ITEM 6
Composite Production

Composite Production

Produced by companies in

- France
- Germany
- Italy
- Japan
- Netherlands
- Russia
- United Kingdom
- United States

Equipment, "technical-data" and procedures for the production of structural composites usable in the systems in Item 1 as follows and specially designed components, and accessories and specially designed software therefor:

(a) Filament winding machines of which the motions for positioning, wrapping and winding fibres can be coordinated and programmed in three or more axes, designed to fabricate composite structures or laminates from fibrous or filamentary materials, and coordinating and programming controls;

Note to Item 6:

(1) Examples of components and accessories for the machines covered by this entry are: moulds, mandrels, dies, fixtures and tooling for the preform pressing, curing, casting, sintering or bonding of composite structures, laminates and manufactures thereof.

Nature and Purpose: Filament winding machines lay strong fibers coated with an epoxy or polyester resin onto rotating mandrels in prescribed patterns to create high strength-to-weight ratio composite parts. The winding machines look and operate like a lathe. After the winding operation is completed, the part requires autoclave and hydroclave curing.

Method of Operation: First, a mandrel is built to form the proper inner dimensions required by the part to be created. The mandrel is mounted on the filament winding machine and rotated. As it spins, it draws continuous fiber from supply spools through an epoxy or polyester resin bath and onto the outer surface of the mandrel. After winding, the mandrel and the part built up on it are removed from the machine, and the part is allowed to cure before the mandrel is removed in one of a variety of ways. Common types of mandrels include water-soluble spider/plaster mandrels; and segmented, collapsible mandrels. Large motor cases for solid rocket motors are usually manufactured on water-soluble sand mandrels. Nonremovable liners are sometimes also used. For example, metal-lined pressure vessels are made by using a metal liner as the mandrel, which is simply left inside the wound case.

Photo Credit: Thiokol Corp.

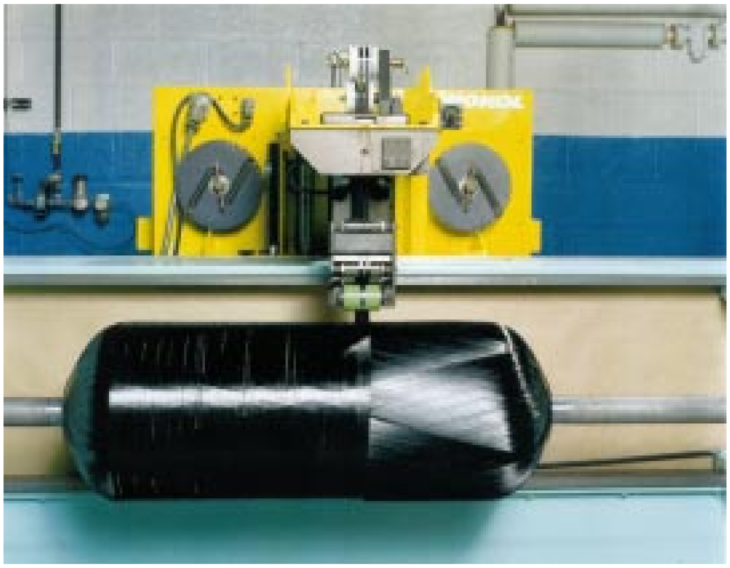

Figure 6-1:
Tabletop filament winding machine.

Typical Missile-Related Uses: Filament winding machines are used to make rocket motor cases, propellant tanks, pressure vessels, and payload shrouds. The high strength and low weight of the resulting structures make increased missile ranges and payload rates possible.

Other Uses: Filament winding machines are used to produce aircraft parts such as tail stabilizers, parts of wings, and the fuselage. They can be used to make liquid natural gas tanks, hot water tanks, compressed natural gas tanks, golf club shafts, tennis racquets, and fishing rods.

Appearance (as manufactured): The size of filament winding machines varies with the size of the part to be made. Filament winders used to manufacture parts 10 cm in diameter measure about 1 × 2 × 7 m and can fit on a tabletop, as shown in Figure 6-1. Winders for large components such as large rocket motor segments (approximately 3 m diameter and 8 m in length) are about 5 × 5 × 13 m and weigh several tons, as shown in Figure 6-2; another view of the same machine, Figure 6-3, shows the multiple spools of fiber. Most older filament winding machines developed during the late 1950s are gear-driven, and settings are made by hand. Most newer winding machines are numerically controlled and can wind complex shapes to meet special requirements.

