.

High Temperature Test

The high temperature test (MIL-STD-810 Method 501-1) is used to evaluate the ability of container materials to resist exposure to high temperatures. Composite and metallic materials perform effectively at temperatures which are substantially higher than the operational temperature range of most non-reinforced thermoplastics.

Low Temperature Test

The low temperature test (MIL-STD-810 Method 502-1) is used to evaluate the ability of container materials to resist exposure to low temperatures. Composite and metallic materials perform effectively at temperatures which are substantially lower than the operational temperature range of most non-reinforced thermoplastics.

Altitude Cycle Test

The altitude cycle test (MIL-STD-500-1) is used to evaluate the ability of container materials to resist rapid changes in atmospheric pressure. Structural rigidity of the container material is essential to prevent distortion of the container during pressure and vacuum cycles which result from rapid changes in atmospheric pressure. Naturally, composites and metallics outperform non-reinforced thermoplastics during this test.

Humidity Cycle Test

Humidity cycle tests (FED-STD-101 Method 4007) (MIL-STD-810 Method 507) are used to evaluate the ability of container materials to resist the effects of high humidity and high temperature. Similar tests can be conducted on open electronic enclosures to evaluate the effectiveness of seals and gaskets used at the mounting locations of the equipment. Container materials that do not possess excellent

structural strength will tend to cause the accumulation of internal condensation because of the frequent opening and closing of the automatic air breather valve. Composite and metallic containers and enclosures are able to use higher cracking pressure valves and therefore resist the ingress of moisture during this test.

Salt Spray Test

The salt spray test (MIL-STD-810 Method 509-1) is used to determine the ability of container materials to resist the corrosive effects of long term salt water exposure. This test is also effective for identifying sources of galvanic decomposition, which results when dissimilar metals are exposed to an electrolyte (i.e. salt water). Non-reinforced thermoplastics and composites perform very effectively during this test. Metallic containers perform well as long as their painted surfaces are not scratched. Bare aluminum, however, will corrode in the presence of salt spray, and no painted container will retain all of its paint very long in the real world.

Sand and Dust Resistance Test

The sand & dust resistance test (MIL-STD-810 Method 510-1) is used to determine the effectiveness of seals and gaskets on the container or enclosure. This test is also useful in determining the ability of the air breather valve to reseal its gasketed opening in the presence of sand and dust. Any effectively designed container, regardless of materials used, should be capable of passing this test.

Water Tests

Water tests for hermetically sealed containers are conducted by a variety of test methods, but the objective of all of these methods is to determine the ability of the container to resist the ingress of moisture. MIL-C-4150H Paragraph 4.5.3.1.1 hot water immersion testing is a quick and inexpensive method to determine the ability of the container to hold interior air pressure while the container is submerged. The presumption is that an air tight container will also be a water tight container. FED-STD-101 Method 5009.1 pneumatic pressure testing also determines the ability of a container to hold interior air pressure while submerged. MIL-STD-810 Method 512.1 Procedure 1 testing requires that the container be submerged under 36 inches of water and that a vacuum differential of 2.0 inches of mercury be drawn on the container and retained for one hour to determine if water will penetrate the container. A variety of other water tests, including water spray and drip-proof testing are also used for similar purposes.

ABOUT SHOCK AND VIBRATION PROTECTION

The physical hazards that are encountered during handling, transportation and man portable use constitute serious dangers for the physical survival of equipment that is enclosed in reusable containers. These physical hazards are in the form of measurable levels of energy that are imparted to the equipment in the form of shock impulses and vibrational forces. Protecting enclosed equipment from these hazards is of equal importance to protecting it from the environment.

FORCES THAT DAMAGE EQUIPMENT

The mechanical forces that damage equipment are shock impulses and vibration. These forces are similar in certain ways, they are inseparably related, but they have unique characteristics that must be considered independently.

Basic Description of Shock Forces

When shock force is generically described, it is frequently assumed that the force is continuous. However, most shock forces that are imparted to containers are actually of measurable or predictable time lengths, because most of these forces are caused by the dropping of the container or the hammer-like blow of a structural impact. The dynamic effect of such forces is of short duration, frequently measurable in milli-seconds (i.e. thousandths of a second), and normally includes the repeated deceleration and acceleration of the equipment which is enclosed in the container. In fact, equipment that is mounted on shock mounts or in foam cushions in a container that has been dropped or impacted will first flex the shock absorption system toward the point of impact. The equipment will reach its maximum flexing of the cushioning system, come to a momentary stop, and then rebound in the opposite direction. If the shock absorption system has been properly designed, the distance the equipment rebounds will decay with each cycle, and the equipment will soon return to a stationary position. The maximum shock force that the equipment will feel will be the force of deceleration that occurs during the first flexing of the cushioning system. Each subsequent rebound will impart lower and lower shock force from acceleration and deceleration. The duration of the shock force will decrease as the cushioning system responds to the decaying dynamics with less and less motion. Shock is measured in units of “G” force (i.e. multiples of the equivalent of gravitational force) and in the length of exposure to that force in seconds (i.e. duration).

Basic Description of Vibration and Vibrational Forces

Vibration is the repeated motion of an object which moves in one direction, then in the opposite direction, and then back in the original direction. This motion is very similar to the rebounding motion of a piece of equipment that is flexing its cushioning system, and this similarity demonstrates a common characteristic of shock and vibration forces that are experienced in a cushioned container or enclosure. This similarity also extends to the shock forces that the vibrating object feels while it is vibrating. If that object is moving in one direction and decelerates to a momentary stop before accelerating in the opposite direction, the forces of deceleration and acceleration are comparable to the larger shock deceleration forces that that object will feel as it flexes its shock mounts or cushions. Vibration, therefore, is measured in units of “G” force (i.e. multiples of the equivalent of gravitational force), in the measurement of the distance of motion (i.e. the amplitude) and in the number of complete oscillations per second (i.e. the frequency).

Natural Frequency

Every object has at least one natural frequency at which it tends to initiate vibrational motion. The classic example is the tuning fork, which can be struck in a variety of ways and yet always vibrates at a single frequency, even though the amplitude of that vibration may vary. It is even possible to cause a motionless tuning fork to begin to vibrate when exposed to the vibration of a second tuning fork with the same natural frequency. Most manufactured products have a number of natural frequencies, because each of the components in the assembly will have a unique natural frequency or will affect the natural frequency of the item to which it is fastened. As a result, an assembled product such as a computer, a laser, or a transportable dental unit will have a number of individual frequencies at which it is prone to vibrate. Such assemblies will also have harmonic frequencies (i.e. the natural frequency times 2, 3, 4 etc.) at which the same components will also be prone to vibrate.

Resonant Frequencies

The natural frequencies and harmonic frequencies of a piece of equipment constitute points of potential damage or destruction of the equipment. If the equipment is exposed to vibrational energy at one of its natural or harmonic frequencies, it will respond by beginning to vibrate in the same way that a turning fork will respond to its natural frequency. This cross-over of forcing frequency and natural frequency causes the amplitude of motion of the vibrating object to continue to grow (i.e. to resonate). In effect, this response is like pushing a child on a swing. In the beginning, the swing is at rest. The first push starts the swing in motion, and each additional push results in a longer arch of motion (i.e. amplitude). In fashion similar to the swing, the amplitude of a resonating object will continue to increase as long as the forcing frequency continues to amplify its motion. That amplification (i.e. resonance) must be structurally damped (i.e. controlled) or the vibrating object may be damaged or destroyed.

ABSORBING SHOCK ENERGY

The container or enclosure must provide a shock absorption system to prevent the forces of impact from being fully transferred to the contained equipment. An effective shock attenuation design will utilize all of the energy absorption capabilities of the container, including the flexibility of the container walls, the shock mounts, and/or a foam cushioned interior.

Structural Attenuation

The container itself should be viewed as an important source of structural attenuation of shock energy. It must be assumed that the container will not be allowed to crush, even though a crushable material yields ideal energy absorption curves, because a crushed container is not reusable. Upon impact, the walls of a composite container will flex and will allow the container's point of impact to move inward into the rectangular envelope of the container. After reaching maximum flexure, the container walls rebound like a spring and rebound the container away from the point of impact. The container is a flexible member which adds structural shock attenuation to the system, and it is effective enough to be included as one of the elements in the cushioning system for the equipment.

Dynamic Attenuation

Shock mounts or foam cushions normally provide the majority of the shock attenuation of the container. The basic objective of a shock attenuation system is to allow the enclosed equipment to move. At the moment of impact, the container will flex toward the equipment and the enclosed equipment will begin to flex the cushion system as it moves toward the container's point of impact. The basic idea is to allow full utilization of the space between the equipment and the container (i.e. the sway space) for flexing the shock attenuation system. It is mandatory that the shock mount system be stiff enough to prevent the internal impacting of the equipment and the container. But as the shock mount or cushion system allows greater displacement (i.e. the allowable distance of movement within the container) for the equipment, the equipment will feel lower peak deceleration (i.e. shock) for an impact of any given magnitude. By way of example:

The concept is quite similar to uniformly decelerating (i.e. braking) an automobile from a speed of 100 miles per hour to a stop. If the car is stopped in a distance of 1000 feet, the driver will experience a low

deceleration force, but he/she will experience that force for a long period of time as the car is slowing to a stop. If the car is stopped in 100 feet, the average force of deceleration will be 10 times greater, but it will only be felt for one tenth as long. If the car is stopped in 10 feet, the average force will be 100 times as great, and the duration of the shock will be one one-hundredth as long. If the car impacts a solid wall at 100 mph, the force of deceleration will approach infinity, but the duration will be reduced to nearly instantaneous.

The container designer will seek to provide adequate sway space to protect the enclosed equipment from peak deceleration forces that would exceed the known fragility (i.e. the mechanical point of breakage) of the equipment. As the fragility of the equipment is reduced (i.e. if it is more fragile), the container must increase in size to allow for greater distance in which to dissipate the force of expected impacts. Therefore, equipment fragility is a primary determinant of container size and the cost of manufacturing that container, and it should never be incorrectly estimated.

Damping of Shock Induced Motion

The shock absorption system of a container actually incorporates two separate functions that are comparable to two individual parts of the suspension system on an automobile. The first function allows the dynamic motion of the equipment, and this corresponds to the coil or leaf springs on a car. The second function is the reduction of the rebounding motion that would result inside the container if the shock attenuation system had springs, but no motion attenuation. It is curious that the “shock mounts” on an automobile actually inhibit motion, but they do little to absorb shock energy, and they perform no purpose in allowing the suspension to flex. If the car’s “shock mounts” are removed, the springs will continue to oscillate for an uncomfortably long time until other frictional forces bring the vehicle to rest. A container shock mount must never be confused with the “shock mount” on a vehicle. The container shock mount must allow effective motion and simultaneously provide the inherent ability to dampen (i.e. reduce that motion) that same shock induced motion. This is generally achieved by a careful selection of materials from which the shock attenuation device is manufactured.

Shock Mounts

Shock mounts are available in a wide variety of materials from elastomers and rubber compounds to coiled steel cable assemblies. Each material and configuration has distinct shock absorption characteristics. Some materials perform more efficiently over a broad range of temperatures than other materials. Some have more efficient vibration damping capabilities. Because there is such a wide range of choices, the selection of a shock mount system should be accomplished in consultation with the ECS Application Engineering Department.

ABSORBING VIBRATIONAL ENERGY

In addition to shock absorption, the container or enclosure must provide effective vibration attenuation to prevent destructive vibrational frequencies from being fully transferred to the contained equipment. An effective vibration attenuation design will benefit from the energy damping characteristics of the container material and from the energy damping characteristics of the shock mounts and/or foam cushioned interior.

Structural Attenuation

The container itself should be viewed as an important source of structural attenuation of vibrational energy. When subjected to forcing vibration frequencies, the walls of a composite container will repeatedly flex and will absorb a portion of the vibrational energy. Certain container materials are less dynamic (i.e. less springy) and are able to more effectively dampen the energy of vibration. The container is a flexible member which adds vibration damping in addition to structural shock attenuation for the cushioning system. It is effective enough to be considered as one of the most important elements in the vibration attenuation system for protecting the equipment. Some container and enclosure designs rely exclusively on the structural attenuation of composite materials for the entire vibration attenuation protection of equipment which is rigidly attached to the interior of their cases.

Dynamic Attenuation

Shock mounts or foam cushions normally provide the majority of the vibration damping of the container. The basic objective of the selection of vibration attenuation characteristics is to avoid transmitting potentially damaging vibration frequencies from the walls of the container to the enclosed equipment. At the least, the shock mounts or foam cushion set must minimize the amplification of vibrational energy that is transmitted to the equipment at potentially damaging frequencies. Minimizing transmissibility helps to assure that the equipment does not resonate.

Linkage of Shock and Vibration Attenuation

Unfortunately, the shock attenuation characteristics of a shock mount system are inseparably linked to its vibration attenuation characteristics, too. In essence, as the shock mount is made softer in order to allow for greater motion within the container during impacts, the softer shock mount system also develops a lower natural frequency. A shock mount system, like all other objects, will have a natural frequency and harmonic frequencies at which it is most prone to vibrate. If the equipment fragility is so low that it forces the use of very soft shock mounts, the equipment may then be subjected to the higher vibrational force and increased amplitude (i.e. distance of motion occurring during each cycle) at those lower frequencies. Under such conditions, the damping characteristics of the shock mount system are put to a severe test of endurance. If the product to be packaged is fragile and requires specialized shock and vibration attenuation, it is very important that design consultations be initiated with the ECS Application Engineering Department.

FOAM CUSHIONING MATERIALS

A variety of foam cushion materials are available for shock and vibration attenuation in reusable containers. These materials can be fabricated, formed and/or molded into an almost endless variety of configurations. Though foam materials are effective for many shock and vibration attenuation applications, they are unable to provide the consistent dynamic characteristics, the long term repeatability or the extended flexure of shock mounts. Some of these materials are more suitable for use in reusable containers and enclosures than other materials. Due to the variety of available materials and their performance differences, please consult with the ECS Application Engineering Department for assistance in the choice of materials and the effective design of foam cushions. Following is additional information on the most commonly specified foam cushioning materials which are manufactured from polyethylene, polyurethane, or polystyrene substrates.

POLYETHYLENE FOAMS

Polyethylene foam cushioning materials are widely specified for use in military transit cases. The U.S. Military specification for polyethylene foam materials is:

PPP-C-1752 Polyethylene Foam, Unicellular, Flexible, for Packaging

These materials are normally supplied in 2 inch thick sheets and are available in a number of densities from 1.5 to 11 Lb/Cubic Foot. This material is also available in the standard colors of white and gray or in a pink anti-static type. Cushions made from sheets of polyethylene foam must be cut, formed, fabricated and bonded together because these materials are not available in a liquid resin type that is moldable similar to the moldability of polyurethane resins. Partially expanded pellets of polyethylene foam can be steam expanded and fused together in a molding process that is similar to the molding of expanded polystyrene (EPS) materials, but this process is not commonly used for cushions in reusable applications. And, polyethylene foam materials of differing cellular size, texture and thickness are available in different parts of the world.

Thermoplastic Material

Polyethylene is a thermoplastic material. It is therefore capable of being heated to a melting point at which it becomes semi-fluid, or it may be cooled to its semi-flexible, solid condition. This property allows individual 2 inch thick sheets of material to be permanently heat fused together into larger blocks and partially formed or die-cut sheets to be bonded into layered cushion assemblies. These foams can be saw-cut, routed, die-cut, and cut or formed with heated knives and wire tools. If required by the container design, the surfaces of the assembled cushion may be densified using heated molds. The result is a relatively smooth, semi-hardened outer coating around most of the cushion's cavities and exterior surfaces.

Cushioning Characteristics

Polyethylene foams have the ability to support relatively high weights per area of surface. This static load bearing strength is due to the closed cell nature of the foam. However, the closed cells also cause the foam to be stiff dynamically, because the entrapped air in each of these small spheres must be compressed in order to compress the cushion. With the cushion sandwiched between the enclosed equipment and an essentially rigid exterior container, the cells of air can only be partially compressed during the dropping or rough handling of the container. With this reduction in deflection, a higher level of shock is transmitted to the equipment than would be transmitted with more compressible foams or with shock mounts. If less foam is used in order to increase dynamic deflection, the potential for total cushion failure is greatly increased, because the cells of foam are likely to be compression ruptured and the foam then loses most of its static load carrying strength. In short, closed cell cushioning materials must be carefully designed - for the protection of fragile equipment that is deployed in rigid, reusable containers.

Temperature and Dynamics

All foam materials tend to lose dynamic cushioning properties at the temperature extremes that are common in the natural environment. Of these materials, however, polyethylene foams tend to retain elasticity over a broader range of temperatures than most other foam materials. This physical characteristic of polyethylene foam is an advantage, however, other characteristics of this foam tend to raise critical container design engineering questions. Please call the ECS Application Engineering

Department to discuss the particular issues that may be associated with a foam cushion design application.

Absorption Vs. Adsorption

Polyethylene foams are closed cell materials. The individual cells of foam retain the air that is trapped inside unless the foam material is so severely compressed or gouged that the walls of the cells are broken. The closed cellular nature of these materials has been highly touted as an advantage because it theoretically reduces the ability of the foam to absorb liquids. In fact, the cut surfaces of polyethylene foams are composed of thousands of cut cells, and each of these cut cells is a small reservoir which can collect and retain liquids (i.e. adsorb rather than absorb). Secondly, as a foam cushion is repeatedly compressed during use, many of its closed cells will be broken, and the foam becomes increasingly absorbent. Worse yet, if liquid seeps into the margin between the interior surfaces of the container and the exterior surfaces of the cushion, it cannot evaporate because the container walls and the cushion are both impervious to moisture vapor. Once trapped between the cushion and the walls of a hermetically sealed container, liquid moisture can only be removed by the frequent changing of saturated desiccant bags or by the removal of the cushion. Since most specifications require that cushions be adhesive bonded into their reusable containers, removal of the cushions normally results in serious damage.

