ADVANCED COMPOSITE MATERIALS AND PROCESSES

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ABSTRACT

Composites are generally defined as two or more individual materials, which, when combined into a single material system results in improved physical and/or mechanical properties. The freedom of choice of the starting components for composites allows the generation of materials that can be specifically tailored to meet a variety of applications. Advanced composites are described as a combination of high strength fibers and high performance polymer matrix materials. These advanced materials are required to permit future aircraft and spacecraft to perform in extended environments. Advanced composite precursor materials, processes for conversion of these materials to structures, and selected applications for composites are reviewed.

INTRODUCTION

The idea of combining two or more materials to form a single composite material system which has desirable physical and mechanical properties has been around for centuries. Tools, weapons, houses, ornaments etc. were constructed of combinations of naturally occurring materials. From these primitive origins composites have evolved into very sophisticated materials which utilize fiber reinforced polymer matrices which are routinely used to fabricate high performance aircraft and spacecraft, automobiles, sporting goods, medical appliances, construction products, and a host of other items. The widespread use of advanced composites is attributable to the ability to design material systems which possess unique properties that satisfy the requirement to perform in specific environments. Desirable characteristics of advanced composites include high strength, lightweight, corrosion resistance, long fatigue life, damage tolerance, and manufacturing economy.

Advanced composites have two generally recognized precursors: high strength fibers and high performance polymer matrix binding materials. The most common high strength fibers for advanced composites are kevlar, graphite and fiberglass whereas the polymer matrices are normally polyester, epoxy or polyimides. The specific requirements of the application for advanced composites dictates the selection of the fiber/matrix combination. After the fiber and matrix are selected they are combined into a single system referred to as prepreg. The prepreg is then assembled into the appropriate shape and thickness and subjected to processing which converts the prepreg to a finished part. This review will include currently available fibers and matrices, processing methodology and selected applications for composites.

ADVANCED COMPOSITES

Fiber Materials

Continuous or long staple high strength, low density, small diameter filaments are generally considered the predominant reinforcement for advanced composite materials. Graphite, kevlar, and fiberglass are the most widely utilized fiber systems for these materials. Selected properties for these fibers are shown in Figure 1.

	GRAPHITE	KEVLAR	FIBERGLASS	STEEL	ALUMINUM
TENSILE STRENGTH, Ksi	400-800	350-450	500-600	200-300	75-150
TENSILE MODULUS, Ksi	20-100	18	12	30	10
DENSITY, gm/cc	1.8	1.5	2.5	9.4	3.4
DIAMETER	0.0003	0.0005	0.0004	--	--

FIGURE 1. FIBER PROPERTIES

The tensile strength and tensile modulus of graphite, kevlar and fiberglass fibers vary depending on the chemical composition of the starting materials, processing conditions, and heat treatment during and after fiber formation. Each of these filament types are generally stronger and lighter than conventional metals such as carbon steel and aluminum. The modulus or stiffness of the same fibers is about half that of steels and about double aluminum. Along with the desirable tensile properties of graphite, kevlar, and fiberglass the weight per unit volume for these fiber systems is substantially lower than steel and aluminum. This combination of high strength and low density is very attractive from a structural efficiency point of view.

Matrix Materials

In order to take advantage of the desirable properties of high performance fibers it is necessary to stabilize the individual filaments with matrix materials. Selection of matrix materials is usually made based on the ease of fabrication, cost, and end-use temperature of the structure to be manufactured. Matrix materials for advanced composites can be metallic or non-metallic. In the aerospace industry organic matrix materials are utilized in the fabrication of a wide variety of structural components for commercial and military aircraft and spacecraft. Polyester and epoxy resin matrix materials are utilized for applications that require retention of strength for moderate periods of time at exposure temperatures under 350°F (see Figure 2). Polyimide resins can be used for applications at temperatures up to 550°F. Although, not used in large quantities, selected metals such as aluminum can be used in applications where strength retention at temperatures up to 700°F is a requirement.

RESIN	REASONABLE USE TEMPERATURE, °C (°F)
POLYESTER	121 (250)
EPOXY	177 (350)
POLYIMIDE	288 (550)
ALUMINUM	371 (700)

FIGURE 2. MATRIX MATERIALS

Composite Material Fabrication

Advanced composite materials are generated by combining reinforcing fibers with matrix materials with one of a wide variety of techniques to make composite prepreg. The selection of the method to create composite prepreg is based on many factors including: the ability to place polymers in solution, the viscosity of the polymer, melt-flow characteristics, fiber forming limitations, resin chemoviscosity, economy, and solvent extraction. The most widely utilized procedures for producing composite prepreg are shown in Figure 3.