Photo Credit: Thiokol Corp.

Figure 6-2:
A large multi spindle filament winding machine.

Appearance (as packaged): The size of filament winding machines dictates their packaging. Smaller machines are crated in shock-absorbing containers or attached to cushioned pallets isolated from other packages. Larger machines are disassembled for shipping and reassembled onsite, and their components are packaged separately in crates or on pallets.

(b) Tape-laying machines of which the motions for positioning and laying tape and sheets can be coordinated and programmed in two or more axes, designed for the manufacture of composite airframes and missile structures;

Produced by companies in

- France
- Germany
- Italy
- Japan
- Netherlands
- Russia
- United States

Nature and Purpose: Tape-laying machines resemble filament winding machines but are used in heavier applications that have sufficiently gradual contours or angles to allow the use of thick or wide tapes. The purpose of using a tape-laying machine instead of a filament winding machine is to reduce the number of revolutions of the mandrel needed to wind the part produced. This speeds up production and lowers cost.

Method of Operation: Tape-laying machines operate much like filament winding machines. The head on tape-laying machines can handle tape of various widths. Structures with little curvature use tapes with larger widths (up to about 30 cm). Structures with moderate to large curvature use tapes in smaller widths or apply them on the bias with respect to the principal direction of curvature.

Photo Credit: Thiokol Corp.

Figure 6-3: The filament winding machine with the multiple spools of fiber on the right.

Typical Missile-Related Uses: Tape-laying machines are used to make reentry vehicle heat shields, exit nozzles, igniters, and other parts exposed to high temperatures.

Other Uses: Tape-laying machines can be used to make many of the items made by filament winding machines, but they are most advantageously used to produce items that are largely cylindrical in shape. Examples are certain aircraft parts, tubes for bicycle frames, and water heaters. They are also used to wrap columns for bridge supports, containers, and pipes. They are extensively used to wrap high-temperature, down-hole pipe in oil-drilling operations.

Appearance (as manufactured): The size of tape-laying machines varies with the size of the required parts. Machines are either operator assisted or numerically controlled (NC). NC machines have a keyboard to input data for the desired composite lay-ups. The flatbed, which is the dominant feature of the machine, measures 1 to 2 m in length for the manufacture of small parts and 10 m for very large parts. The weight of large machines with a steel table and gantry could be 1000 to 2000 metric tons. Examples of two tape-laying machines are presented in Figures 6-4 and 6-5.