Expansion and Contraction Problems

The air entrapped inside each closed cell of all polyethylene foam materials is subject to expansion and contraction with changes in temperature, altitude and atmospheric pressure. Cushions made from these materials are not dimensionally stable, because the foam itself is not dimensionally stable. These dimensional changes are large because the average rate of dimensional change for 2.0 pound per cubic foot polyethylene foam is approximately 0.025 inch per lineal foot at a temperature difference of 10°F. If a cushion has been manufactured at ambient temperature (70°F) and at sea level, it must be dimensionally inspected under the same conditions, or it will not be the same size. Polyethylene foam cushions which are enclosed within a rigid, reusable container will expand against the walls of the container and against the equipment when the temperature or the altitude is increased. Conversely, these foams will shrink away from the container walls and the equipment when the temperature or the altitude drops. In the first instance, the equipment may be difficult to remove from the container or impossible to re-install back into the cushions. In the second instance, the equipment may move loosely around inside the cushion cavities, and the cushions may be loose within the container.

Chemical Characteristics

Polyethylene is resistant to essentially all of the chemicals, compounds and conditions found in the natural and man-made environments. The natural chemical resistance of these materials causes them to be frequently specified for military applications where exposure to debilitating conditions is anticipated. However, the advantage of the natural chemical resistance of these foams is partially negated by the natural disadvantages of marginal shock and vibration absorption, severe expansion and contraction problems, and the surface adsorption of liquids, which are discussed in a following section.

POLYURETHANE FOAMS

Polyurethane foam cushioning materials are widely used for commercial containers and continue to be specified for use in many military transit cases. The U.S. Military specification for polyurethane foam materials is:

MIL-P-26514 Polyurethane Foam, Rigid or Flexible, for Packaging

Polyurethane foams are most commonly supplied in polyester and polyether varieties, which have distinct physical and chemical properties. These materials are available in large pre-foamed buns (i.e. up to 4 feet wide, 3 feet high and 10 feet in length), which can be cut into sheets and blocks of virtually any size. The densities of these foams vary from 0.5 to 10 pounds per cubic foot, they are available in both flexible and rigid formulations, and they are normally supplied in off-white, gray and other specialty colors. Cushions made from sheets of pre-molded polyurethane foam can be saw-cut, die-cut, hot wire cut, contour cut, and adhesively bonded together.

Thermoset Material

Polyurethane foams are very typical of most thermoset materials. The liquid resin and catalyst are mixed together to initiate a chemical reaction that polymerizes the resin and permanently converts it into a long chain polymeric compound. Once the chemical reaction has occurred, polyurethane foam cannot be melted and reused in the same way that thermoplastic foam materials can be melted, bonded, and re-used. During the chemical reaction, the catalyzed resin discharges small bubblets of carbon dioxide gas. The chemical reaction is an exothermic type (i.e. it gives off heat), which causes the resin to warm and the carbon dioxide bubblets to expand. The reaction is chemically controlled so that the resin will reach the polymerizing temperature at the moment that the carbon dioxide bubbles have expanded sufficiently to attain the desired foam density. At that temperature, the semi-fluid resin cross-links chemically, most of the bubbles break, and the foam permanently retains its configuration and its density.

Cushioning Characteristics

Rigid polyurethane foams are not suitable for packaging applications because they are not compressible. The rigid polyurethane foams are closed cell materials and are primarily used for thermal insulation and flotation purposes. As a result, these rigid foams are not discussed further in this technical manual. However, flexible polyurethane foams are excellent cushioning materials and offer considerably better dynamic performance characteristics than their polyethylene foam counterparts. These materials are open celled and do not depend on entrapped air bubbles for strength or dynamic properties. The structure of the foam is instead dependent on the compressive strength of the cell walls. As the foam is compressed during the dropping or rough handling of a transit case, the open structure of foam is able to be compacted to as little as ten percent of its uncompressed thickness. This compressibility allows maximum dynamic deflection and results in excellent shock absorption characteristics. The compressibility of the foam is also related to its flexibility (i.e. its softness), and polyurethane foam formulations are available from super-soft to semi-rigid materials. The vibration attenuation properties of polyurethane foams are also linked to the foam formulation. Some materials are extremely resilient and have less vibration damping ability than less resilient varieties. In general, the best balance of

shock absorption and vibration attenuation is available in moderate density (i.e. 2.5 to 4.0 Lb/cubic foot), moderately resilient materials. Please contact the ECS Application Engineering Department for assistance on specific cushion design problems.

Temperature and Dynamics

The high temperature dynamic properties of most polyurethane foam materials are adequate for the higher temperatures of the natural environment. However, the dynamic characteristics of polyurethane foam materials are adversely affected at low temperatures. The adequacy of these cushioning materials at very low temperatures (i.e. -20°F and lower) is dependent on the chemical formulation and the density of the foam. Please refer questions regarding temperature extremes to the ECS Application Engineering Department.

Expansion and Contraction

Since polyurethane foam materials are open celled, they do not entrap air in the cells of the foam. Therefore, these materials do not expand or contract as a result of changes in temperature, altitude or atmospheric pressure. This is a distinct advantage compared to their closed celled polyethylene counterparts.

Chemical Characteristics

Polyurethane foams are soluble in some solvents such as acetone, and they are not as chemically resistant as polyethylene foam materials. The most serious disadvantage of many polyurethane foams is degradation that results from long term exposure to high humidity and high temperature. This phenomenon is known as hydrolytic instability and can occur to polyurethane foam cushions in a transit case that has collected water and that has not been effectively desiccated. Though hydrolytic instability is an unwanted characteristic of polyurethane foam materials, it is unlikely to occur frequently. It is the obvious intent of the equipment user to avoid collecting water inside a hermetically sealed container or enclosure, because water would first attack the equipment itself. Given an effectively designed, hermetically sealed container and an adequate supply of desiccant, polyurethane foam cushions are less likely to be damaged by humidity and heat than most equipment stored inside those containers.

EXPANDED POLYSTYRENE FOAMS (EPS)

EPS foams are extensively used for commercial, non-reusable packaging applications and for an immense variety of consumer products from hot drink cups to swimming pool flotation devices. This family of foam materials are closed celled, semi-flexible and partially crushable. As non-reusable cushioning materials, EPS foams are nearly perfect because of their low density, low cost, and adequate cushioning properties. However, these foam materials do crush and permanently distort as a result of compression. As a result, they do not demonstrate the long term, repeatable shock absorption properties that are necessary for most hermetically sealed container applications. And, these materials do not have adequate abrasion resistance or tensile strength to prevent flaking and separation of the small beads of expanded polystyrene. Newer co-polymer bead and steam expandable polyethylene pellet materials offer some hope for the future use of EPS-like foam materials in reusable container applications. However, current EPS materials are rarely applicable for hermetically sealed containers and enclosures.

CWA CONTAMINATION & DECONTAMINATION

Chemical Warfare Agents(CWA), including nuclear, biological and chemical weapons present a formidable challenge for the decontamination of military equipment that may have been exposed to these agents or materials. When considering this challenge, the fundamental objective of the container and enclosure designer is to select materials that are inherently resistant to the decontamination solutions that are used to clean the equipment that may have been exposed to NBC agents. The standard issue decontamination solutions are DS2 and super-tropical bleach (STB), and they are capable of removing far more than the contaminants.

Decontamination Agents

DS2 is a strong alkaline solution in a soapy water base. It is the equivalent of a moderate strength paint remover blended with soap and water. It attacks most types of paints and has the potential for chemical reaction with a variety of materials. Super tropical bleach (STB) is a moderate strength hydrochloric acid solution. It is an effective decontaminant, but it has the ability to attack metallic surfaces that are not protected by resistant finishes.

DS2 and STB Resistance

Thermoplastic materials and composite materials that are generally used for the manufacture of reusable containers are resistant to the effects of the DS2 and STB decontamination agents. Metallic containers, however, must be protected from the decontaminants with chemical agent resistant coatings (CARC), which are a family of painted finishes. CARC paints are notorious for their poor adhesion to most metals. This problem has been further compounded by concern for the environment which has forced the use of water based paints, rather than solvent based varieties.

CARC Paint

The real-life problem for metallic containers is the lack of durability of their painted finishes. The CARC painted container must be handled with “kid gloves” to prevent the scratching and chipping of the CARC finish, even when the container is still in the factory where it was manufactured. Once shipped to the end-user, there is no practical way to maintain the CARC finish on a container that is being used in a military environment. And, as the painted finish is worn off, the exposed metal surfaces are more visually detectable to an enemy, and they can be chemically attacked by decontamination agents. In this arena, metallic containers are at a disadvantage compared to thermoplastic and composite materials.

Ideal Materials

In fact, the ideal container design would eliminate the external use of all metallic items, including latches, handles and air valves. Ideally, the decontamination resistant container would utilize composite materials for all of its structural components, and would use an injection molded plastic air breather valve.

ESD/EMI/RFI/TEMPEST SHIELDING

Containers and enclosures for electronic equipment must provide effective electromagnetic shielding for a growing list of applications, both military and commercial. The demand for shielding effectiveness is driven by three primary concerns; first, that an opponent may detect and/or monitor equipment that radiates energy; second, that the electronic equipment may be damaged if it is exposed to energy radiated from an outside source; and third, that electromagnetic radiation from one piece of equipment

may interfere with the functioning of other nearby equipment.

Shielding Methods

Each of these concerns can be addressed by either shielding the equipment (i.e. shielded components or shielded chassis) or by encasing the equipment in an effectively shielded container or enclosure. The methods for achieving effective shielding of containers and enclosures vary, but certain fundamental design and performance objectives must be met, regardless of the materials or methods used. These objectives are dictated by the fundamental characteristics of the electromagnetic radiation to be isolated.

Electromagnetic Waves

All electromagnetic waves include an electric field and a magnetic field. The relative strengths of the electric field (i.e. the “E” field) and the magnetic field (i.e. the “H” field) are determined by the distance the wave has traveled from its source and by the type of source that generated the electromagnetic wave. If the source of the electromagnetic wave has high electrical current flow and relatively low electrical potential (i.e. electromagnets and electrical transmission lines), the resulting electromagnetic wave will be primarily in the “H” field. If the source has high voltage and low electrical current flow, the resulting electromagnetic wave will be primarily in the “E” field. If the sources of radiating electromagnetic energy include both characteristics, then the resulting wave, or waves, may include strong “E” and “H” fields.

“E” and “H” Fields

The shielding of the “E” and “H” field components of all electromagnetic waves must occur in order to achieve the effective attenuation of electromagnetic energy over the broadest possible range of frequencies. This objective is first addressed by selecting a shielding material that provides high electrical conductivity and which is capable of being molded or fabricated into a fully encapsulating shield. This design problem is similar to fabricating a storage tank with no openings in it... nothing can get in, but nothing can escape, either. Secondly, each of the openings thru the shield (including holes, fastener locations, changes in materials, doors, flanges and closures, etc.) must be designed to maintain long term, low resistance, electrical continuity. This electrical continuity should be essentially continuous across every surface of every opening. This design problem is similar to remanufacturing the first tank into a water storage tank that is complete with inspection port and pipe fittings but which has one plug missing...it will still leak water, and is an unacceptable design.

Effective Shielding

So it is with the electromagnetic shielding of containers and enclosures. In the most basic terms, the electromagnetic shielding effectiveness of a container or enclosure is dependent on the electromagnetic characteristics of the materials from which it is manufactured, on the effectiveness of the joints which connect its individual parts, and on the longevity of the electrical interfaces at those joints. Failure of any of these shielding elements will result in the ingress or egress of electromagnetic energy. Partial failure or deterioration of any of these shielding elements will result in deterioration in the shielding effectiveness of the container or enclosure.

EMI/RFI/TEMPEST Shielding

In general, the accepted levels of electromagnetic shielding that are specified for various types of applications are:

| Application | Attenuation | Frequency range |
|--------------------------|--------------------|------------------------|
| Tempest | 60 – 100 db | 50 mhz – 2 ghz |
| MIL–STD–461/462 | 50 – 70 db | 50 mhz – 2 ghz |
| FCC 15–J | 20 – 40 db | 50 mhz – 2 ghz |
| Good commercial practice | 20 – 40 db | 50 mhz – 2 ghz |

Aluminum Shields

Despite some of its other drawbacks, aluminum is the most widely used shielding material for a variety of electronic applications. It is inherently conductive, and demonstrates excellent shielding effectiveness for the electric (E) field. Aluminum, however, is a highly active metal that oxidizes rapidly when exposed to the oxygen in air, and the resulting aluminum oxide coating is non-conductive. The long term shielding effectiveness of aluminum containers and enclosures is adversely affected by the build-up of aluminum oxide on the exposed surfaces of gasketed interfaces, flanges, and other frequently opened areas. Even when these surfaces are protected by chromate conversion coatings (i.e. Iridite) or plated nickel finishes, they are subject to abrasion during normal use and they ultimately build-up non-conductive, aluminum oxide coatings. These points of reduced conductivity along gasketed surfaces are sources of electromagnetic leakage.

Shielded Plastics

With the exception of electrostatic discharge applications, all non-metallic containers and enclosures must be provided with supplemental shielding materials, because these thermoplastics and composites are inherently non-conductive and, therefore, non-shielding. The effectiveness of electromagnetic shielding for these materials varies greatly, and is a function of the base container material, the selection of shielding method and the effectiveness of the application of the shielding material and gaskets.

THERMOSET COMPOSITES

ECS Composites has demonstrated excellent electromagnetic shielding effectiveness in its compression molded, glass fiber reinforced composite materials. Using proprietary techniques, ECS molds its composite container shells with interior layers of nickel and/or iron/tin materials that are tough and abrasion resistant. The combinations of materials, thicknesses, and performance characteristics of these conductive composites can be readily changed to accommodate different levels of shielding effectiveness. These composite shells are then attached to nickel plated aluminum extrusions using a continuous, highly conductive interface between the shells and the extrusions. A slow curing, epoxy potting compound used at the joint insures that this conductive interface is protected from environmental exposure, chemical corrosion and galvanic corrosion. The molding of glass fibers, resin and shielding materials into an integrated composite product is a unique capability of the ECS compression molding technique. And, the resulting product retains all of the external chemical resistance characteristics and broad temperature performance of the ECS non-shielded composite container.

THERMOPLASTIC COMPOSITES

ECS Composites has successfully demonstrated its ability to apply conductive coatings to the interior of its compression molded thermoplastic composites. The company is able to apply coatings of nickel or zinc and a variety of conductive paints. The primary deficiencies of all coating methods, regardless of the surfaces to which they are applied, are the adhesive strength of the coating to the surface of the part and the abrasion resistance of the coating itself. When applied to relatively rigid thermoplastic composites (as compared to flexible non-reinforced plastics) these coatings can demonstrate acceptable adhesion, and are suitable for a variety of applications. Specific applicability of these methods should be discussed with the ECS Composites Application Engineering Department.

CONDUCTIVE THERMOPLASTIC COMPOSITES

ECS has pioneered the experimental molding of highly conductive, thermoplastic composite materials. These non-production-available materials have experimentally demonstrated the most desirable properties of composite and metallic materials, and few of the drawbacks. However, insufficient demand for these materials has resulted in non-commercial availability of economically viable production quantities. The electrical properties of the materials offer low surface resistivity for effective gasketing of joints, connectors and fasteners, and high levels of conductivity for effective electromagnetic shielding. These materials can be molded into complex configurations without supplemental manufacturing steps, they retain the natural chemical resistance of the thermoplastic substrates, and they will not corrode to non-conductive surfaces, as will aluminum. These materials were initially available in plastic substrates that are capable of operating temperatures of approximately 93°C, but later generations of materials operate at temperatures in excess of 177°C. Specific inquiries about the future availability of these dramatic material developments should be directed to the ECS Composites Application Engineering Department.

NON-REINFORCED THERMOPLASTIC MATERIALS

Non-reinforced thermoplastic materials are seriously deficient where electromagnetic shielding is required. Suitable grades of static discharge (ESD) capable materials are available, but these will not begin to provide EMI/RFI/TEMPEST shielding effectiveness. Non-reinforced thermoplastics are typically either rotationally molded from a powdered plastic (i.e. polyethylene) or are thermoformed from sheets of ABS or polyethylene. Neither manufacturing process permits the molding of parts with either an integrated layer of conductive material or with integral conductivity which is dependent on long strand conductive fibers. These parts must be coated with paints or other conductive finishes to provide shielding effectiveness. Even when applied using the finest materials and techniques, these coatings may chip and crack, are easily scratched from container surfaces, fail to maintain effective electrical conductivity at joints and gaskets, and tend to decompose with long term exposure to harsh environments. Additionally, the flexibility of non-reinforced thermoplastic materials may cause the conductive coatings to craze, chip and peel during rough handling, drops and thermal or pressure caused expansion and contraction of the container.

CASE STYLES OLD & NEW

Reusable containers have been manufactured in a wide range of styles for many years. The functional characteristics of each style are normally considered during the process of selecting the best container design for each application. The following descriptions of container styles will assist in that selection process.

NON-OPERATING CASE STYLES

Containers and enclosures are generally categorized according to the functioning of the equipment that is stored inside. If the equipment is not expected to be operated while installed in the container, the container is classified as a non-operating style case. If the equipment is intended to be operated while installed or restrained within the container, the container is considered to be an operating style case or enclosure. This first group of container styles is primarily used for the transportation and storage of equipment, not for the operation of that equipment.