COMPOSITE FABRICATION METHOD	FEATURES
Solution Coating	Matrix resin dissolved in solvent. Solvent removal can be difficult.
Hot Melt	Widely used for epoxy prepregs. Industry standard prepreg method.
RTM and RIM	Used to infiltrate preforms. Voids and incomplete wet out are concerns.
Intermingled Filaments	Matrix resin in filament form combined with reinforcement fibers.
Powder	Solvent free. Potential for economical, large volume production.
Slurry	Can use non-organic carrier materials.

FIGURE 3. COMPOSITE FABRICATION TECHNIQUES

ADVANCED COMPOSITE PROCESSING PROCEDURES

Many factors are considered when selecting the appropriate assembly and cure procedure for the fabrication of advanced composite structural articles. In order to select the most efficient processing method for a particular resin/fiber combination a basic understanding of the behavior of the resin matrix material under the influence of temperature and pressure is required. In addition, the ease of assembly of the component, economy of the process, surface finish required, and requirement for secondary operations must be understood. Selected composite processing techniques are detailed hereafter.

Autoclave

Autoclaves are widely used to fabricate complex advanced composite structures. Autoclaves are pressure vessels which range in size from very small to over 100 feet in length. Pressures up to 1,000 psi and temperatures up to 1,200°F can be generated in properly designed autoclaves, but for the fabrication of typical aircraft and spacecraft structures pressure and temperature in the range of 100 psi and 350°F, respectively, are routinely employed. After the composite material is assembled for fabrication of a particular structure, the lay-up is placed in a vacuum bag and inserted in the autoclave (see Figure 4). The vacuum line inside the autoclave is connected to the bag containing the composite part. Appropriate heat and pressure are applied to the part to effect complete consolidation and cure. The part is cooled down and removed from the bag. Autoclaves can be utilized to process a wide range of material systems including polyesters, epoxies, polyimides, bismaleimides, and others. In the aerospace industry structural parts ranging in size from a few inches to over 50 feet long are routinely processed in autoclaves.

Heated Platen Presses

Hydraulically actuated heated platen presses are routinely used to fabricate flat composite laminates (see Figure 5). Very high pressures (>5,000 psi) and high temperatures can be applied with this equipment to cure composite laminates. Heated presses are frequently used to fabricate mechanical test samples including tensile, flexure and short beam laminates. Computer controlled ramp temperature and pressure functions allow precise cure cycles to be maintained for proper laminate fabrication. Hydraulic presses can be equipped with vacuum chambers, cooling manifolds, and displacement monitors to assist in the processing of various composite parts.

Trapped Rubber Processing

Silicone rubber expands rapidly when heat is applied. This characteristic combined with its' excellent high temperature properties permit the fabrication of complex composite parts with economical tooling systems (see Figure 6). Silicone rubber material is first mixed and poured into a cavity which contains the master pattern of the part to be fabricated. The rubber is allowed to chemically cure and the master for the part is removed. The composite material is then laid up with the proper fiber orientation and overall thickness. This assembly is then inserted into the cavity in the cured silicone rubber tool. The cast rubber block with the composite lay-up inside is placed in a pressure containment box and the entire assembly is heated up in the oven. As the heat is introduced into the rubber it expands, which in turn applies pressure to the composite part. The temperature of the oven is increased until the cure temperature for the composite material is reached. If the tool is properly designed the pressure can be accurately controlled at the cure temperature. After the appropriate time at temperature, the entire assembly is cooled down which causes the rubber to shrink away from the fully cured part. The finished composite part is then removed. An example of a composite airfoil fabricated in this manner is shown in Figure 7.

Resin Transfer Molding

Resin Transfer Molding (RTM) is a process in which low viscosity resin is pumped into dry fiber preforms contained in a tooling cavity. The individual layers of the dry fiber material is usually in cloth form which is cut and assembled into the desired shape and thickness. This preform is inserted into a tooling cavity which has the final shape of the structural part. Resin is pumped into the preform with a combination of vacuum and pressure until the preform is fully saturated. This assembly is then heated up to cure the matrix resin. The fully cured structural part is then removed from the tool. This process has the potential for being cost effective and for producing very large complex structures.