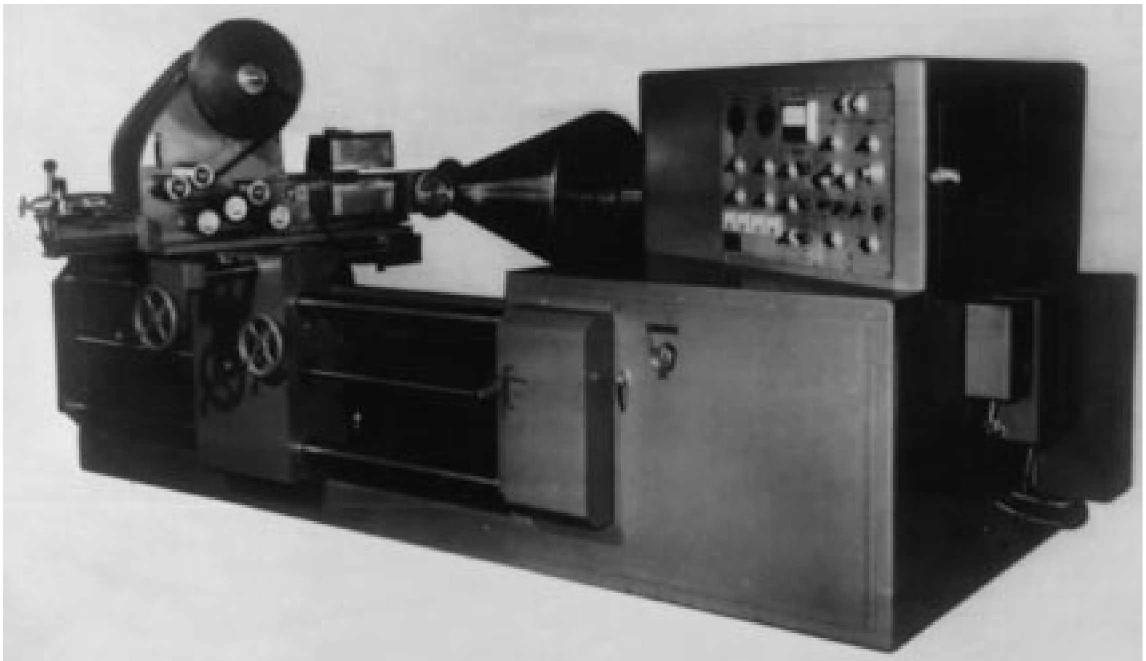

Figure 6-4: A tape winding machine that resembles a lathe.

Figure 6-5: A modern, multi-axis numerically controlled tape laying machine.

Appearance (as packaged): The packaging of tape-laying machines depends on their size. Smaller machines can be completely encased in packing crates. Larger machines are disassembled for shipping and reassembled onsite. Their components are packaged separately in crates or on pallets. Very large flatbed tables can also be disassembled for shipment. All packaging is suitably protected for shock and vibration during transportation and handling.

(c) Multi-directional, multi-dimensional weaving machines or interlacing machines, including adapters and modification kits for weaving, interlacing or braiding fibres to manufacture composite structures, except textile machinery not modified for the above end uses;

Nature and Purpose: Multi-directional, multi-dimensional weaving machines are used to interlink fibers to make complex composite structures. Braiding machines provide a general method of producing multi-directional material preforms. The purpose is to systematically lay down fibers along anticipated lines of stress in complex preform configurations and thereby make the parts stronger and lighter than otherwise possible.

Method of Operation: In one system, a weaving mandrel is first installed onto the machine. As the mandrel assembly rotates, circumferential fibers are continuously laid down at the weaving site by a tubular fiber delivery system, which includes fiber-tensioning devices and missing-fiber sensors. At each pie-shaped corridor formed by the weaving network, a radial knitting needle traverses the corridor, captures a radial fiber at the inside of the port, and returns to the outside of the port, where it makes a locking stitch that prevents movement of the radial fiber during subsequent operations. This process is continued and completed by final lacing.

Braiding machines intertwine two or more systems of fibers in the bias direction to form an integrated structure instead of lacing them only in a longitudinal direction as in weaving. Thus, braided material differs from woven and knitted fabrics in the method by which fiber is introduced into the fabric and in the manner by which the fibers are interlaced.

Typical Missile-Related Uses: Multi-directional, multi-dimensional weaving machines are used to make critical missile parts such as reentry vehicle nose tips and rocket nozzles that are exposed to high temperatures and stress.

Other Uses: Weaving machines are used to make a broad range of complex composite parts such as aircraft propellers, windmill spars, skis, utility poles, and sporting goods.

Appearance (as manufactured): A weaving machine has a work area on a rotating table with a network of rods penetrating pierced plates around which the fiber is woven. The work area is surrounded by spooled fiber dispensers and by weaving and lacing needles. The drive motors, cams, and push rods that do the weaving are also mounted on the main frame of the machine.

Weaving machines used to make small parts might measure 2 m in length and 1 m in width. Those used to make large parts might be 10 m long if arranged horizontally or 10 m high if arranged vertically.

Produced by companies in

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- Germany
- Japan
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- United States

Textile machinery not controlled and readily modified for low-end use can be purchased in many countries.

Photo Credit: Wardwell Braiding Machine Co.