VALISE CASES

ECS valise cases are the equivalent of industrial grade suitcases, and are intended for hand carrying, baggage handling and limited shipment.

Shape. ECS valise cases have the general clam-shell configuration of suitcases. The top and bottom halves of any valise case may be of different depths.

Sizes. Standard valise cases are available in maximum depths of sixteen inches and maximum length and width dimensions of approximately thirty inches and twenty-four inches, respectively.

Hardware. These cases are hinged with a piano-style hinge, and they have a single suitcase style handle located opposite the hinged side of the case. Standard valise cases are equipped with rain-proof, anodized, extruded aluminum closures and lockable latches.

Materials. ECS valise style cases are available in thermoset composite, thermoformed polyethylene and ABS, and pressure molded electro-static discharge materials.

Options. Valise cases may be equipped with foam cushions, shock and vibration isolation systems, and a variety of special hardware devices to adapt to unusual applications.

CARRYING CASES

Carrying cases are a unique family of containers that are designed to be hand carried using a handle that is centered on the top surface of the container.

Shape. These containers normally have a relatively deep bottom half and a shallow top half, and should be limited in width to a size that is narrow enough to be comfortably hand carried.

Sizes. Carrying Cases may be manufactured in a large number of small to intermediate sizes, but the container width is generally sixteen inches or less.

Hardware. Carrying Cases have the option of being hinged using a piano-style hinge with a stay hinge for holding the lid open at approximately 90°, or they may have fully removable tops. These cases may be equipped with an assortment of hardware types including rain-proof or hermetically sealed closures, latches, handles, air breather valves, and other devices. When equipped with an interior flange for the mounting of equipment, this style is more typically described as a panel mount case or a combination case.

Materials. Carrying Cases are manufactured in thermoset composites, thermoplastic composites, thermoformed polyethylene and ABS, rotationally molded polyethylene, and pressure molded electrostatic discharge materials.

EMI/RFI shielding. Thermoset composite and thermoplastic composite cases are capable of being EMI/RFI shielded.

Options. Carrying Cases may be equipped with foam cushions, shock and vibration isolation systems, and a variety of special hardware devices to adapt to unusual applications.

COMMERCIAL TRANSIT CASES

ECS standard commercial transit cases are the most commonly specified non-military containers.

Shape. ECS commercial transit cases are generally of the clam-shell configuration, with equal or variable depth top and bottom halves.

Sizes. Standard containers are manufactured in a wide range of dimensions from very small to intermediate and larger sizes. The depths of top and bottom case halves are variable within the maximum allowable dimensions of the tooling.

Hardware. These transit cases have the option of being hinged using a piano-style hinge or slip-apart hinges, or may have fully removable tops. They are rain-proof, but not hermetically sealed, so air valves are not required. The standard design includes rain-proof, anodized, extruded aluminum closures, spring-loaded lever action latches, and spring-loaded steel handles with neoprene grips. Thermoplastic composite cases incorporate molded-in closure features and are able to include the consolidation of many other case features during the molding process.

Materials. These transit cases are available in thermoset composites, thermoplastic composites, thermoformed polyethylene, rotationally molded polyethylene, and pressure molded electrostatic discharge materials.

EMI/RFI shielding. Thermoset composite and thermoplastic composite cases are capable of being EMI/RFI shielded.

Options. Commercial transit cases are frequently equipped with foam cushions for the protection of delicate equipment. Shock and vibration isolation systems and a variety of special hardware devices are available to adapt these cases to unusual applications.

HEAVY DUTY TRANSIT CASES

Heavy Duty Transit Cases are the industrial equivalent of ECS' MIL-SPEC cases.

Shape. ECS heavy duty transit cases are generally of the clam-shell configuration and have fully removable tops. However, certain case sizes and configurations are capable of being hinged using heavy duty piano-style hinges or stainless steel slip-apart hinges.

Sizes. Standard containers are manufactured in a wide range of dimensions from smaller cases to very large sizes. The depths of top and bottom case halves are variable within the maximum allowable dimensions of the tooling.

Hardware. These cases are hermetically sealed and are equipped with manually activated air breather valves. The standard case design includes heavy duty, hermetically sealed, anodized, aluminum extrusion closures. Thermoplastic composite cases incorporate molded-in closure features and are able to include the consolidation of many other case features during the molding process. All heavy duty transit cases, regardless of case shell material, are equipped with heavy duty spring-loaded latches and spring-loaded steel handles with neoprene grips.

Materials. These transit cases are available in thermoset composites, thermoplastic composites, thermoformed polyethylene, rotationally molded polyethylene, and pressure molded electro-static discharge materials.

EMI/RFI shielding. Thermoset composite cases and thermoplastic composite cases are capable of being EMI/RFI shielded.

Options. Heavy Duty Transit Cases are frequently equipped with foam cushions for the protection of delicate equipment, but shock and vibration isolation systems and a variety of special hardware devices are available to adapt these cases to unusual applications.

MILITARY TRANSIT CASES

Military Transit Cases are manufactured for a tremendous variety of applications. As a result, there is no such thing as a "standard" military transit case. These are generally unique designs which are tailored to specifically meet the needs of each application. However, these cases have many common features.

Shape. ECS military transit cases are generally of the clam-shell configuration and normally have fully removable tops. However, certain case sizes and configurations are capable of being hinged using heavy duty piano-style hinges or stainless steel slip-apart hinges. The container design may take on a variety of forms and configurations to satisfy the vagaries of the mundane to the unique application. They are designed and manufactured to withstand the most rigorous usage in the extreme environments of man and nature.

Sizes. Military containers are manufactured in a wide range of dimensions from small cases to exceptionally large sizes. Unusual case sizes can be fabricated by joining two or more molded composite case shells together. Hardware styles, container wall thicknesses and corner build-up are

varied to accommodate the container size and the weight of enclosed equipment. The depths of top and bottom case halves are variable within the maximum allowable dimensions of the tooling.

Hardware. These cases are hermetically sealed and are equipped with automatic air breather valves. Thermoset composite military case designs include heavy duty, hermetically sealed, aluminum extrusion closures which are anodized following the completion of all fabrication steps. Thermoplastic composite cases incorporate molded-in closure features and are able to include the consolidation of many other case features during the molding process, many of which eliminate the need to drill holes thru the case. Military Transit Cases are equipped with heavy duty spring-loaded latches, spring-loaded steel handles with neoprene grips, and hardware protection devices. Many hardware devices are available in passivated stainless steel, and all hardware can be supplied with MIL-SPEC finishes, including cadmium or zinc plating, powder coating or CARC paint.

Materials. Military Transit Cases for deployment in the most severe climatic environments are available in thermoset composites and thermoplastic composites. Military transit cases for applications which demand exposure to the temperature extremes of the real environment are manufactured from thermoset and thermoplastic composite materials. Applications that can be definitely restricted to lesser temperature extremes may be made from all of ECS's materials, including non-reinforced thermoformed polyethylene and ABS, rotationally molded polyethylene, and the higher performance composite materials.

EMI/RFI shielding. Thermoset composite cases and thermoplastic composite cases are also capable of being EMI/RFI shielded.

Options. Military Transit Cases are frequently equipped with foam cushions for the protection of delicate equipment, but shock and vibration isolation systems and a variety of special hardware devices and fabricated sheet metal components are available to adapt these cases to unusual applications.

OPERATING STYLE CASES

Containers and enclosures that allow the operation of enclosed equipment, without requiring the removal of that equipment, provide added utility for the end-user of many types of devices. These applications include tremendously diverse types of equipment from transportable pumps and air compressors to computerized test systems, communications systems and intelligence gathering devices. Each operating style case, container or enclosure must provide the transportability and environmental protection of a transit case together with the simplicity of use of a normal equipment cabinet. This need for design versatility requires attention to container performance characteristics as well as to the ergonomic design features that will allow efficient use of the equipment.

Rackmount Electronic Enclosures

ECS designed the first transportable electronic enclosures for nineteen inch rack mountable equipment in 1965. The initial product line, covered by US Patent 3,482,895, has evolved into a comprehensive group of operating case styles which meet the needs of a wide range of applications.

RIGID RACK-MOUNT CASES

These cases provide protection for rigidly rack mounted 19 inch equipment in an enclosure with minimum overall dimensions. These containers are ideally suited for sheltered applications or fixed installations where space is limited. They are also ideal for mechanically durable equipment that does not demand substantial shock and vibration protection but still needs transportability in an environmentally secure enclosure. Even though no shock or vibration mounts are used, the compression molded composite case shells provide vibration damping properties that are helpful in meeting vibration test requirements.

Shape. Rigid rack mount enclosures are typically designed with front and rear removable covers. They are designed to be operated horizontally and have features for stackability with other enclosures, so that systems of equipment may be interconnected.

Size. Standard enclosures are available in rack heights from three units (3U) to twelve units (12U) (i.e. 5.25" to 21.0") and in five standard front-to-back depths of 8.63", 13.78", 18.90", 24.00", and 30.00". Custom enclosures can be manufactured in other sizes.

Hardware. Standard enclosures are equipped with 10-32 threaded clip nuts for installation of equipment panels on the aluminum vertical rack mount members of the enclosure. Uni-strut rails and movable 10-32 nuts are used for fastening support members, slides, drawers and other devices to the interior of the rack mountable framework within each enclosure. Exterior hardware includes hermetically sealed closures, a choice of the exclusive ECS Roto-Tim latch or surface mounted compression latches, spring-loaded handles, air breather valve, and stacking rails or feet on the bottom surface.

Materials. Rigid rack mount enclosures are primarily manufactured from ECS' compression molded thermoset composite materials.

EMI/RFI shielding. Developmental designs have been completed for the manufacture of these enclosures using ECS' thermo-stamped composite (TSC) material. Electromagnetic Shielding of transportable operating enclosures is offered as an option.

VIBRATION ATTENUATED RACK-MOUNT CASES

Vibration attenuated enclosures strike an optimum balance between attenuation and compactness. Moderate interior sway space is allowed for the absorption of vibrational energy. Since motion due to vibration is normally less than that caused by impact, the moderate sway space of this enclosure family provides minimum attenuation of shock energy from impacts. These enclosures represent a balance between dynamic performance and overall enclosure size, and they are ideal for many man-portable and shelter applications.

Shape. Vibration attenuated rack mount enclosures are typically designed with front and rear removable covers. They are designed to be operated horizontally and have features for stackability with other enclosures, so that systems of equipment may be interconnected.

Sizes. Standard enclosures are available in rack heights from three units (3U) to twelve units (12U) (i.e. 5.25" to 21.0") and in five standard front-to-back depths of 8.63", 13.78", 18.90", 24.00", and 30.00".

Custom enclosures can be manufactured in other sizes. Standard enclosures are equipped with 10-32 threaded clip nuts for installation of equipment panels on the aluminum vertical rack mount members of the enclosure. Uni-strut rails and movable 10-32 nuts are used for fastening support members, slides, drawers and other devices to the interior of the rack mountable framework within each enclosure. Exterior hardware includes hermetically sealed closures, a choice of the exclusive ECS Roto-Tim latch or surface mounted compression latches, spring-loaded handles, air breather valve, and stacking rails or feet on the bottom surface.

Shock attenuation. These enclosures are equipped with orbital vibration attenuation mounts which flexibly attach the aluminum rack mount frame to the inside of the enclosure. These vibration mounts are available in various spring rates and quantities to accommodate a range of equipment weights.

Materials. Vibration attenuated rack mount enclosures are manufactured from ECS' compression molded thermoset and thermoplastic composite materials and in rotationally molded polyethylene.

EMI/RFI shielding. Electromagnetic Shielding of transportable operating enclosures is offered as an option.

SHOCK & VIBRATION ATTENUATED RACKMOUNT CASES

These enclosures offer the full range of shock and vibration attenuation together with the environmental protection of hermetically sealed containers. ECS manufactures four different families of these enclosures (i.e. the 3000 Series, the 5000 Series, the 6000 Series, 7000 Series and the 8000 Series) together with a tremendous variety of custom designs. Shock and vibration attenuated enclosures are larger in size than vibration attenuated enclosures in order to provide added interior sway space. Motion caused by impact is normally greater than motion caused by vibration. Therefore, increased sway space has been designed into these enclosure families to provide for the attenuation of potentially damaging levels of shock and impact energy. By dissipating that energy over a greater distance, which is provided by greater interior sway space, it is possible to reduce the shock levels that reach the enclosed equipment. These three enclosure families offer three different levels of shock absorption thereby allowing the selection of an enclosure based upon an evaluation of fragility of the equipment and maximum allowable enclosure size. These enclosures are ideal for the majority of transportable electronic applications. In addition to the many standard features of the 2000, 4000, 5000, 6000, 7000 and 8000 Series enclosures, the 3000 Series enclosures can be manufactured with double-wide or triple-wide racks, with rack depths up to 36 inches and rack heights up to 60 inches.

Shape. Shock and vibration attenuated rack mount enclosures are typically designed with front and rear removable covers. They are designed to be operated horizontally and have features for stackability with other enclosures, so that systems of equipment may be interconnected.

Sizes. Standard 5000, 6000, 7000 and 8000 Series enclosures are available in rack heights from three units (3U) to twelve units (12U) (i.e. 5.25" to 21.0") and in five standard front-to-back depths of 8.63", 13.78", 18.90", 24.00", and 30.00". The 3000 Series family is manufactured in standard rack heights from three units (3U) to twenty-seven units (27U) (i.e. 5.25" to 47.25"). The 3000 Series enclosures can be custom manufactured with double-wide or triple-wide racks, with rack depths up to 36 inches

and rack heights up to 60 inches. Custom enclosures can be manufactured in an immense variety of additional sizes and configurations.

Hardware. Standard enclosures are equipped with 10-32 threaded clip nuts for installation of equipment panels on the aluminum vertical rack mount members of the enclosure. Uni-strut rails and movable 10-32 nuts are used for fastening support members, slides, drawers and other devices to the interior of the rack mountable framework within each enclosure. Exterior hardware includes hermetically sealed closures, a choice of the patented ECS Roto-Tim latch or surface mounted compression latches, spring-loaded handles, air breather valve, and stacking rails or feet on the bottom surface.

Shock attenuation. These enclosures are equipped with shock mounts which flexibly attach the aluminum rack mount frame to the inside of the enclosure. Shock mounts in 5000, 6000 and 7000 Series enclosures are installed diagonally. 3000 Series mounts are installed horizontally within each enclosure. 8000 Series mounts are installed vertically within each enclosure. These mounts are available in various spring rates and quantities to accommodate a significant range of equipment weights.

Materials. Vibration attenuated rack mount enclosures are manufactured from ECS' compression molded thermoset and thermoplastic composite materials and rotationally molded polyethylene.

EMI/RFI shielding. Electromagnetic Shielding of transportable operating enclosures and/or rack-mount inner frames for these enclosures is offered as an option.

COMBINATION CASES

The term "combination case" is synonymous with the term "operating case", and originates in US Military specifications (i.e. MIL-T-28800, Test Equipment for Use with Electrical and Electronic Equipment) which include field portable cases and enclosures for use with such equipment. In general, combination cases are designed for the electronic equipment to be rigidly attached and to allow that equipment to be operated while installed in the case. Most combination cases, however, require that the equipment be able to withstand the effects of the environment while the cover, or covers, of the case are removed. This requirement clearly affects the methods selected for sealing the equipment panels, for sealing the joints between the equipment panels and mounting flanges, and for cooling and ventilation of the equipment.

Shape. Combination cases are manufactured in a diverse variety of shapes and configurations. Some will have single covers, and others will have multiple covers.

Sizes. There is no standard combination case. These containers are generally custom manufactured for each application, and may range in size from rather small to rather large containers.

Hardware. These cases are hermetically sealed and are equipped with automatic air breather valves. Thermoset composite combination case designs include heavy duty, hermetically sealed, anodized, aluminum extrusion closures. Thermoplastic composite cases incorporate molded-in closure features,

flanges, panel mounting fasteners and are able to include the consolidation of many other case features during the molding process. Combination cases are equipped with heavy duty spring-loaded latches, spring-loaded steel handles with neoprene grips, and hardware protection devices. Many hardware devices are available in passivated stainless steel and aluminum and can be supplied with MIL-SPEC finishes, including cadmium or zinc plating, anodizing, powder coating or CARC paint.

Shock attenuation. These containers may utilize shock and vibration mounts, but are more likely to have rigidly mounted equipment installed in them.

Materials. Combination cases for deployment in the most severe climatic environments are available in thermoset composite and thermoplastic composite materials. Military Transit Cases for applications which demand exposure to lesser temperature extremes are manufactured in all of ECS' materials including thermoformed polyethylene, rotationally molded polyethylene, and the higher performance composite materials.

EMI/RFI shielding. Thermoset composite cases and thermoplastic composite cases are capable of being EMI/RFI shielded.

PANEL MOUNT CASES

Panel mount cases are a specific variety of combination case. A panel mount case will always have a flange, an equipment mounting surface or some other provision to mechanically affix the equipment into the case. These mounting features are frequently gasketed to allow the hermetic sealing of the equipment into the case. In most other respects, the design of panel mount combination cases is very similar to other combination cases.

Shape. Panel mount cases are manufactured in a diverse variety of shapes and configurations. Some will have single covers, and others will have multiple covers.

Sizes. There are many standard panel mount case sizes. In addition, custom panel mount containers are manufactured in a range of sizes from rather small to rather large containers.