Thermal Expansion Molding

Thermal expansion molding takes advantage of the "memory" characteristic of high temperature closed cell foam (see Figure 8). Polyamide foam is heated up to the softening point and compressed to a thickness on the order of 75 percent of its' original room temperature thickness. The compressed foam is then cooled down in the deflected state under pressure and removed from the press. Composite prepreg is laid up over the compressed foam surface and is inserted into the tooling cavity for the desired shape. Upon reheating, the foam expands which moves the composite material against the tool surface. Once the final cure temperature is reached the foam exerts sufficient pressure to consolidate the composite prepreg. The assembly is held at these conditions until the composite is fully cured.

Reaction Injection Molding

Reaction Injection Molding (RIM) is used to fabricate a wide variety of large self-supporting moldings for automotive and aircraft structures (see Figure 9). Polyurethane precursor materials are routinely employed for the fabrication of RIM parts. Automobile dashes, bumpers, removable hardtops, and splash aprons are made by this technique. Polyurethane resin and hardener are mixed and pumped under pressure (up to 20,000 psi) into the tool cavity after which it begins to rapidly foam and fill the cavity. The chemical reaction and cure time for this material system and process is on the order of 10 seconds, which makes this a very fast production process. Several million items are fabricated on an annual basis by this method.

Polymer Cure Cycles

In each of the aforementioned processes the polymer materials undergo either a chemical or physical change which renders the composite prepreg material a finished structural part. For thermoset resin matrix composite materials the prepreg is converted to a rigid structure after a polymer chemical reaction which can be initiated by the application of heat, radiation, catalysts, or other initiators. A typical cure cycle for epoxy materials is shown in Figure 10. Thermoplastic matrix materials are "cured" or converted to finished products by the physical shaping of the starting composite under heat and pressure. These materials have the capability to be reshaped in a follow-up processing cycle, therefore thermoforming is considered reversible fabrication process.

CONCLUSIONS

Advanced composite materials are being utilized to fabricate a wide variety of structures requiring high performance in specific environments. Applications for these materials are limited only by the imagination of designing engineers due to the versatility afforded by the vast array of combinations of fibers and resins available. The growth of this industry exceeds the growth of most industries in the USA. Applications for advanced composite materials range from tennis rackets to space shuttle components. The need for lightweight, high performance structures will continue to grow in all major manufacturing sectors. This is driven largely by increasing demands for conservation of resources and reduction of life cycle costs for consumable products. This growth pattern is expected to continue for an unlimited time in the future.