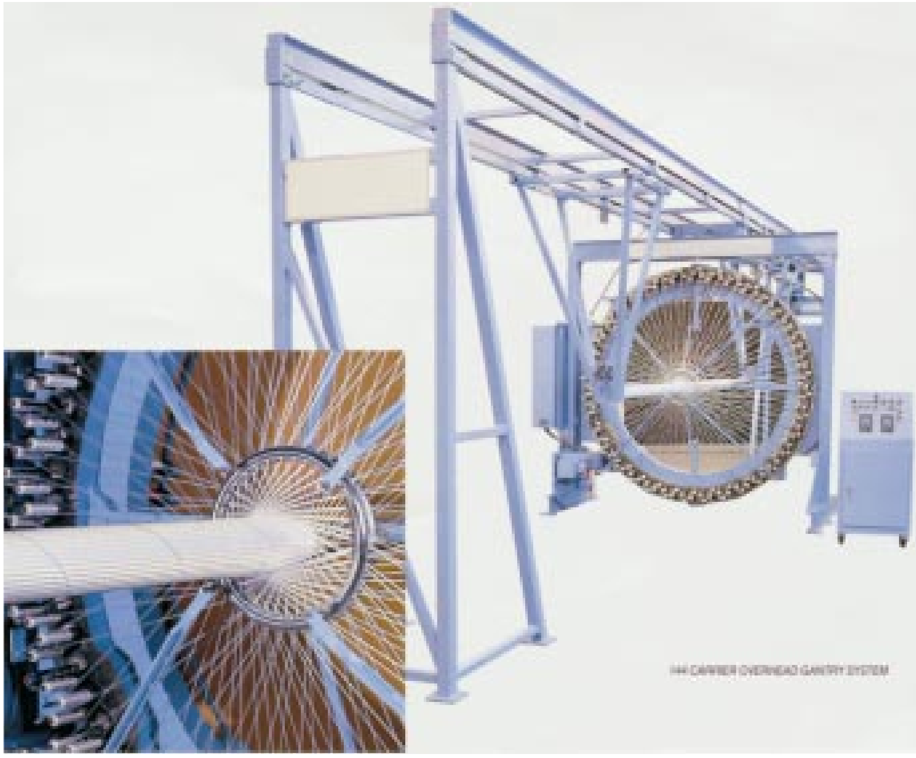

Figure 6-6: A 144 carrier overhead gantry braiding machine.

Braiding machines can be either floor-mounted or have an overhead gantry supporting the spindle on which the preform is made. In either configuration, the fiber is fed to the spindle radially through a large wheel centered on the spindle. The control panel is located at the center of the gantry in order to monitor preform development. A 144 carrier horizontal braider capable of bi-axial or tri-axial braiding is shown in Figure 6-6. Figure 6-7 shows a floor-mounted version. Both machines can be controlled by special software run by a common PC.

Appearance (as packaged): The packaging of weaving machines depends on their size. Smaller machines can be completely encased in packing crates. The components of larger machines are disassembled for shipping and reassembled onsite, and are packaged separately in crates or on pallets. All components are suitably protected from shock and vibration during transportation and handling.

Additional Information: These machines have the intricate fiber handling mechanisms to perform their task with spools and rotation/movement mechanisms integral within each machine. Some machines, particularly those used for reentry vehicle heat shields, are mounted on a bed and rely on rigid rods in at least one direction to stabilize the weave geometry. For weaving machines used to manufacture 3-D polar preforms, the basic network construction needed to do the weaving includes pierced plates with spe-

Figure 6-7: A 144 carrier floor-mounted traverse braiding machine.

Photo Credit: Wardwell Braiding Machine Co.

cially designed hole patterns, plain plates, metallic rods, knitting needles, retraction blades, and, if the process is fully automated, the machinery required to operate the knitting needles and retraction blades. The subelements for other types of weaving depend on the specific design of the machine.

(d) Equipment designed or modified for the production of fibrous or filamentary materials as follows:
   (1) Equipment for converting polymeric fibres (such as polyacrylonitrile, rayon or polycarbosilane) including special provisions to strain the fibre during heating;

Produced by companies in

- Germany
- Japan
- Russia
- United Kingdom
- United States

Nature and Purpose: Polymeric fibers are precursors to high-temperature carbon and ceramic fibers that have great strength and stiffness at high temperatures. The conversion from a polymer to a high-temperature fiber occurs when the polymeric fiber is stretched and heated while exposed to a specific reactive atmosphere. The equipment controlled under this subitem heats, stretches, and exposes the fiber to the required reactive atmosphere.

Method of Operation: The polymeric fibers are fed into a machine with controlled tensioning, speed, heating, and atmosphere. The fiber path is usually long and complex because the total time for the conversion is lengthy so higher production rates require a longer fiber processing length. The fiber passes through a series of furnaces with controlled temperature and atmosphere, and is driven at higher and higher speeds to convert it into a small-diameter, high-temperature fiber with a high degree of crystallographic order. Critical pieces of equipment include the process controllers, which maintain the desired temperatures at each step, and the textile rollers and drive motors, which carry product through the various heat treatment steps.