Hardware. These cases are hermetically sealed and are equipped with automatic air breather valves. Thermoset composite combination case designs include heavy duty, hermetically sealed, anodized, aluminum extrusion closures. Thermoplastic composite cases incorporate molded-in closure features, flanges, panel mounting fasteners and are able to include the consolidation of many other case features during the molding process. Panel mount cases are equipped with heavy duty spring-loaded latches, spring-loaded steel handles with neoprene grips, and hardware protection devices. Many hardware devices are available in passivated stainless steel and aluminum and can be supplied with MIL-SPEC finishes, including cadmium or zinc plating, anodizing, powder coating or CARC paint.

Shock attenuation. These containers do not utilize shock and vibration mounts, but the dynamic responsiveness of the composite case materials will provide some shock and vibration attenuation for the equipment installed in them.

Materials. Panel mount cases for deployment in the most severe climatic environments are available in thermoset composites and thermoplastic composites. Panel mount cases for applications which

demand exposure to lesser temperature extremes are manufactured in all of ECS' materials including thermoformed polyethylene, rotationally molded polyethylene, and the higher performance composite materials.

EMI/RFI shielding. Thermoset composite cases and thermoplastic composite cases are capable of being EMI/RFI shielded.

FOAM SUSPENSION OPERATING CASES

A foam suspension operating case is another unique type of combination case. These cases are designed to retain the enclosed equipment in molded or fabricated foam cushions which will not interfere with the operation of the equipment while the equipment is in the case. Such cases have limited application because of the limitations of the foam materials that are available for use. These limitations include the insulating characteristics of both open celled and closed celled foams, which tend to prevent the dissipation of heat from the inside of the case. Secondly, foam materials tend to take a compression set (i.e. permanent sagging or compression) over time, and they may not effectively retain a piece of equipment when the covers of the case are removed. If these and other design limitations can be overcome, foam suspension operating cases offer a cost effective design alternative to shock mounted operating cases.

Shape. Foam Suspension Operating Cases can be manufactured in a diverse variety of shapes and configurations. Some will have single covers, and others will have multiple covers.

Sizes. There is no standard foam suspension operating case. These containers are generally custom manufactured for each application, and may range in size from rather small to rather large containers.

Hardware. These cases are hermetically sealed and are equipped with automatic air breather valves. Thermoset composite case designs include heavy duty, hermetically sealed, anodized aluminum extrusion closures. These cases are equipped with heavy duty spring-loaded latches, spring-loaded steel handles with neoprene grips, and hardware protection devices. Many hardware devices are available in passivated stainless steel and aluminum, and hardware can be supplied with MIL-SPEC finishes, including cadmium and zinc plating, anodizing, powder coating and CARC paint.

Shock attenuation. These containers do not utilize shock and vibration mounts, but the foam suspension system is intended to provide effective shock and vibration protection for the enclosed equipment.

Materials. Foam suspension cases are available in thermoset composites and thermoplastic composites, thermoformed polyethylene, rotationally molded polyethylene.

EMI/RFI shielding. Foam suspension operating case designs do not allow effective electromagnetic shielding. The case itself may be shielded, but it is extremely difficult to maintain shielding integrity between the walls of the case and the equipment. It is therefore not possible to provide shielding for the equipment while it is in operation, if the cover is not installed on the case.

FINISHES FOR CONTAINERS & HARDWARE

EXTERIOR CONTAINER FINISHES

The exterior finish of a reusable container or enclosure is essential for its long term utility and survivability in the natural and man-made environments. The first objective when seeking reliable exterior container finishes is to select materials and/or finishes that are inherently resistant to the chemicals, solvents, sunlight and naturally occurring elements to which the container will be exposed during an extended lifetime. The second objective is to specify exterior materials and/or finishes that will permanently resist abrasion so that the exterior surfaces of the container or enclosure are able to permanently resist those hazards of man and the environment.

Container Hardware Finishes

Exterior hardware devices also need long term protection from the hazards of the environment. Because many of these devices have moving parts, it is impossible to provide plated or painted finishes that will not be abraded during normal use, due to contact between their moving parts. And, because most of these parts are manufactured from low carbon steel, the loss of plated or painted finishes invariably leads to corrosion and ultimately to malfunction of the hardware. At greater expense, many latches, handles, hinges and other hardware devices are available in passivated stainless steel materials, which demonstrate significantly better corrosion resistant properties than their low carbon steel counterparts.

Permanence of Finishes

Permanence of exterior finishes enhances the longevity of reusable containers and enclosures. If the container materials are inherently resistant to all of the hazards, and therefore do not require supplemental finishes, permanence of protection is guaranteed. However, as the chemical resistant properties of the materials decrease, the use of increasingly durable supplemental finishes is required. By way of example, steel is rarely specified for reusable containers and enclosures despite its cost effectiveness, because steel cannot be permanently protected from corrosion. Aluminum is more commonly specified than steel but it, too, must be painted, alodined or anodized, and still corrodes when those protective finishes are scratched off during use. At least by comparison with steel, which was the dominant container material during World War II, aluminum corrodes more slowly and only corrodes severely in a salt laden environment.

Pigmented Plastic Materials

Plastic substrates, both thermoplastic and thermoset, have the significant advantage of inherent resistance to most of the chemicals, solvents, sunlight and naturally occurring compounds that are the adversaries of reusable containers. These polymeric plastics invite the use of pigments that are blended throughout the thickness of the container material and which provide an immense variety of high density colors for the molded containers. Compared to metallic containers, the color of the molded thermoplastic or composite container cannot be scratched off during use. These materials therefore demonstrate permanent and inherent resistance to the corrosive environments that are most destructive to their metallic competitors. Pigmentation of these materials is a distinct advantage compared to materials that must be painted or supplementally finished.

PLATED FINISHES & CONVERSION COATINGS

Steel and aluminum parts are most effectively protected from corrosion by the application of electro-deposited finishes, electroless finishes or chemical conversion coatings. Electro-deposited finishes such as cadmium and zinc offer excellent adhesion to steel, but these finishes are typically only a few ten-thousandths of an inch thick, and are subject to surface abrasion. Of the two finishes, cadmium is significantly more resistant to the corrosive attack of salt spray than zinc. However, genuine concerns about the industrial pollution of the environment have caused cadmium plating to become increasingly expensive and fewer platers continue to offer this process. The result has been an increased focus on achieving the best possible corrosion resistant properties from zinc, despite its clear inferiority to cadmium.

Aluminum Finishes

Electroless nickel, anodized and duranodic finishes are the best protective coatings for aluminum. Anodized finishes can be applied in a variety of hardnesses, thicknesses and colors, but they are non-conductive finishes and are therefore not suitable for EMI/RFI shielded applications. Electroless nickel provides a highly conductive and corrosion resistant surface treatment for aluminum, however it is costly and is no more abrasion resistant than anodized finishes. Chemical conversion coatings for aluminum are conductive and are suitable for EMI/RFI applications, but these finishes are extremely thin, they are not abrasion resistant, and they do not offer long term resistance to corrosive environments.

MIL SPEC Finishes

Most protective finishes for metals are applied in accord with the requirements of US Military specifications. The most commonly used processes for containers and enclosures are:

QQ-P-416 Electro-deposited Cadmium Coatings for Steel

QQ-Z-325 Electro-deposited Zinc Coatings for Steel

MIL-A-8625 Anodized Coatings for Aluminum

MIL-C-5541 Chemical Conversion Coatings for Aluminum

MIL-C-26074 Electroless Nickel Coatings for Metals

PAINTS

Painted finishes are typically applied to metallic containers and container hardware for the purpose of providing an acceptable color, reduced reflectivity and corrosion protection for the metallic parts. These finishes can either be applied with the use of conventional liquid paints or the more recently available powder coatings. Liquid paints typically require that the material to be painted first be surface treated with a plated finish, alodine, anodize and/or primer coatings. Such surface treatments are necessary to achieve effective bonding of the paint to the surface of the metallic material. The use of liquid paints has been further complicated by concerns for the environment, which has resulted in the demand for the use of water-based paints rather than solvent-based varieties. The objective of the change in paint types is to reduce the quantity of volatile organic compounds that are released into the atmosphere. While the

water-based paints do achieve that objective, they do not exhibit the adhesion or abrasive resistance of their solvent-based counterparts. The resulting finishes are not capable of adhering to the surfaces of metallic containers or metallic hardware when those products are used in the real world of military and industrial applications.

CARC Paint

One family of liquid paints, the aliphatic polyurethanes, is increasingly specified for use on containers and enclosures because of the resistance of these paints to the decontamination agents that are used to clean US Military equipment in the event of exposure to nuclear, biological or chemical warfare agents. These paints, known as chemical agent resistant coatings (CARC), are notorious for their poor adhesion to most metals. As a result, CARC painted containers and enclosures must be handled carefully to prevent the scratching and chipping of the CARC finish. Once shipped to the end-user, there is no practical way to permanently retain the CARC finish on a container that is being used in a military environment. Unlike the factory worker, military personnel are unable to keep a bottle of touch-up paint handy at all times to repair scrapes and scratches to the CARC finish.

Powder Coating

Because of the inherent problems associated with liquid paints, there has been a growing use of dry paints that are electrostatically applied and baked onto the surface of the metallic parts. This method of painting, known as powder coating, applies the most durable painted surfaces that are suitable for containers and enclosures. Powdered paints are available in a variety of types, including epoxies, acrylics and polyurethanes, and they are able to be applied to any surface that can be electrostatically charged and that is capable of being baked at elevated temperatures. The resulting finishes demonstrate excellent chemical resistance and weatherability. These powder coated finishes demonstrate substantially improved adhesion, abrasion resistance, and chip resistance compared to aliphatic polyurethanes which are applied as liquid coatings. The US Military specifications for CARC and powder coated epoxy paints are:

MIL-C-46168 Aliphatic Polyurethane, Chemical Agent Resistant Coatings

MIL-C-24712 Coatings, Powdered Epoxy (Metric)

GEL COATS FOR FIBERGLASS PARTS

Compression molded glass fiber reinforced composites are able to be pigmented and do not need supplemental exterior or interior finishes. However, fiberglass parts that are not compression molded do require supplemental finishes. This need results from the undesirable cosmetic finish that is achieved using hand lay-up, spray-up and resin injection molding processes. These non-compression molding techniques are unable to effectively force a high content of glass fibers and pigmented resin onto all of the surfaces of the mold, and the result is a molded surface with pits, voids and an undesirable appearance.

Gel Coat Application

Improvement in the appearance of non-compression molded parts is achieved by applying gel coat to the surface of the mold prior to molding the part. The gel coat is applied with airless spray equipment, and is allowed to harden for a few minutes prior to completing the molding process. The gel coat is actually

a highly pigmented thermoset resin that has been thickened so that its viscosity will allow it to cling to the surfaces of the mold.

Gel Coat Bonding

The gel coat resin is promoted (i.e. catalyzed) using a hardener that causes it to harden at room temperature on the surfaces of the mold. The exposed surface of the hardened gel coat remains tacky enough for subsequent layers of resin and glass fibers to effectively bond during the molding process. When the fiberglass part is molded over the top of the hardened gel coat, the gel coat bonds tenaciously to the surface of the part. This surface treatment is cosmetically attractive, but it conceals a molded fiberglass part that is very inferior to the structural strength and impact resistance of compression molded composite parts.

Gel Coat Unnecessary

Gel coats cannot be successfully applied to the heated tools that are used in the compression molding processes. But gel coated finishes are not needed for compression molded containers and enclosures because of the effectiveness of pigmented finishes that can be achieved during the molding process. Therefore, the lack of a gel coated finish on a composite container or enclosure is a strong indication that the product has been compression molded.

Compression Molding Preferred

Reusable containers and enclosures with gel coated finishes should be avoided unless the application is for a prototype or a model. Containers manufactured by the hand lay-up, spray-up and resin transfer processes, which require gel coated finishes, have never successfully met the rough handling requirements of US Military specifications. Even if they could, the weights of such containers would substantially exceed the weights of their compression molded composite counterparts.

MANUFACTURING METHODS FOR CONTAINERS

MOLDING METHODS FOR CONTAINERS

Selecting the correct molding process for a composite part requires a knowledge of the differences between many different manufacturing methods. Each of these techniques has applications where it is the ideal method for manufacturing composite parts of specific configurations, of specific materials, or of specific finishes. For example, the ideal choice of manufacturing method for making a thirty foot boat hull will probably not be the best method for manufacturing a safety helmet. The choice of manufacturing method will be influenced by the quantity of parts being manufactured, because of the tooling cost and production rate differences between various methods.

The most prominent manufacturing methods for molding composite parts are found in two primary categories of tooling techniques, closed tool methods and open tool methods.

CLOSED TOOL METHODS

Closed Tool Molding techniques always utilize male and female tool halves. These techniques utilize different methods of distributing the composite materials within the tools; different methods of curing the parts within the tools; and different closing, clamping and/or compression means for activating the tools. These methods allow the use of a wide variety of reinforcement materials and hundreds of different types and blends of resins or plastic substrates. The result is extensive latitude in the performance characteristics of molded composite parts.

Elastomeric Compression Molding

This is the technique that is employed by ECS to manufacture its glass fiber reinforced, isophthalic polyester composite containers and enclosures. The process requires a polished female mold which has been machined from either aluminum or steel and which exhibits the configuration that is desired for the exterior of the molded part. The male half of the tool is an elastomeric material that is capable of being hydraulically compressed into the female mold. The two mold halves are mounted on a vertical hydraulic press with sufficient daylight (i.e. the fully open dimensions of the press) and tonnage to mold the part.

Reinforcement Materials

Glass fiber reinforcement materials, in the form of sheets, are placed into the tool. These sheets of glass fibers do not contain any molding resin. Reinforcement materials are available in a variety of weights of glass fibers per square foot; in a variety of fiber lengths including continuous strands; in different counts of glass filaments per strand; and contain an assortment of sizings and binders for proper bonding of the resin to the glass filaments.

Repeatability

The glass fiber reinforcement sheets are of statistically reliable weight per square foot. It is therefore possible to repeatedly manufacture molded parts that will have a specific content of glass fibers per square foot. And, these sheets of reinforcement fibers are able to be overlapped in the corners and edges of the parts where additional strength is required. The elastomeric plug is small enough and sufficiently

flexible under pressure that it allows the molding of a variety of container wall thicknesses within the same female mold. Wall thicknesses that are ideal for light duty commercial applications or for heavy duty military uses can be manufactured from the same mold without modification.

Resin Application

An isophthalic polyester resin is blended with a pigment concentrate and with a catalyst to achieve the specified color and rate of cure that will be achieved within the heated halves of the mold. The resin is then poured over the exposed surfaces of the glass fiber sheets that have been previously placed into the tool.

Closing the Mold

After the mold has been charged with the glass fiber reinforcement materials and the blended resin, the hydraulic press is activated, and the elastomeric male half is lowered into the female cavity of the mold. Near the end of the travel of the hydraulic press, the bottom surface of the elastomeric plug will contact the glass fibers and resin that are located on the inside, bottom surface of the female mold. At this point, the hydraulic press is allowed to continue to increase the applied force on the elastomeric male half, and the elastomer expands to fill the entire interior volume of the glass fiber and resin part.

Uniform Pressure

The hydraulically applied vertical force is uniformly distributed in the form of pressure and is applied against all vertical and horizontal, interior surfaces of the female mold. The process is very similar to a closed fluid hydraulic system, where pressure applied against any point in the system will be applied equally against all of the remaining surfaces of the system.

High Fiber Percentage

The net effect of this equally applied pressure is the ability to compress the glass fiber reinforcements on every surface of the part prior to the curing of the polyester resin. This squeezing of the glass fibers reduces the amount of resin that would otherwise be needed to thoroughly wet-out all of the reinforcement filaments. The process maximizes the glass fiber content of the finished part, and it results in optimum strength-to-weight ratios. And, every surface of the molded part will achieve equal compaction, equal percentages of glass fibers and resin, and therefore equal strength.

Curing the Part

The heated mold halves quickly cause the catalyst to activate, and the resin is fully cured in very few minutes. At the end of the curing process, the part is removed from the tool and is prepared for subsequent fabricating steps. Since the process occurs within the confines of a closed mold, there are no fumes, no dangerous by-products, no atomized resins or volatile solvents, and very little mess.

Flow Form Compression Molding

This is the technique that is used at ECS for the manufacture of glass fiber reinforced thermoplastic composite parts, which we refer to as thermo-stamped composites (TSC). It requires the use of matched metal mold halves which define the interior and the exterior surfaces of the finished part. Unlike the elastomeric plug assisted method, this molding technique does not allow the molding of parts which are specified to have different wall thicknesses from one part to the next. Like every other matched molding technique, the flow forming technique requires molds that are specifically designed and manufactured

with the configurations and wall thicknesses for every cross section of the part that has been designed. The molding process yields parts that are identical, part after part after part.

High Pressure Molding

This is a high tonnage process. As a result, the molds used in this process must be capable of resisting approximately 1500 PSI on all interior surfaces of both halves of the mold. And, these tools must be capable of containing that high pressure while the mold halves are in motion. Tools that have been designed for injection molding are not suitable for the flow form compression molding process because they are designed to clamp the male and female halves together prior to injecting the material into the mold. By comparison, this process requires that the mold halves be capable of sliding together while the charge of composite material is already in the mold. By compressing that material, it is forced to flow into all of the areas of the mold.