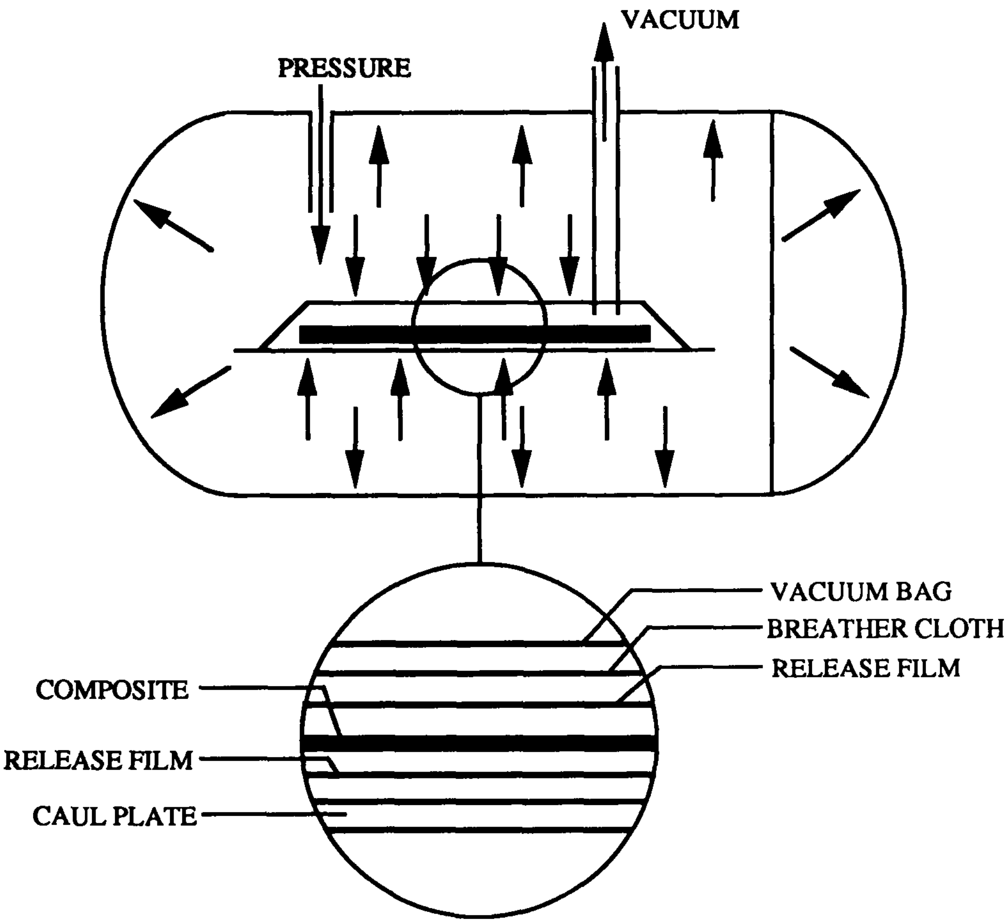


FIGURE 4. AUTOCLAVE AND VACUUM BAG SCHEMATIC

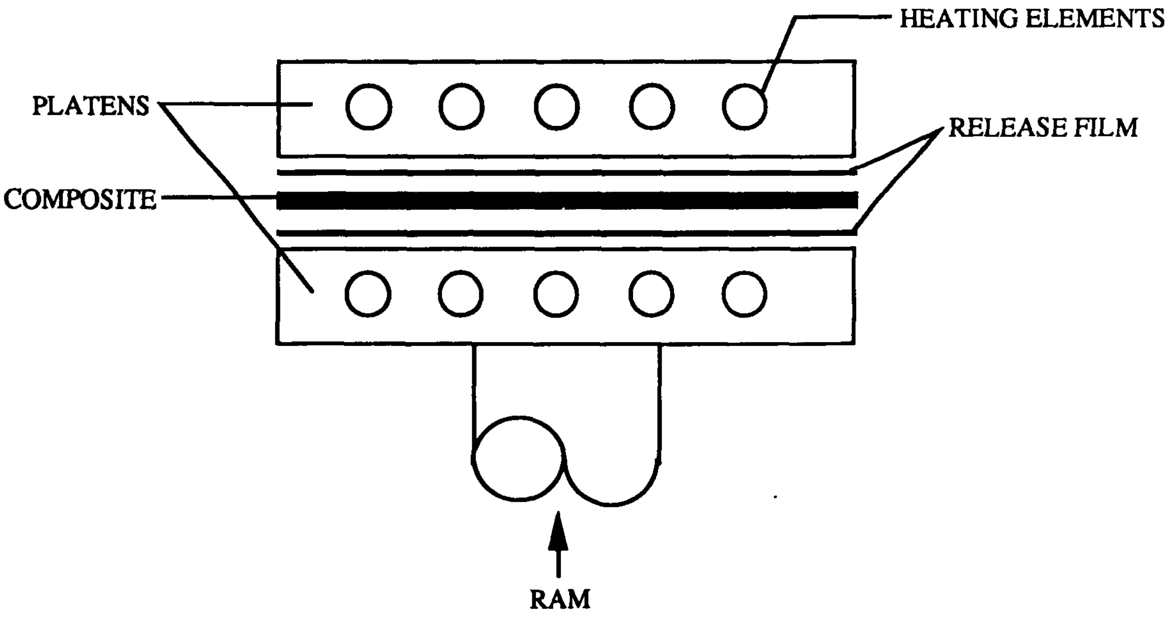
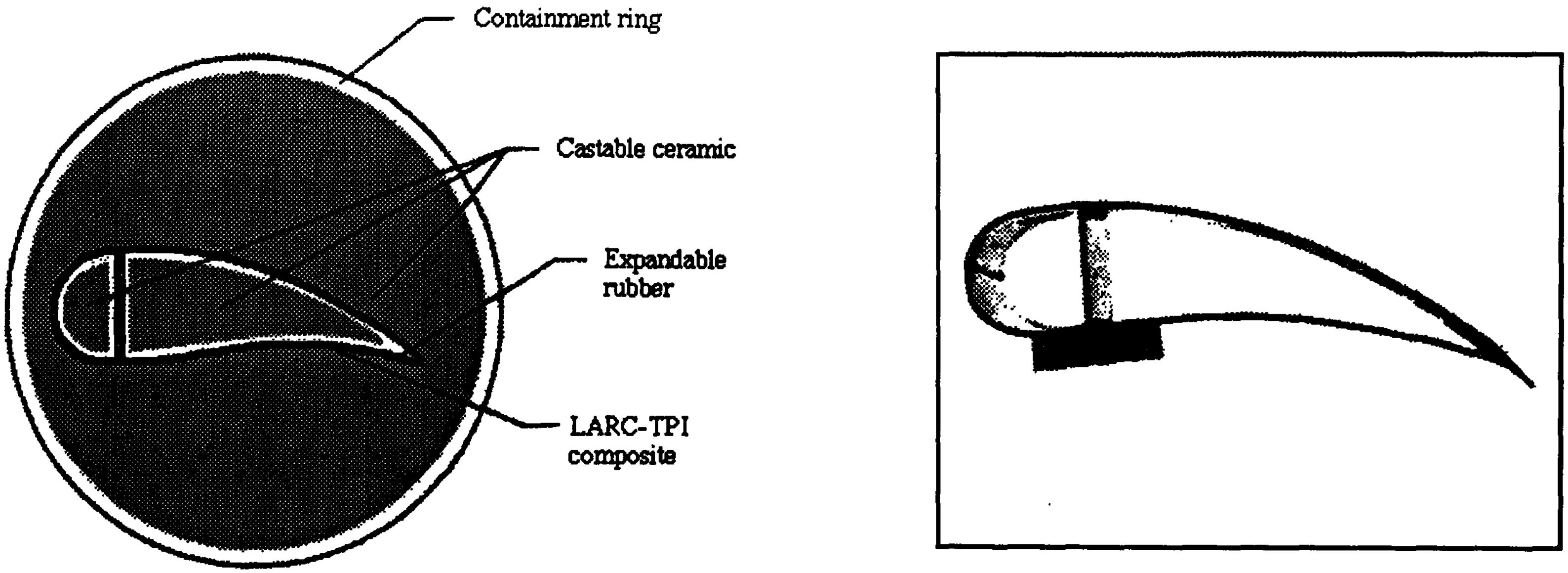