Typical Missile-Related Uses: The equipment is used to convert or strain synthetic fibers to produce fibers used in missile applications where great strength and light weight are paramount. These fibers are used in missiles to improve the strength of the motor case, fairing, and propellant tank while reducing weight and thereby increasing the range and payload capacity of the missile.

Other Uses: The equipment is used to convert polymeric fibers for many uses, including aircraft structures, tires, golf clubs, and boat hulls.

Appearance (as manufactured): Describing the appearance of the equipment used to convert polymeric fibers is difficult because of the variety of ways in which equipment layout can occur. The layout is usually tailored to the production building and covers considerable floor space. The most noticeable items are the many precision rollers and the mechanisms for their control. The rollers are typically 8 to 20 cm in diameter by 30 to 120 cm long, with their size related to the ovens in which they are to be used. Drive rollers are used to slowly pull the organic precursor fiber through an oven under controlled tension. The drive rollers are typically made of polished stainless steel or chromeplated steel and are either driven in a manner to keep the filaments at a constant tension or are driven at a preprogrammed rate to elongate the filaments as a part of the process. Thus, rollers may be driven by individual motors on their shafts or proportionately driven by gears from one motor-driven shaft.

The machinery is designed to allow the fiber to make several passes through the heated zone with precise control of the speed of the fiber, the temperature in each zone of the furnace, and the tension on the fiber. The fiber must pass through several of these furnaces because the process requires a wide variety of different reactions. A typical fiber-drawing oven system has many rollers and isolated heating zones in the furnace. The size of the equipment varies widely.

Typically, the vertical-treating oven systems are used for higher temperature thermal treatment. However, the diverse treatments required to produce a carbon or other refractory fiber from a polymeric fiber demand that several pieces of equipment be used. Typical requirements include low-temperature furnaces with critical textile handling systems and high-temperature ovens with fiber handling capability for conversion of the fiber to its final state.

Appearance (as packaged): The ovens, furnaces, and processing equipment needed to produce carbon fibers vary in packaging depending on their size, weight, and sensitivity to environmental factors. Generally, laboratory versions of the equipment can be completely crated and shipped by rail or truck. Larger furnaces designed for commercial use generally have to be shipped in component units and assembled onsite. However, some of the furnaces can be of such large diameter that they must be specially handled as oversize cargo. The weight for these larger furnaces approaches 1000 metric tons or more.

Produced by companies in

- Germany
- Japan
- Russia
- United Kingdom
- United States

(2) Equipment for the vapor deposition of elements or compounds on heated filament substrates; and

Nature and Purpose: The equipment for vapor deposition applies a very thin coating to filaments and thereby changes the properties of the filaments in several different ways. Metallic coatings are conductive and add abrasion resistance; some ceramic coatings protect fibers from reacting with either the atmosphere or adjacent materials. Coatings may also improve the eventual compatibility of the fibers with a matrix material, as is the case for some metal matrix composites.

Method of Operation: This equipment provides a suitable partial vacuum environment for condensing or depositing a coating on filaments. The vapor deposition process has several variations; two of the most important basic processes are chemical vapor deposition (CVD) and physical vapor deposition (PVD).

The CVD process deposits solid inorganic coatings from a reacting or decomposing gas at an elevated temperature. Sometimes this process occurs in a radio-frequency-generated plasma to ensure thermal uniformity and improve the quality of CVD coatings in a process called plasma-assisted CVD (PACVD).

The PVD processes use sputtering, evaporation, and ion plating to deposit the coating on the filaments. The equipment for PVD is similar to the equipment for CVD except that the chamber does not have to operate at a high temperature and does not require a reactive gas supply.

Typical Missile-Related Uses: The equipment for the deposition of elements on heated filaments produces fibers used in rocket motor nozzles and reentry vehicle nose tips.

Other Uses: This equipment coats fibers used in jet aircraft. PACVD is currently an important technique for the fabrication of thin films in the microelectronics industry and has been applied to the continuous coating of carbon fibers.