Materials Described

In this process, the raw material is in the form of compacted sheets which contain glass fiber reinforcements, thermoplastic resin substrate, pigmented color, and additives. There are no other catalysts or additives that are needed to manufacture finished parts. These sheets of composite material are available with a variety of types of glass reinforcement, including chopped strands up to two inches long, continuous strands, short milled fibers, and combinations of these reinforcements. Additionally, these composite sheets are available manufactured from a variety of plastic substrates and combinations of additives for flame retardance, ultra-violet stability, electrical conductivity, etc.. Selection of the ideal thermoplastic composite material for each application should be made in consultation with the ECS Application Engineering Department.

Material Preparation

Large sheets of the thermoplastic composite material are sheared into sizes that fit each tool. When placed in the mold, the material is never allowed to drape over the surface of the male half of the tool, so the blank pieces must be small enough to fit on the top surface of the male half. Sheared pieces of the proper size are placed in an infra-red oven and are heated to approximately 450°F prior to molding.

Placing the Material

The matched metal mold halves are secured to the upper and lower platens of the hydraulic press. The female half of the mold is secured to the upper platen, and the male half of the mold is secured to the bottom platen of the press. The sheets of heated material are stacked and placed onto the top surface of the male half of the mold. The press is then activated, and the two halves of the mold slide together along the guide pins, bushings and other alignment features of the tool.

Closing the Mold

The tool halves continue to approach each other until the stack of heated sheets of thermoplastic composite material begins to be squeezed within the mold. With the application of substantial force, the stack of heated material is squeezed between the horizontal surfaces of the mold and it is forced to flow horizontally away from the stack. This horizontal flow then progresses into a vertical flow of semi-molten material down the sidewalls and cavities of the mold. The process is similar to the result obtained by squeezing a sphere of putty between two parallel surfaces. The sphere is reduced to a

round, flat sheet of putty which gets thinner but larger in diameter as additional force is applied by the parallel surfaces. Such squeezing of the raw material causes velocity of flow, and causes the material to ultimately fill every nook and cranny in the mold.

Glass Fiber Distribution

In this process, the semi-molten thermoplastic substrate maintains such high viscosity that it carries the glass fiber reinforcements along with it into every cavity of the mold. The process therefore is able to maintain consistent reinforcement in every area of the molded part. This is precisely the same requirement that is fulfilled by the elastomeric plug assisted process which ECS uses for the molding of high strength thermoset composite parts.

Removing the Part

The molding cycle is completed when the temperature of the part has been reduced sufficiently to allow it to be removed from the tool. Demold temperatures of these materials vary considerably, but in general the parts are physically stable at temperatures in excess of 250°F, and are able to be removed from the tool. The total cycle-to-cycle molding times for these materials allow up to 25 parts per hour to be completed in single cavity molds. Wall thicknesses and part complexity will vary the demold times of these materials, but the process is still quite fast. Molded parts require very little flash removal and are virtually ready for final assembly steps when completely cooled to room temperature.

Molded-In Features

Like injection molding, the molds for this process allow the incorporation of extremely detailed features which are then imparted to every item molded in the tool. Such features include molded-in inserts, fastener attachment points, male and female closures, O-ring depressions, ribs and bosses, and many more.

Matched Metal Molding with Pre-forms

This is the technique that is used at ECS for the manufacture of glass fiber reinforced thermoplastic composite parts, which we refer to as thermo-stamped composites (TSC). It requires the use of matched metal mold halves which define the interior and the exterior surfaces of the finished part. Unlike the elastomeric plug assisted method, this molding technique does not allow the molding of parts which are specified to have different wall thicknesses from one part to the next. Like every other matched molding technique, the flow forming technique requires molds that are specifically designed and manufactured with the configurations and wall thicknesses for every cross section of the part that has been designed. The molding process yields parts that are identical, part after part after part.

Pre-Form Making

The pre-form molding technique gets its name from the pre-formed pattern of glass fiber reinforcements that is placed in the tool at the start of the molding cycle. Pre-forms approximate the interior shape of the female half of the mold. These pre-shaped charges of glass fiber reinforcements are manufactured in advance of the molding process by spraying chopped strands of glass fibers over a metal screen that is similar in shape to the male half of the mold. The shaped screen is mounted on a revolving table, and air is drawn down thru the screen as it revolves. Strands of glass fibers are applied using a hand held

chopper gun that sprays chopped lengths of glass fibers onto the revolving screen and simultaneously applies a liquid binder that holds the strands together.

Pre-Form Drying

When the operator has applied a sufficient amount of glass fibers to the surface of the screen, the screen is placed in an oven and the liquid binder is allowed to dry. The pre-form is then capable of being removed from the screen and is strong enough to be a free standing, pre-shaped charge of glass fiber reinforcements.

Molding Process

As the molding process begins, the pre-form is placed into the female half of the mold. Polyester resin, which has been blended with a pigment concentrate, a heat activated catalyst and inorganic fillers (i.e. chalk and/or clay) is poured into the mold. The hydraulic press is then activated, and the two halves of the mold slide together along the guide pins, bushings and other alignment features of the tool. The two halves of the matched metal mold continue to approach each other until they reach the permanent stops on the mold which prevent further motion. The closing motion of the mold will also be stopped when the charge of resin and pre-formed glass fibers completely fills the space between the male and female mold halves. Since solid matter cannot be compressed, the mold will stop moving when it is completely filled with material, even if the mold has not yet reached the permanent stops.

Curing the Part

The heated mold halves quickly cause the catalyst to activate, and the resin is fully cured in very few minutes. At the end of the curing process, the part is removed from the tool and is prepared for subsequent fabricating steps. Since the process occurs within the confines of a closed mold, there are no fumes, no dangerous by-products, no atomized resins or volatile solvents, and very little mess. In this respect, the pre-form molding process is quite similar to the elastomeric plug assisted method, but there are many important differences between these processes and the quality of parts molded with them.

Low Fiber Percentage

Matched metal molding with pre-forms is specifically suited to applications where a precise distribution of glass reinforcement materials is not critical to the performance of the finished product. This process is also not appropriate where high percentages of glass fiber reinforcement are necessary to provide adequate strength for the finished product. These limitations are the result of inherent problems with the process of manufacturing the pre-form itself and with the use of matched metal tools.

Process Inconsistencies

Pre-forms cannot be manufactured with a controlled placement of the glass strands on all of the exposed surfaces of the revolving screen. This problem is easy to understand when one recognizes that the operator of the chopper gun can only estimate the thickness of glass fibers that have been applied to any one area of the revolving screen. Once the first layer of chopped fibers has covered the screen, it is impossible to accurately estimate the actual thickness of any one area of the pre-form. At best, the chopper gun operator can apply a specific weight of glass fibers to the total surface area of the pre-form, but he/she cannot assure that the glass fibers have been properly distributed. The pre-form is therefore a far less dependable method of composite reinforcement than the use of glass fiber reinforcement sheets

that are known to be of statistically reliable weight per square foot. The use of robotic assisted chopper guns has proven to be of limited value, and they are clearly not economical for many manufacturers.

Structural Weaknesses

The matched metal mold is also a significant source of structural weakness in molded thermoset composite parts. The male and female halves of these molds are both manufactured from either steel or aluminum and are machined to define the precise interior and exterior surfaces of the molded part. Because of the rigidity of the male half, it is impossible to compress the glass fibers against the vertical, interior surfaces of the female cavity. This rigidity causes two specific sources of structural failure in pre-form molded parts. First, it is impossible to achieve high glass fiber content (i.e. 50% and above) on the side walls of molded parts, and these surfaces therefore cannot achieve optimum strength-to-weight ratios or the impact resistance of elastomeric plug assist molded parts. Secondly, any of the variations in glass fiber placement that occurred at the time the pre-form was manufactured will be concealed by the rigid tools themselves. In other words, the molded part will always have the same wall thicknesses regardless of the amount of glass fibers that are placed in any specific area of the tool. Any of those areas that are lacking glass content will simply fill up with resin and the inorganic fillers (i.e. chalk and clay) that are blended into the resin. This results in variations in the impact resistance of one area of the part compared to another area of the same part. If the product is a container, it is impossible to certify that every item in a production quantity will perform at the same level as every other item in that group.

Process Comparisons

Matched metal molding with pre-forms does have some advantages, but none of them are structural. This process allows the molding of parts with a smooth interior surface as well as a smooth exterior surface. This is mandatory for such items as shower pans and food handling bins. The process also allows the incorporation of some additional details into the interior surfaces of molded parts, but these features are limited by the ability of the pre-formed glass fiber shape to fit into small ribs, bosses, etc.. The process is clearly unable to provide the structural integrity of the elastomeric plug assisted compression molding process, and it cannot provide the consolidation of molded-in features that is possible with the flow form compression molding technique.

Matched Metal Molding with Sheet Molding Compound

The design of matched metal tools that are used for the molding of sheet molding compound is essentially identical to the design of molds used for matched metal molding with preforms. The male and female halves of these molds are both manufactured from either steel or aluminum and are machined to define the precise interior and exterior surfaces of the molded part. This process requires that the mold halves be capable of sliding together while the charge of composite material is already in the mold. By compressing that material, it is forced to flow into all of the areas of the mold.

Materials Described

In this process, the raw material is in the form of semi-cured sheets which contain glass fiber reinforcements, polyester thermoset resin substrate, a heat activated catalyst, pigmented color, inorganic fillers such as chalk or clay, and additives. These sheets of composite material can be manufactured with

a variety of types of glass reinforcement, including chopped strands up to two inches long, continuous strands, short milled fibers, and combinations of these reinforcements. The raw materials in SMC materials are mechanically kneaded to a uniform consistency and are then rolled into sheets which are about a quarter-of-an-inch thick. The sheets of material are covered on each side with a thin plastic film which prevents the tacky sheets from bonding together. The sheets are then allowed to semi-harden into a partially cured condition at which the resin attains the firmness of putty. These partially cured sheets are then refrigerated in order to prevent the premature hardening of the semi-cured resin substrate.

Placing the Material

The matched metal mold halves are secured to the upper and lower platens of the hydraulic press. The female half of the mold is secured to the upper platen, and the male half of the mold is secured to the bottom platen of the press. The sheet molding compound is cut and weighed for each molded part. The semi-hardened material is easily handled because of its putty-like consistency. The plastic film coverings are removed prior to molding, and the stack of cut SMC sheets are placed on the top surface of the male half of the mold. The press is then activated, and the two halves of the mold slide together along the guide pins, bushings and other alignment features of the tool.

Closing the Mold

The tool halves continue to approach each other until the stack of un-heated sheet molding compound begins to be squeezed within the mold. With the application of moderate force, the stack of un-heated material is squeezed between the horizontal surfaces of the mold and it is forced to flow horizontally away from the stack. This horizontal flow then progresses into a vertical flow of the highly viscous material down the side walls and cavities of the mold. The flow dynamics of the SMC process are very similar to the flow characteristics achieved in the flow form compression molding of thermoplastic composite materials. Such squeezing of the raw material causes velocity of flow, and causes the material to ultimately fill every nook and cranny in the mold.

Glass Fiber Distribution

In this process, the semi-hardened SMC substrate maintains such high viscosity that it carries the glass fiber reinforcements along with it into every cavity of the mold. The process is able to maintain consistent reinforcement in every area of the molded part. However, the percentage of glass fiber reinforcement is low compared to parts molded by the elastomeric plug assisted compression molding process.

Curing the Part

The heated mold halves quickly cause the catalyst to activate, and the resin is fully cured in very few minutes. At the end of the curing process, the part is removed from the tool and is prepared for subsequent fabricating steps. Since the process occurs within a closed mold, there are no fumes, no dangerous by-products, and no atomized resins or volatile solvents.

Process Comparisons

Matched metal molding with sheet molding compound does have some advantages, but none of them are structural. This process, like all matched metal molding processes, allows the molding of parts with a smooth interior surface as well as a smooth exterior surface. The process also allows the consolidation

of a large variety of additional details onto the interior and exterior surfaces of molded SMC parts. Unlike matched molding with pre-forms, the SMC process allows the incorporation of extremely detailed features which are then imparted to every item molded in the tool. This mold design flexibility is similar to injection molding and the flow forming of thermoplastic composites.

Structural Weaknesses

The SMC molding process is clearly unable to provide the structural integrity of parts molded with the elastomeric plug assisted compression molding process. The inadequate impact resistance of SMC molded parts is the direct result of the inability of this process to allow high levels of glass fiber reinforcement. Despite the developmental work that has been done with directionally oriented reinforcement materials, the SMC process is not suitable for containers or other applications where impact resistance and rough handling durability are required.

Matched Metal Molding with Bulk Molding Compound

This process is exactly the same as the matched metal molding of sheet molding compound, but with one exception. The material that is molded in the matched metal tool is different. Unlike SMC, bulk molding compound is reinforced with short strand glass fibers. The material is not produced in sheet form, because it is a blended mixture of short glass fiber reinforcements, polyester thermoset resin substrate, a heat activated catalyst, pigmented color, inorganic fillers such as chalk or clay, and additives. These raw ingredients are mechanically mixed by the blades of a large dough blender until they have become homogeneous, and then the BMC material is readied for molding.

Placing the Material

The batch of BMC material may be allowed to semi-harden into a partially cured condition at which the resin attains the firmness of putty. This partially cured material must then be refrigerated in order to prevent the premature hardening of the semi-cured resin substrate. The semi-hardened material is easily handled because of its putty-like consistency. The BMC material is weighed to establish a correct charge for the mold, and the wad of material is placed on the top surface of the male half of the mold. The press is then activated, and the two halves of the mold slide together along the guide pins, bushings and other alignment features of the tool.

Closing the Mold

The tool halves continue to approach each other until the un-heated bulk molding compound begins to be squeezed within the mold. With the application of relatively low pressure, the un-heated material is squeezed between the horizontal surfaces of the mold and it is forced to flow. The flow of material progresses down the side walls and into the cavities of the mold. The flow dynamics of the BMC process are very similar to the flow characteristics achieved in the flow form compression molding of thermoplastic composite materials. Such squeezing of the raw material causes velocity of flow, and causes the material to ultimately fill every nook and cranny in the mold.

Glass Fiber Distribution

In this process, the BMC resin substrate maintains such high viscosity that it carries the glass fiber reinforcements along with it into every cavity of the mold. The process is able to maintain consistent

reinforcement in every area of the molded part, but the percentage of glass fiber reinforcement is low, and the length of glass fibers is very short.

Curing the Part

The heated mold halves quickly cause the catalyst to activate, and the resin is fully cured in very few minutes. At the end of the curing process, the part is removed from the tool and is prepared for subsequent fabricating steps. Since the process occurs inside a closed mold, there are no fumes, no dangerous by-products, and no atomized resins or volatile solvents.

Process Comparisons

Matched metal molding with bulk molding compound has the same advantages as the SMC molding process, but none of them are structural. This process, like all matched metal molding processes, allows the molding of parts with a smooth interior surface as well as a smooth exterior surface. The process also allows the consolidation of a large variety of additional details onto the interior and exterior surfaces of molded BMC parts. Unlike matched molding with pre-forms, the BMC process allows the incorporation of extremely detailed features which are then imparted to every item molded in the tool. This mold design flexibility is similar to injection molding, the flow forming of thermoplastic composites, and the matched metal molding of sheet molding compound.

Structural Weaknesses

The BMC molding process is clearly unable to provide the structural integrity of parts molded with the elastomeric plug assisted compression molding process. Structurally, BMC parts are even inferior to SMC molded parts because the length of glass fiber reinforcement materials achievable with the BMC raw material is far shorter than with the SMC process. And, the inadequate impact resistance of BMC and SMC molded parts is further reduced by the inability of these processes to allow high percentages of glass fiber reinforcement.

Resin Transfer Molding

Resin transfer molding is not a compression molding process, despite the use of matched mold halves. This molding process uses matched male and female mold halves that are typically made from fiberglass reinforced polyester resin, not aluminum or steel. The tools are designed to resist a moderate level of internal pressure that results from the molding process. Each half of the mold will define the configuration that is imparted onto the finished item, and the surfaces of those molded parts will typically be smooth. These characteristics sound reminiscent of many of the features of matched metal molds, but that is where the similarity ends.

REQUIRED EQUIPMENT

Resin transfer molds are typically mounted on a pneumatic or hydraulic press which has sufficient capacity to lift and to lower the top half of the tool. The press, however, does not necessarily need to have sufficient capacity to hold the mold together during the molding process. Instead, the mold may be equipped with clamps or other fasteners that allow the two mold halves to be mechanically secured together during the resin injection process.

Surface Preparation

At the beginning of the molding process, the tool is opened, and the female half of the mold is typically located on the bottom platen of the press. A mold release agent will be sprayed onto all surfaces of both

mold halves in order to guarantee the removal of the molded part. When the mold release has dried, a polyester gel coat will be applied, with airless spray equipment, to those surfaces of the mold where color is required on the molded part. The gel coat is allowed to partially cure prior to placing other materials in the mold (See gel coats in the section on Finishes for Containers and Hardware).

Placing the Material

The partially cured gel coat is viscous enough to resist flowing off of the surfaces of the mold, even vertical surfaces. Its exposed surface is tacky and will bond inseparably with the resin that will soon be injected into the mold. When the gel coat has cured adequately, glass fiber reinforcement materials are placed into the mold. These materials may be cut from sheets of chopped strand or continuous strand reinforcement materials, or the process may use pre-forms, which are essentially identical to pre-forms used in the matched metal molding process. All of the glass fiber reinforcements must be installed in the mold prior to the closing of the tool and prior to the injection of the polyester resin.

Closing the Mold

When all of the glass fiber reinforcement materials are in place, the press is activated to close the mold. The top and bottom halves of the mold will be securely clamped, bolted or otherwise fastened together. When the tool halves are securely attached, resin is injected into the mold thru a series of ports (i.e. openings) in the walls of the mold. The injection of resin may occur simultaneously at a variety of strategically located ports in the mold, or it may occur at only one port. The injection process applies sufficient pressure to the resin that it flows into all of the areas of the mold and permeates all of the strands of glass fibers that have been placed in the tool.

Injecting the Resin

The polyester resin is mixed, dispensed and injected in a continuous process. The resin, which is generally unpigmented, is blended with a metered percentage of room-temperature activated catalyst and resin hardening system as it flows thru the mixing head of the resin injection equipment. The catalyst and hardener begin to immediately cause the promotion of a chemical reaction that cures the polyester resin in the mold. Because the catalyst system functions at room temperature, no supplemental mold heating is required. Typically within one hour the resin will be adequately cured to allow the removal of the part from the tool.

Process Comparisons

The resin transfer molding process has some interesting advantages, but it also has some serious deficiencies. Its primary advantage is the ability to manufacture cosmetically attractive parts in relatively low cost tooling and to do so using inexpensive equipment. As a method for molding glass fiber reinforced polyester parts, it offers improvements in quality and repeatability compared to the open mold, hand lay-up process. It is most suitable for use where impact resistance is not of primary importance, and where lower to moderate production rates are sufficient.

Structural Weaknesses

However, as a process for the manufacture of reusable containers and enclosures, the resin transfer molding process is seriously deficient. First, since the molding process is not a compression molding method, it is impossible to attain high percentages of glass fiber reinforcement in the finished parts. This

results in inadequate structural strength for most container applications. Second, the injection of resin thru the ports tends to wash glass fiber reinforcement materials away from the areas adjacent to the ports, and these areas then lack sufficient reinforcement to withstand normal impact testing. Finally, the rate of production is too slow to be competitive with other molding processes.

Molding of Pre-Impregnated Thermoset & Thermoplastic Materials

Pre-impregnated, reinforced materials are available in a wide range of reinforcement materials and resin substrates. These materials are generally supplied in sheet or roll form, and the sheet raw material will have been saturated with a molding resin, catalyst system and any other additives that are specified. These materials are most commonly available in glass fiber, graphite fiber and polyester fiber reinforcements and will most commonly be saturated with polyester, epoxy or high temperature thermoplastic resin systems.

SMC Similarities

In many ways, pre-impregnated molding materials are similar to sheet molding compound (SMC). The molding material is prepared in advance of the molding process; all of the components of the raw material are contained within the sheet; the raw material is frequently allowed to partially cure to a highly viscous condition; and these materials are normally kept refrigerated prior to molding.

Process Comparisons

The molding process used with pre-impregnated materials is normally a high pressure, matched metal, compression molding process. Unlike other matched metal molding processes (i.e. flow form, SMC and BMC) pre-impregnated materials are not generally expected to flow any significant distance within the mold. Instead, these materials are normally cut to rather precisely fit the contours of the tool, and are clamped tightly within the mold by the closing of the press. This limitation restricts the complexity of configurations that can be comfortably molded. As a result, this process is generally limited to parts with predominately two dimensional shapes, or where the third dimension is somewhat shallow.

Thermoset Materials

If the resin system used in the pre-impregnated material is of a thermosetting variety, the heated mold halves quickly cause the catalyst to activate, and the resin normally cures in a few minutes. At the end of the curing process, the part is removed from the tool and is prepared for subsequent fabricating steps. Tools may even be designed to incorporate shearing blades or trimming features that will cut the part to finished dimensions during the molding process.

Thermoplastic Materials

If the resin system used in the pre-impregnated material is of a thermoplastic variety, the mold temperature must be capable of being cycled between high and low temperatures. The high temperature must be sufficient to melt the resin which is impregnated into the reinforcement material so that the resin can flow sufficiently to conform to the shape of the mold halves. Many of these thermoplastic resins demonstrate melt ranges well in excess of 500°F, and so the molds are generally built from steel. Once formed within the mold, the material must be cooled enough to allow the removal of the finished part. Such extreme variations in mold temperature normally require the use of pressurized steam heat and

subsequent chilling with water. Molding cycles may be relatively long compared with other processes, but these materials are capable of being manufactured into products with phenomenal performance characteristics.

Cold Molding

Cold Molding is a variation on a very familiar matched molding method. Generally, matched tools are metal, such as steel or aluminum, and they are designed for heating the thermoset polyester resin after the resin has been introduced into the tool. The heating of the resin causes the activation of the catalyst, which is normally blended into the resin, and the activated catalyst then causes the chemical reaction which permanently alters the liquid resin into a solid.

Low Cost Molds

Cold molding employs the use of low cost matched molds which are manufactured from glass fiber reinforced polyester. These tools are similar to the tools used for resin injection molding, however, the male and female mold halves must be designed to withstand the modest pressures of this compression molding process. As with other compression molding processes (i.e. matched metal molding with pre-forms, sheet molding compound and/or bulk molding compound), the mold halves are installed on the top and bottom platens of the press. The female half is generally on the bottom platen and the male half on the top platen. Since this is a process requiring low to moderate force, parts can normally be molded on pneumatic presses, but hydraulic presses may be utilized as long as applied tonnage is sufficiently controlled to avoid damage to the tools.

Mold Preparation

At the beginning of the molding cycle, the press is opened and the surfaces of the mold are coated with mold release agent to insure that the finished part can be removed from both halves of the tool. If the molded part requires a cosmetically attractive finish, the surfaces of the mold may be sprayed with a gel coat. After allowing the gel coat to partially cure, the mold is ready for the installation of glass fiber reinforcement materials. These materials may be in the form of sheets of chopped strand or continuous strand glass fibers or as a pre-form similar to those used in the process for matched metal molding with pre-forms.

Room Temperature Molds

At this stage in the molding cycle, this process appears to be very similar to other matched tool molding processes. The real distinctions for the cold molding process, however, are that the mold halves are not heated and that a highly promoted (i.e. catalyzed) polyester resin is introduced into the tool and is compressed into the glass fiber reinforcement materials. The polyester resin is mixed and dispensed in a continuous process. The resin, which is generally unpigmented, is blended with a metered percentage of room-temperature activated catalyst and resin hardening system as it flows thru the mixing head of the resin dispensing equipment. The catalyst and hardener system, after a slight delay for closing the mold, quickly cause the promotion of a chemical reaction that cures the polyester resin in the mold. Because the catalyst system functions at room temperature, no supplemental mold heating is required.

Curing the Part

After dispensing the resin into the mold, the press is activated and the two halves of the mold are closed. The press is used to apply sufficient pressure against the mold halves that the resin will flow into all of the areas of the tool and will saturate all of the glass fiber reinforcements. Typically within one hour the resin will be adequately cured to allow the removal of the part from the tool. The press will be opened, and the molded part will be removed and prepared for supplemental finishing operations

Process Comparisons

The cold molding method for manufacturing glass fiber reinforced composite parts has the advantages of relatively low tooling cost and moderate capital equipment expense, however, the manufactured parts have substantial structural deficiencies. Unlike the elastomeric plug assisted compression molding technique, the cold molding process is unable to compress the glass fiber reinforcement materials against all of the surfaces of the mold. This limitation is normal for all matched metal molding methods that are used for glass fiber reinforced thermoset parts. The result is a low percentage of glass fiber reinforcement in the molded parts and the associated loss of impact strength. Additionally, the molding process is unable to achieve high enough rates of productivity to effectively compete with hot mold manufacturing techniques. As a result, the cold molding technique is not suitable for the manufacture of reusable containers or enclosures.

OPEN TOOL METHODS

Open Tool Molding techniques never utilize matched male and female tool halves. These techniques may utilize either a male or a female shaped mold, but the molded part will always be formed against only one mold surface. These molding methods allow the manufacture of extremely complex part configurations because the open tools allow excellent access to difficult surfaces, and the curing process is generally slow enough to allow hand placement of reinforcement materials and resins. A wide variety of reinforcement materials and resin substrates are available for selection by the composite part designer.

Hand Lay-Up Fiberglass Molding

The hand lay-up method of molding fiberglass parts is widely used for the manufacturing of commercial and industrial products. The average consumer is familiar with products as diverse as power boats, outdoor seating, and traffic signal enclosures that have been manufactured by this process. Every town in America seems to have one or more fiberglass shops that make and repair hand lay-up fiberglass parts of all descriptions. This manufacturing process is so simple to learn, so basic in materials and technology, and so broadly used that it is not unusual to see it proposed for products that cannot tolerate its weaknesses. The misapplication of this process has been responsible for early misconceptions that composite parts were inherently fragile and prone to cracking and fracturing upon impact. Because of the severe performance differences between hand lay-up parts and compression molded parts, this manual prefers to refer to such hand lay-up parts as “fiberglass parts” and other parts as “composite parts”.

Mold Preparation

At the beginning of the molding process, a mold release agent will be sprayed onto all of the surfaces of the mold in order to guarantee the removal of the molded part. When the mold release has dried, a polyester gel coat will be applied, with airless spray equipment, to those surfaces of the mold where

color is required on the molded part. The gel coat is allowed to partially cure prior to placing other materials in the mold.

Material Placement

The partially cured gel coat is viscous enough to resist flowing off of the surfaces of the mold, even vertical surfaces. Its exposed surface is tacky and will bond inseparably with the resin that will soon be applied to the mold. When the gel coat has cured adequately, glass fiber reinforcement materials are placed into the mold. These materials may be cut from sheets of chopped strand or continuous strand reinforcement materials, from woven reinforcements, or the process may rarely use pre-forms, which would be essentially identical to pre-forms used in the matched metal molding process. The glass fiber reinforcements may be placed progressively into the mold during the molding process, and the wall thicknesses of the part may be selectively increased by the molder.

Curing the Part

As the glass fiber reinforcement materials are placed onto the mold, the resin is manually or saturation sprayed. After the application of the resin, the part must be rolled, squeegeed, and brushed to saturate all of the exposed glass fibers. The polyester resin, which is normally an unpigmented orthophthalic type, is blended with a measured percentage of room-temperature activated catalyst and resin hardening system prior to application. The catalyst and hardener begin to initiate the promotion of a controlled chemical reaction that cures the polyester resin on the mold. Because the catalyst system functions at room temperature, no supplemental mold heating is required. The curing of the part may require a number of hours because a rapid cure creates such high temperatures, due to the heat generated by the chemical reaction of the resin, that a rapidly cured part may warp significantly.

Process Comparisons

Since this molding process does not require a second tool half, there is no mold closing cycle, and the process does not need the use of hydraulic or pneumatic presses. The hand lay-up process also has the cost advantage of inexpensive fiberglass molds, which are generally fabricated from the same resins and reinforcement materials as the molded parts. Such tooling simplicity has led to the theft of unique product designs by simply making a duplicate mold (also known as a splash) from the surfaces of a previously molded part. If the product is to be a new design, a mold is made from the surfaces of a wooden or plaster-of-paris pattern.

Structural Weaknesses

Despite the stated advantages of the hand lay-up process, parts manufactured from this technique are totally inadequate for most reusable container and enclosure applications. The only viable container use for this process is for exceptionally large containers that exceed the currently available compression molding capacity of respectable manufacturers. This process is incapable of manufacturing parts with glass fiber reinforcement percentages that achieve high strength-to-weight ratios. In order to achieve high impact strength with this process, it is mandatory to build up very thick wall sections, and that leads to unacceptable container weight. Because transportability and man-portability are essential for most reusable container applications, grossly overweight containers effectively reduce the payload that can be carried. Additionally, this process is so slow that production rates can only be improved by manufacturing and using multiple molds.

Spray-Up Fiberglass Molding

The spray-up method of manufacturing fiberglass parts is very similar to the hand lay-up method. The molds are open, the materials are applied to the exposed surfaces of the mold, and compression is not used to increase the glass fiber percentages of molded parts.

Mold Preparation

At the beginning of the molding process, a mold release agent will be sprayed onto all of the surfaces of the mold in order to guarantee the removal of the molded part. When the mold release has dried, a polyester gel coat will be applied, with airless spray equipment, to those surfaces of the mold where color is required on the molded part. The gel coat is allowed to partially cure prior to placing other materials in the mold.

Material Placement

The gel coat is viscous enough to resist flowing off of the surfaces of the mold, even vertical surfaces. Its exposed surface is tacky and will bond inseparably with the resin that will soon be applied to the mold. When the gel coat has cured adequately, chopped strands of glass fiber reinforcement are sprayed onto the surface of the mold. These strands of glass fiber are applied by a chopper gun that cuts prescribed lengths of glass fiber from a continuous length of spooled glass roving. At the same time that the glass fibers are being applied, the chopper gun applies a spray of polyester resin. In addition to the application of chopped strands of glass fiber, other reinforcements may be applied in the form of woven or sheet materials. The glass fiber reinforcements may be placed progressively into the mold during the molding process, and the wall thicknesses of the part may be selectively increased by the molder.

Curing the Part

The polyester resin, which is normally an unpigmented orthophthalic type, is blended with a metered percentage of room-temperature activated catalyst and resin hardening system as it is passing thru the airless spray head of the chopper gun. The catalyst and hardener begin to initiate the promotion of a controlled chemical reaction that cures the polyester resin on the mold. Because the catalyst system functions at room temperature, no supplemental mold heating is required. The curing of the part may require a number of hours because a rapid cure creates such high temperatures, due to the heat generated by the chemical reaction of the resin, that a rapidly cured part may warp significantly.

Process Comparisons

Since this molding process does not require a second tool half, there is no mold closing cycle, and the process does not need the use of hydraulic or pneumatic presses. The spray-up process also uses inexpensive fiberglass molds, which are generally fabricated from the same resins and reinforcement materials as the molded parts. Such tooling simplicity has led to the theft of unique product designs by simply making a duplicate mold (also known as a splash) from the surfaces of a previously molded part. If the product is to be a new design, a mold is made from the surfaces of a wooden or plaster-of-paris pattern.

Structural Weaknesses

Parts manufactured from this technique are totally inadequate for most reusable container and enclosure applications. Compared to the hand lay-up process, the spray-up process applies additional excessive amounts of resin to the surface of the mold, and parts manufactured by this method are completely

unacceptable for reusable, man-portable container applications. The only potential container use for this process is for large containers that exceed the currently available compression molding capacity of respectable manufacturers. This process is incapable of manufacturing parts with glass fiber reinforcement percentages that achieve high strength-to-weight ratios. In order to achieve high impact strength with this process, it is mandatory to build up extremely thick wall sections, and that leads to unacceptable container weight. Because transportability and man-portability are essential for most reusable container applications, such grossly overweight containers effectively reduce the payload that can be carried. Additionally, this process is so slow that production rates can only be improved by manufacturing and using multiple molds.

Vacuum Bag Molding

The vacuum bag molding method is a clever method of applying modest pressure to the surface of open mold manufactured composite parts. The molds used for this process are generally made from glass fiber reinforced polyester, or they may be metallic if the composite parts are to be heat cured. This technique is used to manufacture glass fiber reinforced thermoset composite parts and for the manufacture of laminated, thermoset composite structures which may include rigid foam, honeycomb, balsa wood and/or other core materials. This technique is used for the manufacture of light-weight structural components which are suitable for use in aircraft interiors and other weight sensitive applications.

Mold Preparation

At the beginning of the molding process, the mold must be cleaned and coated with a mold release agent to guarantee the removal of the molded part. When the mold release has dried, a gel coat may be applied if color is required on surfaces of the molded part. If a gel coat is required, it is allowed to partially cure prior to placing other materials in the mold.

Material Placement

When the gel coat is viscous enough to resist flowing off of the surfaces of the mold, the reinforcement materials and core materials are applied. Reinforcement materials are normally in the form of sheets of chopped strands of glass fibers, graphite fibers or polyester fibers; or in the form of sheets of woven glass fibers. These reinforcement materials may be pre-impregnated with polyester resin or epoxy resin, or the resin may be uniformly applied over the non-impregnated reinforcement materials. The glass fiber reinforcement material, the core materials (i.e. rigid foam, honeycomb etc.), and resin are placed progressively into the mold until the structural laminate has been assembled. The wall thicknesses of the part may be selectively increased by the molder by adding reinforcement materials or by increasing the thickness of core materials.

Applying the Vacuum Bag

When all of the reinforcement materials and resin have been applied to the surface of the tool, a sheet of plastic film is applied over the top of the mold. This plastic film must be carefully sealed around all of the edges of the mold to insure that a vacuum can be retained between the film and the mold. After the film is applied to the mold, a vacuum is drawn under the film and it is sucked down against the reinforcement materials and resin. The applied vacuum is sufficient to compress all of the materials together and to cause them to conform to the surface of the mold.

Curing the Part Without Heat

When parts are vacuum bag molded with unheated molds, the polyester or epoxy resin is blended with a measured percentage of room-temperature activated catalyst and resin hardening system prior to application onto the reinforcement materials. The catalyst and hardener system begin to initiate the promotion of a controlled chemical reaction that cures the resin on the mold. Because the catalyst system functions at room temperature, no supplemental mold heating is required. The curing process may require an hour or more because a rapid cure can cause excess heating of the resin and warping of the part. When the part is cured, the plastic film is stripped, and the part is removed from the mold and made ready for supplemental processing.

Curing the Part with Heat

When parts are vacuum bag molded using heat to cure the resin, the polyester or epoxy resin is blended with a measured percentage of heat activated catalyst prior to application onto the reinforcement materials. After drawing a vacuum between the plastic film and the mold, the mold is moved into an autoclave or infra-red oven for the curing of the part. With exposure to heat, the catalyst system begins to initiate a chemical reaction that cures the resin on the mold. When the part is cured, the plastic film is stripped, and the part is removed from the mold and made ready for supplemental processing.