Appearance (as manufactured): CVD and PVD chamber configurations vary greatly. Some are long tubes with seals at each end that permit the passage of filaments but not gases. Others are large chambers, 2 to 3 m on a side, with room enough to hold the filament spools, filament guide equipment including spreading and tensioning rollers, a hot zone if needed, and the reactant gases. Because of this variation, the only standardized and readily recognizable parts of the equipment are the gas supply system, a large power supply, vacuum pumps, and possibly the instrumentation that controls the temperature. In all cases, the power supplies are of substantial size and weight, typically greater than 0.6 × 0.9 × 1.5 m with water inlets for cooling, pumping, and safety cutoffs. PACVD equipment looks like a conventional CVD or PVD system except that it has a radio-frequency power supply to produce the plasma.

Appearance (as packaged): Packaging varies depending on size, weight, and sensitivity to environmental factors. Generally, laboratory versions of the equipment can be completely crated and shipped by rail or truck. However, even laboratory versions generally have components packaged separately so that the textile spools, motors, and special glassware can receive adequate protection. Larger systems designed for commercial use are usually shipped as components and assembled onsite.

(3) Equipment for the wet-spinning of refractory ceramics (such as aluminum oxide);

Produced by companies in

- Germany
- Japan
- Russia
- United Kingdom
- United States

Nature and Purpose: Wet-spinning equipment is used to produce long filaments from a mixture of liquids and solids. These filaments are further processed to produce high-strength, high-temperature ceramic filaments for ceramic or metal-matrix composites.

Method of Operation: In wet-spinning of refractory ceramics, a slurry of fiber-like particles is physically and chemically treated and drawn into a filament through an orifice called a spinneret. The chamber in which the filaments are created either rotates or contains an internal mixing device, either of which produce the vortex in which filament entanglement occurs. The material emerges from the spinneret and is solidified by a temperature or chemical change, depending on the binder system used in the wet bath surrounding the spinneret. The bath supports and stabilizes the filaments produced as it cools.

Typical Missile-Related Uses: The wet-spinning equipment is used to make high-grade ceramic fibers for making missile nose tips and rocket engine nozzles. Such fibers are also used to produce some ramjet and turbojet engine parts applicable to cruise missiles.

Other Uses: Wet-spinning equipment is used to make ceramic fibers for producing engine parts for small gas turbine engines, chemical processing containers, and high-temperature structural applications. Ceramic fibers or whiskers can be combined with other composite materials to enhance strength and high-heat resistance in many commercial products.

Appearance (as manufactured): A major component of wet-spinning equipment is the cylindrical chemical reaction chamber. Although glassware is acceptable for laboratory and prototype wet-spinning equipment, stainless steel or glass-lined reaction chambers are used for production grade wet-spinning equipment. Typically, the chamber is tapered at the bottom, where the dies that extrude the filaments are located.

Other equipment associated with the chemical reaction chamber includes a cylindrical vessel (much longer than its diameter) that contains the chemical slurry from which the filament is produced; a pressure gauge and gas exhaust line attached to the vessel; a tube assembly containing sections of both fixed and rotating glass tubes; a ball valve connected to the fixed glass tube; a motor and controller for driving the rotating tube; and a snubber roller and take-up reel for the finished filaments.

Appearance (as packaged): Packaging is typical of any similarly sized industrial equipment. Generally, fully assembled laboratory versions of the equipment can be crated and shipped by rail or truck. Components of larger equipment designed for commercial use are shipped in separate boxes or crates and assembled onsite.

Produced by companies in

- France
- Germany
- Sweden
- Switzerland
- United Kingdom
- United States

(e) Equipment designed or modified for special fibre surface treatment or for producing prepregs and preforms.

Note:

(2) Equipment covered by subitem (e) includes but is not limited to rollers, tension stretchers, coating equipment, cutting equipment and clicker dies.

Nature and Purpose: Fiber surface treatment and prepregging equipment is used to coat fibers in preparation for making high quality composite materials. Surface treatments improve adhesion or change electrical properties of the fibers; prepregging adds enough resin to the fiber (or filaments, roving, or tape) for curing it into a composite.

Method of Operation: The fiber filaments, roving, or tape to be processed in this equipment is passed through a series of dip baths made up of liquid reactants for etching or resins (sizings). A reactant etches or activates the surface of the fiber for additional operations. Materials are fed on rollers through a bath of reactants in a simple dip operation. The number and speed of rollers in the bath determines how long the part is etched or how much sizing is retained. Heaters are used to modify the reactivity of the etch system, to control the viscosity of the sizing bath, to promote chemical reactions that make the sizing stable, and to dry the product.