Process Comparisons

Since this molding process does not require a second tool half, there is no mold closing cycle, and the process does not need the use of hydraulic or pneumatic presses. The vacuum bag process does require tooling that is more expensive than the molds used for the hand lay-up or spray-up processes, but these tools are less expensive than comparable matched metal molds. Unlike matched metal molding processes (i.e. flow form, SMC and BMC) the vacuum bag method uses applied resin or pre-impregnated resin that is not expected to flow any significant distance within the mold. Instead, the reinforcement materials are normally cut to rather precisely fit the contours of the tool, and are pushed tightly to the surface of the mold by the vacuum pressure. This limitation restricts the complexity of configurations that can be comfortably molded. As a result, this process is generally limited to parts with predominately two dimensional shapes, or where the third dimension is somewhat shallow.

Structural weaknesses

Parts manufactured from this technique do not demonstrate the impact resistance required for reusable containers and enclosures. This process is ideal for the manufacture of structurally rigid components that demonstrate minimum weight and rigidity, and which can be subsequently cut, fabricated and joined into complex structures. The only potential container use for this process is for large containers that exceed the currently available compression molding capacity of respectable manufacturers. This process is capable of manufacturing parts with fiber reinforcement orientation that achieves high tensile and flexural strength-to-weight ratios, but not high impact resistance. In order to achieve high impact strength with this process, it is necessary to build up thick wall sections, and that leads to unacceptable container weight. Additionally, this process is too slow to compete with compression molding techniques, and it requires the use of multiple molds to achieve higher production rates.

MOLDING METHODS FOR NON-REINFORCED THERMOPLASTICS

Non-reinforced thermoplastic materials are available in an immense range of types, forms and shapes. These materials, like their composite counterparts, are capable of being molded using a number of well established manufacturing methods. Each combination of thermoplastic material and manufacturing method is ideally suited to specific applications based upon the performance requirements of the product, unique product design features, product configuration, production quantity, and other considerations. The following outline gives an overview of the most prominent manufacturing methods used to manufacture non-reinforced thermoplastic containers.

Injection Molding

Injection molding is a process that is gaining an increasing role in the manufacture of reusable containers and enclosures. The injection molding process has been in use for many years in the manufacture of an immense variety of commercial, industrial and consumer products. No one in the industrialized world will likely spend an entire day at work or at play without touching, using or being dependent on products that have been molded using this technique. But as a method for manufacturing reusable containers and enclosures, this technique is beginning to be viable because of the continued development of improved plastic substrates which exhibit the physical characteristics necessary for some container applications. These materials do not demonstrate the strength of their composite counterparts, but injection molding is destined to be used for an increasing number of container applications.

Mold Design

The injection molding process uses molds that look remarkably like the matched metal molds used in the flow form compression molding process. Unfortunately, injection molding tools cannot be used for the flow form molding process, but flow form tools can generally be modified for use in injection molding. This manufacturing method requires the use of matched metal mold halves which define the interior and the exterior surfaces of the finished part. Unlike the elastomeric plug assisted method used to manufacture composite parts, this molding technique does not allow the molding of parts which are specified to have different wall thicknesses from one part to the next. Like every other technique that uses matched mold halves, the injection molding technique requires molds that are specifically designed and manufactured with the configurations and wall thicknesses for every cross section of the part that has been designed. The molding process yields parts that are identical, part after part after part.

High Pressure Molding

This is a high tonnage process. As a result, the molds used for injection molding must be capable of resisting high clamping pressures as the mold is closed, and high interior pressures on all surfaces of both halves of the mold as the molten material is injected into the tool. Tools that have been designed for injection molding are not suitable for the flow form compression molding process because they are designed to clamp the male and female halves together prior to injecting the material into the mold. By comparison, the flow form molding process requires that the mold halves be capable of sliding together while the charge of composite material is already in the mold. This process difference causes the molds to function differently, even though they are quite similar in appearance.

Materials Described

In this process, the raw material is in the form of granulated thermoplastic substrates which contain pigmented color and additives. These materials may also contain fiber reinforcement materials of a variety of types. These materials may also contain blowing agents that cause the plastic substrate to foam and to be reduced in density. Since this is a thermoplastic molding process, catalysts are not needed to manufacture finished parts. Additionally, these granular materials are available manufactured from a variety of plastic substrates and combinations of additives for flame retardance, infra-red resistance, electrical conductivity, etc.. Selection of the ideal injection moldable thermoplastic material for each application should be made in consultation with resin manufacturers.

Closing the Mold

The matched metal mold halves are secured to the vertical surfaces of the horizontally movable platens of the hydraulic press. The press is then activated, and the two halves of the mold slide together along the guide pins, bushings and other alignment features of the tool. The tool halves continue to approach each other until they reach the mechanical stops on the mold. When the mold halves are in full contact at the stops, the press applies substantial clamping pressure to hold the mold halves in the closed position. The clamping pressure continues as the molten plastic substrate is injected into the cavity that is defined by the interior surfaces of the two mold halves.

Clamping the Mold

With the application of substantial injecting force, the molten material flows away from the injection ports and fills all of the space between the male and female mold halves. The clamping pressure must be maintained throughout the injecting process in order to keep the mold halves closed despite the build-up of interior pressures that are attempting to open the tool. The injection molding process therefore requires press equipment that can apply two different forms of pressure; hydraulic pressure for the clamping of the mold, and injecting pressure to flow the molten plastic substrate into the tool.

Injecting the Material

The granulated material is conveyed into the barrel of the injection molding press. There it is heated in a continuous process until it has reached the appropriate molding temperature and viscosity. After the mold halves have been clamped together at the beginning of the molding cycle, the heated material is forced thru the opening, or openings, in the mold and into all of the cavities within the tool.

Glass Fiber Distribution

When the injection molding material includes glass fiber reinforcement, the heated thermoplastic substrate maintains such high viscosity that it carries the glass fiber reinforcements along with it into every cavity of the mold. The process therefore is able to maintain consistent reinforcement in every area of the molded part. This is precisely the same requirement that is fulfilled by the elastomeric plug assisted process which ECS uses for the molding of high strength thermoset composite parts. Unfortunately, the injection molding process is only able to utilize short fiber reinforcements, and it is unable to achieve part strengths that are comparable to compression molded composite parts.

Removing the Part

The molding cycle is completed when the temperature of the part has been reduced sufficiently to allow it to be removed from the tool. Wall thicknesses and part complexity will vary the demold times of these materials, but the total cycle-to-cycle molding times for injection molded parts can be very fast. Molded parts require very little flash removal and are virtually ready for final assembly steps when completely cooled to room temperature.

Molded-In Features

Like flow form compression molding, the molds for this process allow the incorporation of extremely detailed features which are then imparted to every item molded in the tool. Such features include molded-in inserts, fastener attachment points, male and female closures, O-ring depressions, ribs and bosses, and many more.

Process Comparisons

Injection molding does have advantages, but injection molded parts have varying degrees of structural integrity based on the selection of plastic substrate and reinforcement materials specified. None of these materials approach the structural attributes that are required for reusable containers that are used in the most severe conditions. This process, like all matched metal molding processes, allows the molding of parts with a smooth interior surface as well as a smooth exterior surface. The process also allows the consolidation of a large variety of additional details onto the interior and exterior surfaces of molded parts. The injection molding process allows the incorporation of extremely detailed features which are then imparted to every item molded in the tool. This mold design flexibility is similar to SMC and BMC molding and the flow forming of thermoplastic composites.

Structural Weaknesses

The injection molding process is clearly unable to provide the structural integrity of parts molded with the elastomeric plug assisted compression molding process for thermoset composites or the flow form compression molding process for thermoplastic composites. The inadequate impact resistance at high levels of rigidity of injection molded parts is the direct result of the inability of this process to allow high levels of glass fiber reinforcement and the inability to utilize long strand reinforcement materials. Development work continues to enhance the physical properties of injection molded materials, but the limitations of the injection molding process cause it to be only suitable for smaller containers or other applications where impact resistance and rough handling durability are required.

Thermoforming

The thermoforming process consists of a number of similar techniques for forming heated sheets of thermoplastic materials. The variations in these forming techniques are related to the choice of plastic material, to the design of the tooling, to the alternative use of vacuum and air pressure, and to the programmed motion of the upper and lower platens of the thermoforming equipment. Each thermoforming technique utilizes a unique combination of these elements, which causes it to be the most suitable method for individual formed parts. The choice of thermoforming technique is therefore as important as the choice of material when designing a formed part. Though many of these techniques have been used for many years and have been applied to a variety of plastic substrates, the selection of the ideal thermoplastic sheet material and thermoforming technique for each application should be made in consultation with the ECS Application Engineering Department.

Basic Thermoforming

For the purposes of this engineering manual, the basic thermoforming technique is the most useful method for the manufacture of containers and enclosures. This technique uses a male tool over which the heated sheet of plastic is formed. The use of a male tool distinguishes basic thermoforming from the pressure forming technique which is described in another section of this engineering manual.

Selecting the Thermoplastic Material

Thermoformed containers and enclosures are most frequently manufactured from polyethylene or ABS (Acrylonitrile Butadiene Styrene) sheets. These materials are available in a variety of thicknesses, in a wide variety of pigmented colors, and in textured or non-textured finishes. These materials are available in non-conductive grades and in ESD (electro-static discharge) capable grades. Given the variety of material types that are available, it is important to evaluate the performance requirements that are demanded for each specific application before committing to a choice of material. Each material demonstrates a unique yield temperature at which it structurally fails. And these materials demonstrate different tolerance to chemicals, different flammability and smoke generation characteristics, and differences in formability. Selection of the ideal thermoplastic sheet material and thermoforming technique for that material should be made in consultation with the ECS Application Engineering Department.

Preparing the Thermoplastic Sheet

The blank sheet of thermoplastic material is selected in a thickness that will yield the specified wall thickness after forming. Since the forming process stretches the sheet as it is drawn over the male tool, the finished thickness of the part will be less than the starting caliper of the sheet. The blank sheet is sheared to length and width dimensions that are approximately four inches greater than the length and width of the male tool, thereby leaving two inches of material around the perimeter of the male tool. This additional material is needed for clamping the thermoplastic sheet into the thermoforming machine, and it allows a more consistent wall thickness in the molded part.

Heating the Thermoplastic Sheet

The blank sheet is clamped into the frame of the thermoforming machine. The clamping frame is then moved into a zonally controlled infra-red oven which is capable of radiating different intensities of heat onto different sections of the blank sheet. Micro-processor control of the infra-red oven is necessary to assure that the sheet of plastic is properly heated to a specific temperature in each zone. The variable control of material temperature is vital for the control of the wall thicknesses of different areas of the formed part. When the sheet has been properly heated, the clamping frame is moved into a position over the male tool, and the forming cycle is initiated.

Forming the Part

When properly heated, the sheet of thermoplastic material is stretched by its own weight into a paraboloid shape beneath the clamping frame. Hotter areas of the sheet stretch more readily than cooler areas of the sheet, and the stretched paraboloid is therefore composed of areas of greater and lesser wall thicknesses. The male tool is lifted by a hydraulic or pneumatic cylinder up into the stretched paraboloid of thermoplastic material. As the male tool rises, the heated plastic sheet drapes onto the top of the tool, rolls over the edges of the tool, and then drapes down the vertical sides of the tool. When

the male tool has completed its vertical motion, the formed sheet of plastic material is drawn by vacuum pressure onto the surfaces of the male tool. This forming step may also be assisted with air pressure which pushes the plastic sheet against the male tool.

Removing the Formed Part

When the formed sheet of thermoplastic material has been cooled sufficiently to be dimensionally stable, the male tool is lowered out of the formed part. The clamping frame is opened, and the part can be removed from the thermoforming machine. The part is then ready for the trimming of excess material and for supplemental manufacturing steps.

Process Comparisons

The basic thermoforming technique utilizes a male tool rather than the female tool used in the pressure forming technique for non-reinforced thermoplastic materials. If a textured surface is required on the outside of the part, the use of a male tool forces the manufacturer to select a textured sheet of thermoplastic material. During the stretching and forming process, the texture on the blank sheet of material is distorted and is less distinguishable on corners and areas of the part where greater stretching is required to form the part. The male mold also causes the exterior of the part to have a poorly defined appearance, because the variations in wall thickness and stretching of the material over the male tool disguise the details found on the male tool itself.

Structural Weaknesses

Non-reinforced thermoplastic materials cannot achieve the structural strength of their composite counterparts. These materials will not perform equally with reinforced materials at the extreme temperatures found in the natural environment. The stretching of the thermoplastic sheet cannot be accomplished if that sheet of material contains long strand glass fiber reinforcements, so thermoformed composites are not possible. The inability to employ fibrous reinforcements in the sheet also denies the ability to gain internal conductivity through the use of conductive fiber such as nickel coated graphite and/or metallic fibers.

Summary

In summary, thermoformed non-reinforced thermoplastic parts have many applications in commercial and industrial containers and enclosures. The thermoforming process and the materials that are commonly thermoformed are usable in military applications where temperature and performance extremes do not exceed the inherent limitations of the materials.

Pressure Forming

Pressure forming is one of many variations of the thermoforming process. In addition to the basic thermoforming technique, the pressure forming technique is an extremely useful method of manufacturing thermoplastic containers and enclosures. This technique uses a female tool into which the heated sheet of plastic is formed. The use of a female tool distinguishes pressure forming from the thermoforming technique which is described the previous section of this engineering manual.

Selecting the Thermoplastic Material

Pressure formed containers and enclosures are most frequently manufactured from polyethylene or ABS (Acrylonitrile Butadiene Styrene) sheets. These materials are the same materials that are most commonly used for the basic thermoforming process previously described. Please refer to that section of this engineering manual for a more complete description of available materials.

Preparing the Thermoplastic Sheet

The blank sheet of thermoplastic material is selected in a thickness that will yield the specified wall thickness after forming. Since the pressure forming process stretches the sheet as it is formed into the female tool, the finished thickness of the part will be less than the starting caliper of the sheet. The blank sheet is sheared to length and width dimensions that are approximately four inches greater than the inside length and width of the female tool, thereby leaving two inches of material around the perimeter of the female tool. This additional material is needed for clamping the thermoplastic sheet into the thermoforming machine.

Heating the Thermoplastic Sheet

The blank sheet is clamped into the frame of the thermoforming machine. The clamping frame is then moved into a zonally controlled infra-red oven which is capable of radiating different intensities of heat onto different sections of the blank sheet. Micro-processor control of the infra-red oven is necessary to assure that the sheet of plastic is properly heated to a specific temperature in each zone. The variable control of material temperature is vital for the control of the wall thicknesses of different areas of the formed part. When the sheet has been properly heated, the clamping frame is moved into a position over the male assisting feature, and the forming cycle is initiated.

Stretching the Sheet

The female tool is mounted on the upper platen of the machine, and a male assisting feature is mounted on the lower platen of the machine. When the sheet of material has been properly heated, the female tool is lowered onto the clamping frame, and air pressure is applied inside the female half of the tool. The heated sheet of thermoplastic material is stretched by the air pressure into a paraboloid shape beneath the clamping frame. Hotter areas of the sheet stretch more readily than cooler areas of the sheet, and this can be controlled by selectively heating the sheet in the zonally controlled oven. The stretched paraboloid of heated material may therefore have controlled wall thicknesses which result in selective control of the wall thicknesses of the molded part. The male assisting feature is lifted by a hydraulic or pneumatic cylinder up into the stretched paraboloid of thermoplastic material. As the male assist rises, the heated plastic sheet drapes onto the top of the feature, rolls over the edges, and then drapes down the vertical sides of the feature. As the male assist feature continues to rise, it carries the heated sheet of thermoplastic material upward into the female mold.

Forming the Part

When the male assist has completed its upward vertical motion, the stretched sheet of plastic material is positioned within the female mold, but it is draped over the male assist feature. The male feature is sealed to and held securely against the bottom of the clamping frame, and the female mold is held securely against the top of the heated material which is held in the clamping frame. When the male feature, the clamping frame, and female mold have been securely attached and sealed together as an air-tight assembly, the heated plastic sheet is ready to be formed up into the female mold. Vacuum pressure

is drawn between the female mold and the heated plastic sheet simultaneous with the application of air pressure between the male feature and the bottom of the heated plastic sheet. The pressure beneath the plastic sheet forces the heated material tightly against all of the features of the female mold.

Removing the Formed Part

When the formed sheet of thermoplastic material has been cooled sufficiently to be dimensionally stable, the male tool is lowered and the female mold is raised above the formed part. The clamping frame is opened, and the part can be removed from the thermoforming machine. The part is then ready for the trimming of excess material and for supplemental manufacturing steps.

Process Comparisons

The pressure forming technique utilizes a female tool rather than the male tool used in the basic thermoforming of non-reinforced thermoplastic materials. This process also provides two additional preforming features that help to control the uniformity of the wall thickness of the molded part. If a textured surface is required on the outside of the part, the use of a female tool allows the manufacturer to use non-textured thermoplastic materials. During the pressure forming process, the etched texture on the interior surfaces of the female mold are imprinted onto the exterior surfaces of the formed part. Logos and other detailed features may be incorporated into the female mold, and these are faithfully reproduced onto the exterior surface of every formed part. Any distortion that occurs as the blank sheet of material is stretched during the forming process appears on the inside of the part, rather than the outside. The female mold also causes the exterior of the part to have a crisply defined appearance, because the mold can be manufactured with precise radii, ribs and other features that are transferred to every molded part.