Typical Missile-Related Uses: This equipment is used to surface treat various fibers used in the manufacture of missile parts in order to improve bonding and to give additional strength to missile components such as nose tips, motor cases, and exhaust nozzles.

Photo Credit: Hunting Engineering, Ltd.

Figure 6-8: A machine adding resin to seven lines of roving.

Other Uses: This equipment is identical to that used to make the fibers for all commercial applications of composite technology from boat hulls to golf clubs.

Appearance (as manufactured): A laboratory bench with small rollers and heater guns is the only equipment needed to treat or prepreg fiber on a prototype basis. For production-level activity, the textile handling equipment is much larger so that multiple lines can be treated at the same time. A machine adding resin to seven lines of roving is shown in Figure 6-8; dry fibers enter from the left and are coated by the wet wheel on the right. A machine processing numerous lines of roving is shown in Figure 6-9. Alternatively, a process may involve heater stacks many stories high. All of the systems have rollers for keeping the textile material moving, maintaining tension on the fiber, and squeezing out excess liquid. They also have an oven with a complex path over the rollers so that the filaments traverse the oven several times.

Photo Credit: Cytec Fibrite, Inc.

Figure 6-9: A machine processing numerous lines of roving.

Appearance (as packaged): The packaging of the equipment, with the exception of small laboratory apparatus, usually requires that components be shipped separately and assembled onsite. The reason is that the base, the vats for holding chemicals, and the textile handling apparatus require different types of packaging protection. The vats for chemicals can be packaged in simple corrugated boxes, but the rollers, which have a precision or special surface finish to avoid damaging the filaments, need cushioning and rigid mounting in substantial crates. Electrical control equipment, if included, will be packaged like other fragile electronics.

Produced by companies in

The autoclave or hydroclave equipment is produced in most industrial countries because it is used in common manufacturing processes. Although general knowledge of these processes is widely known, data on processes for specific applications are proprietary.

(f) "Technical data" (including processing conditions) and procedures for the regulation of temperature, pressures or atmosphere in autoclaves or hydroclaves when used for the production of composites or partially processed composites.

Nature and Purpose: Process control data are used to manage the processing of composites or partially processed composites into useful component parts. The technical data of interest with respect to autoclaves and hydroclaves generally concern processing conditions and procedures, tooling and preparation for cure, and cure control. Because the precise process settings for temperature, pressure, and duration have a critical effect on the strength, impact resistance, and flexural modulus of the parts produced, manufacturers have developed proprietary processes and rarely release the information for production of specific parts. Processing conditions, debulking periods, and procedures are usually individually tailored for the specific part.

Method of Operation: These data are used as guidance in making or partially processing specific, high-heat-tolerant, composite parts in autoclaves and hydroclaves. Cure control can be carried out by a human operator, but more commonly it is carried out by computer. The latter may be based on a prescribed process cycle or may take the form of intelligent processing in which the computer makes decisions on the basis of the combined input of analytical process models, sensors in or near the part being processed, and human knowledge built into the system as artificial intelligence.

Typical Missile-Related Uses: These data are part of the instructions for preparing the preform or composite for use as high-heat-tolerant and ablative components such as reentry vehicle nose tips and rocket motor nozzles.

Other Uses: Similar processes and procedures are used to make the materials for commercial applications of composite technology from boat hulls to golf clubs.

Appearance (as manufactured): In general, technical data can take the form of blueprints, plans, diagrams, models, formulae, engineering designs and specifications, and manuals and instructions written or recorded on other media or devices such as disk, tape, and read-only memories. These data are usually provided in handbooks and graphs as part of either the autoclave or hydroclave manufacturer's documentation, or as a part of the resin manufacturer's recommendations. The manufacturer's documentation refers to each of the subcomponents and compiles specifications and instruction manuals for each of them. These components include items such as solid-state controllers or computers for controlling and monitoring temperature and pressure during the cure operation.

Appearance (as packaged): The data accompanying the equipment and containing the cure information are typically placed in loose-leaf books or a collated set of instructions. Documentation has a report format and accompanies new equipment. Data supplied by manufacturers of resin or prepreg are on data sheets and accompany the raw resin or prepreg material.