Structural Weaknesses

Non-reinforced thermoplastic materials cannot achieve the structural strength of their composite counterparts. These materials will not perform equally with reinforced materials at the extreme temperatures found in the natural environment, though proper design of these materials can minimize many of their weaknesses. The stretching of the thermoplastic sheet cannot be accomplished if that sheet of material contains long strand glass fiber reinforcements, so the thermoforming of composite materials is not possible. The inability to employ fibrous reinforcements in thermoforming sheet materials also denies the ability to gain internal conductivity through the use of conductive fiber such as nickel coated graphite and/or metallic fibers.

Rotational Molding

The rotational molding technique has been employed for the manufacture of many hollow-form plastic parts. This molding process is different than all other plastic and composite molding techniques because it utilizes finely powdered thermoplastic resin that is melted onto the interior surfaces of a rotating mold. The process has been successfully used to manufacture large items such as kayaks, portable outhouses, water storage tanks, septic tanks and a tremendous variety of recreational products. It is also used for the manufacture of hollow ducting, equipment housings, containers and enclosures.

Required Equipment

The basic rotational molding machine has three arms that are attached to a central rotating hub. At the outward end of each of the arms is a mold attachment platform that is capable of multi-axis rotation. As the machine's hub rotates, the three arms rotate to the three stations of the manufacturing process. At the first station, the mold is opened, the part is removed, a pre-measured charge of powdered resin is poured into the mold, and the mold is closed. At the second station, the arm carries the mold into the oven, and the mold is multi-axis rotated to melt the powdered resin onto all of the interior surfaces of the mold. At the third station, the mold continues to rotate as it is cooled by room temperature air and/or the use of chilling water. The process allows the installation of one or more molds on each of the platforms on each of the three arms of the machinery. The equipment thereby allows a nearly continuous production flow since each of the arms is engaged in one step of the process at each of the three stations of the machine.

Materials Described

The most commonly used material in the rotational molding process is linear low density polyethylene. Other grades of rotomoldable polyethylene resin are available in a variety of grades from low density to ultra high molecular weight (i.e. very high density) types. The resins are internally pigmented with a variety of colors, and they are ground into very fine powder prior to molding.

Tooling Described

The typical rotational molding tool is a clam shell design that incorporates quick release bolts or fasteners to securely attach the two halves of the mold together. These molds are normally thin wall aluminum castings, fabricated and welded aluminum, or fabricated steel. The wall thicknesses of the mold are kept to a minimum in order to allow the most rapid heating and cooling of the tool during the molding process. Thicker sections in the tool heat more slowly to the melting temperature of the thermoplastic resin, and this results in thinner sections at those locations in the molded part. The molds are designed for easy installation on the machinery, and they generally incorporate lifting hooks or eyes for the lifting of the top half of the mold from the bottom half at the end of the molding cycle.

Molding the Part

A weighed charge of powdered thermoplastic resin is poured into the cool, open mold. The top half of the mold is lowered onto the bottom half, and the mold halves are secured together. When the machine has moved the mold into the oven, the mold is rotated in a multi-axis fashion such that all of the surfaces of the mold rotate under the powdered resin that is contained in the mold. As the mold temperature increases to the melt point of the thermoplastic resin, the powdered resin begins to melt and to adhere to the surfaces of the mold. The rotation of the mold continues as the balance of the powdered resin melts onto the interior surfaces of the mold and gradually builds up the wall thickness of the part. The continued rotation of the mold imparts centrifugal force onto the molten material and assists with the adhesion of that material onto the interior surfaces of the mold. When the powdered resin is completely melted, the machine is able to move the hot tool into the cooling station. A combination of cool air and cool water is used to chill the mold and the molded part. When the part has reached a low enough temperature to be dimensionally stable, the mold is opened, and the part is removed.

Process Comparisons

The rotational molding process has the unique ability to manufacture hollow and double walled structures. This characteristic enables the molding of unusual shapes that may be impossible in the compression molding and/or thermoforming processes. The process allows the incorporation of many features in the molded part, including male and female closures, alignment lugs, and a limited number of fasteners. Unlike compression molding processes, however, the rotational molding process does not allow the use of long strand glass fiber reinforcements or conductive fibrous additives. Rotational molding succeeds in manufacturing molded parts with chemical and operating temperature characteristics that are comparable to those manufactured by the thermoforming processes.

Structural Weaknesses

Rotational molded parts are manufactured from non-reinforced thermoplastic resins. These materials cannot achieve the structural strength of their composite counterparts. These materials will not perform equally with reinforced materials at the extreme temperatures found in the natural environment, though proper design of these materials can minimize many of their weaknesses. The required use of powdered thermoplastic materials forbids the use of long strand glass fiber reinforcements, so rotationally molded composites are not possible. The inability to employ fibrous reinforcements in the powdered resin also denies the ability to gain internal conductivity through the use of conductive fibers such as nickel coated graphite and/or metallic fibers.

Summary

In summary, the rotational molding process is capable of molding very unique shapes from a variety of grades of polyethylene resins. Containers and enclosures molded from these materials have been broadly used in commercial and industrial applications. However, proper design of containers made from these materials is essential in order to minimize the inherent strength disadvantages of polyethylene materials at high and low temperatures.

Blow Molding

There are two prominent blow molding methods that are potentially suitable for the manufacture of re-usable containers. The oldest technique is extrusion blow molding and is especially suited for medium to larger molded parts. The more recent technique is the injection blow molding process which lends itself to the high production of small to medium sized parts. The primary differences between these alternative processes is the method used to prepare the molten thermoplastic resin charge that is blown into the mold. Secondly, the injection blow molding process is more precise and is capable of manufacturing parts with very little flash (i.e. the excess material that needs to be trimmed from the part) compared to the extrusion blow molding technique.

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Mold Design

Blow molding tools are relatively inexpensive and are comparable with the cost of aluminum tools for thermoforming and rotational molding. The typical mold is a clam shell design that allows the ready separation of the split halves of the cavity. These tools are normally cast from aluminum alloy and are cooled with water that circulates thru cast-in-place tubing. The two halves of the mold are capable of incorporating detailed features which may include the exterior shape of a container in one half of the mold and the interior equipment storage cavity configurations in the opposite half of the mold. The mold surfaces may be etched to include a variety of textures which will be molded onto the surfaces of the parts.

Low Pressure Process

The blow molding process requires interior pressures of approximately 100 to 150 PSI, and it is therefore considered to be a low pressure technique. The molding pressure is achieved using compressed air, which is used to expand the molten thermoplastic resin against the interior surfaces of the mold. The compressed air may be dry or may include atomized water to accelerate the cooling process after the part is fully formed inside the mold. Molded parts may also be chilled with carbon dioxide gas.

Materials

A vast number of thermoplastic materials are capable of being blow molded. Of these, the most common are polyethylene, polypropylene, poly vinyl chloride (PVC), and polyethylene terephthalate (PET). There are many specialty materials that have been developed for the packaging of foods, pharmaceuticals and other sensitive products. Many of the high performance, engineering grade, thermoplastic materials are also blow moldable. This process is also successfully used for the simultaneous molding of multi-layer parts which incorporate the advantages of two different materials.

Equipment

Blow molding machines are constructed in two basic types, vertical and horizontal. Vertical machines are used for the extrusion blow molding technique and are capable of expansion forming a tubular charge of molten thermoplastic material which has been extruded downward and which is encapsulated by the closing of the mold. Horizontal machines are used for the injection blow molding technique and are capable of high production molding of pre-formed tubular charges of thermoplastic material. These machines incorporate a hydraulically activated clamping press that holds the mold halves and which is capable of opening and closing the mold. Both machine types incorporate a barrel that heats the pelletized thermoplastic material to a molten consistency. The molten material is then extruded thru the nozzle into an extruded, tubular shape, known as a parison, which is the blank form that is blow molded into the tool.

Molding the Part

In the first step, the parison is extruded into a tubular shape of molten material that is sufficient in size and weight to manufacture the part. The clamping press then closes the clam shell mold around the molten parison, which may be pinched off by the edges of the mold halves at a point which is opposite the extruding nozzle. When the mold is closed, the tubular parison remains open at the nozzle end and

closed at the opposite end. Compressed air at approximately 100 to 150 PSI is injected into the open end of the parison, and the molten material is blown outward against the interior walls of the mold. The shaped part is cooled and is removed from the mold after the clamping press has opened the mold halves. The remaining ends of the parison may require flash removal prior to completion of the part.

Process Comparisons

The blow molding process is similar in speed to the injection molding of non-reinforced thermoplastic materials. Unlike injection molding, however, this process has the ability to mold hollow shapes and double-walled shapes similar to the rotational molding process. The blow molding process is not capable of utilizing materials with long strand fiber reinforcements. Parts molded by this process therefore retain all of the structural and temperature performance weaknesses of non-reinforced thermoplastic parts manufactured by other processes.

METAL FORMING

Metal containers and enclosures continue to have an important place in commercial and military markets despite the advancing march of plastic and composite materials. Aluminum Alloys are the primary non-ferrous metals of choice for all types of metallic containers and enclosures, and these alloys have displaced the use of steel which was the dominant material during the 1940's and 1950's. Many aluminum alloys are readily formed, fabricated and welded, and they provide considerable design freedom and manufacturing flexibility for the container specifier.

Aluminum Characteristics

Unfortunately, aluminum displays natural characteristics that cause it to be less than ideally suited for a variety of applications. Because it is an active metal (i.e. on the atomic scale of chemical activity), aluminum oxidizes rapidly in the presence of oxygen, and the product of that corrosion is a non-conductive aluminum oxide coating. Such non-conductive surface coatings present a serious problem for EMI/RFI shielded applications because of the difficulty of maintaining long term conductive joints at aluminum interfaces. Aluminum also corrodes in the presence of salt spray and therefore requires supplemental chemical coatings and/or paint for effective environmental resistance. CARC paints must be applied to achieve adequate resistance to the DS2 and STB decontamination agents. CARC paints do not adhere well to aluminum, they are readily scraped from the surface of aluminum containers and enclosures, and they add expense to the cost of the container. Aluminum has a higher specific heat (i.e. the ability to retain heat energy) than plastic and composite materials, and therefore it has a more detectable infra-red image and is hotter to the touch in extreme natural environments than its non-metallic counterparts. And, aluminum containers are frequently dented and distorted by rough handling and field deployment. Despite these disadvantages, aluminum continues to be used for many containers and enclosures.

Deep Drawing

Aluminum is formed into continuous walled cans using the deep drawing method. This method of manufacture exploits the natural ductility of non-heat-treated aluminum alloys, and is capable of converting flat sheets of aluminum into continuous, five sided, cylindrical, rectangular or irregular shapes.

Required Equipment

The deep drawing process for aluminum requires the use of specialized hydraulic press equipment. Draw forming machinery requires moderate to high tonnage to effectively form flat sheets of material into three dimensional shapes. Actual tonnage and dimensions of the press are determined by the size of the part to be formed. Such presses are typically dual acting. The upper platen is movable vertically, the lower platen (i.e. the bolster plate) is stationary, and a hydraulic or pneumatic cushion beneath the lower platen controls clamping pressure on the aluminum sheet material.

Tooling Description

Draw forming tools generally consist of a male punch, a draw ring and a binder ring. The male punch matches the interior dimensions of the part to be formed, and it is mounted on the fixed lower platen, or bolster plate, of the press. The draw ring is attached to the movable upper platen of the press, but it is spaced a sufficient distance away from the surface of the upper platen to allow the draw ring to travel the full height of the male punch. The rectangular opening in the draw ring is slightly larger than the male punch and the opening is radiused at the bottom to allow the smooth passage of the aluminum sheet during the forming operation. The binder ring is attached to the top of the pressure pins which protrude up thru the fixed lower platen of the press. The rectangular opening in the binder ring is larger than the male punch and allows the binder ring to be raised and lowered with a clearance dimension between itself and the male punch. The hydraulic or pneumatic cushion beneath the lower platen raises and lowers the binder ring during the forming process. The cushion also provides adjustable holding pressure on the aluminum sheet, which is held between the draw ring and the binder ring, during the draw forming process.

Preparing the Aluminum Sheet

Most deep drawn containers are square or rectangular in configuration. The aluminum sheet material is typically annealed or used in a soft condition (i.e. a “0” condition). Aluminum sheet material which is to be drawn into a rectangular shape is initially sheared into a rectangular blank of approximately the same length-to-width ratio as the finished part. The length and width dimensions of the blank are larger than the length and width dimensions of the part to be formed, and this extra material around the perimeter of the blank is available for forming the vertical walls of the part. After being sheared to correct size, a generous radius of material is removed from each of the square corners of the blank. The removal of the corners of the blank facilitates the forming of the part and minimizes wrinkling and stretch cracking as the blank is drawn by the forming tool. Drawing compound, which is a lubricant, is applied to the aluminum sheet prior to forming.

Placing the Material

When the press is positioned for the beginning of the forming process, the upper platen is up, and the clamping ring is raised to its upper-most position by the pressure pins and pressure cushion. In this position, the binder ring is located above the top surface of the male punch. The press operator then places the sheet aluminum blank onto the binder ring in a position that is centered over the opening in the binder ring. The press is activated, and the upper platen carries the forming ring downward until the aluminum sheet is clamped between the forming ring and the binder ring. The clamping pressure is controlled by the hydraulic or pneumatic cushion beneath the lower platen, but the hydraulic force of the upper platen is able to overcome the pressure applied by the lower cushion.

Forming the Part

With the sheet aluminum blank clamped between the forming ring and the binder ring, the upper platen continues to carry the aluminum sheet downward toward the male punch. As the aluminum sheet touches the top surface of the male punch, the forming ring begins to stretch the sheet over the corners of the punch. The forming ring continues to pass downward around the punch and stretch forms the aluminum sheet material as it moves. Gradually, the aluminum sheet slides between the forming ring and the binder ring, it is drawn around the forming radius on the forming ring, and it is stretch formed down the vertical walls of the male punch. In this fashion, the excess aluminum sheet material that is clamped between the forming ring and the binder ring is consumed as it is allowed to slide at a controlled rate of motion toward the male punch. The horizontally sliding sheet then slides 90° around the forming radius of the forming ring and ends up stretch formed along the vertical surface of the male punch. At the end of the process, the upper platen is moved upward to its open position, and the binder ring returns to its position above the male punch. The formed aluminum can is left resting on the surface of the binder ring and can be readily removed.

Multiple Stage Drawing

Simple parts may be drawn in a single forming step. However, deeper parts and/or complex configurations may require multiple drawing steps. The requirement for multiple stage drawing is generally dictated by the draw ratio of the part. As the depth of the part increases compared to the length and width dimensions of the part, multiple stage drawing is more likely. A pre-drawn, or first stage drawn part will generally have a generous shape that allows the flat aluminum sheet blank to be uniformly stretched into a domed configuration which retains the length and width dimensions of the opening in the draw ring. The work hardening of the pre-drawn blank may require annealing prior to the second or third drawing stages. Each stage requires individual tooling and an individual set-up on the forming press. The final drawing step is performed in the same way as a single stage forming operation.

Secondary Operations

The drawn can may require the forming of additional features such as ribs, dimples and other custom shapes. If these features are not included in the final draw forming tool, they can be added in supplemental operations. When formed, the drawn aluminum can must be trimmed of excess material that was needed for clamping the blank between the draw ring and the binder ring. The formed part may require straightening to relieve wrinkles and/or distortions that may occur on the formed side walls of the can. And, the formed part, which will work harden as the aluminum is drawn around the forming radius of the forming ring, may need supplemental heat treating to achieve acceptable strength for the intended use.

Process Comparisons

The deep drawing process is unlike any of the compression molding processes and thermoplastic molding processes. It requires unique equipment, unique tooling, and unique post-forming processes.

Fabrication

In lieu of deep draw forming equipment and tools, aluminum sheet can be formed into a vast range of sizes and configurations with common fabrication equipment. Rectangularly shaped container and enclosure shells can be manufactured from precisely configured blanks using automated equipment.

The blank shape can then be press brake folded into a five sided container shell. Joints, formed corners and other components can then be spot welded and/or heliarc welded onto the finished container shell. Such fabricated aluminum container shells have the advantage of lower cost tooling, fewer supplemental manufacturing steps such as heat treating, and an unlimited range of configurations. Such fabrication methods are extremely labor intensive, and they lead to higher unit container costs. And, the basic aluminum material retains all of the disadvantages of the deep drawn aluminum material including oxidation in the presence of air and the need for supplemental chemical or painted finishes.

Modular Assembly

Aluminum containers and enclosures are also commonly assembled from a variety of aluminum sheets, extruded aluminum sections and cast aluminum shapes. The assembly process allows the manufacture of an almost unlimited range of product shapes and sizes, including very large containers. The joints which occur between the numerous parts of the container may be spot-welded, heliarc welded or epoxied together to form a hermetically sealed container. Unfortunately, the basic aluminum material retains all of the disadvantages of deep drawn and fabricated aluminum materials including oxidation in the presence of air and the need for supplemental chemical or painted finishes. And, the modular assembly process for even a simple container is labor intensive and requires the handling of as many as thirty individual pieces to assemble just the top and bottom container shells

FABRICATION OF LAMINATED CONTAINERS

Over the past twenty years, laminated containers have been fabricated using a variety of materials and techniques. The most prominent assembly technique joins plastic and plywood laminated panels together with extruded aluminum shapes and formed steel hardware items. All of these bits and pieces are attached with a multitude of rivets. Recessed hardware plates are installed into cut-outs in the container, and they, too, are riveted into place. The resulting product is heavy, bulky, and impossible to effectively seal from the ingress of water. The assembly process is similar to the modular assembly of aluminum containers detailed above, but the laminated product is vastly inferior to the modular aluminum product. While such containers continue to have commercial applications where weight is not an issue, they are unsuitable for field portable, hand carried or military applications.