FIGURE 5. HEATED PLATEN PRESS



TOOLING

FINISHED PART

FIGURE 6. TRAPPED RUBBER MOLDING OF AIRFOIL

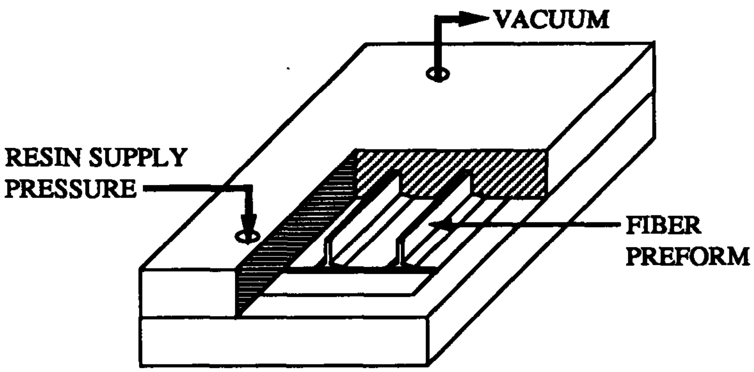


FIGURE 7. RESIN TRANSFER MOLDING

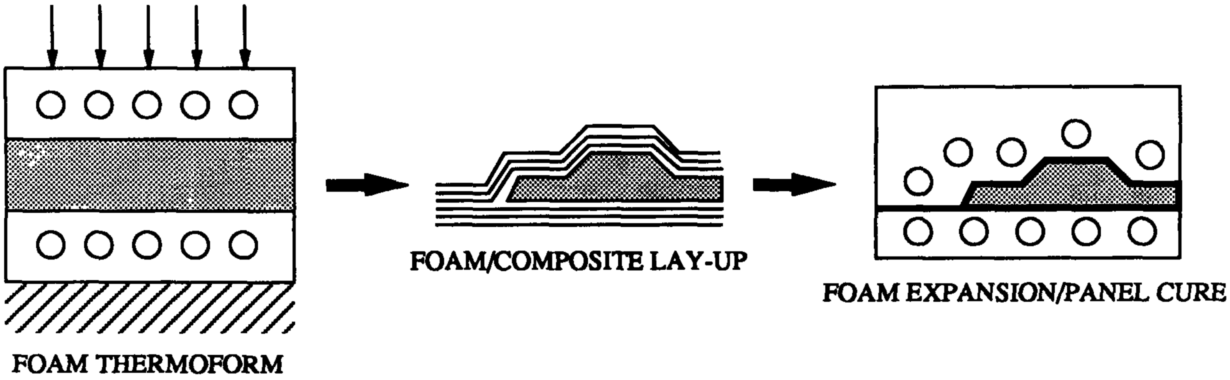


FIGURE 8. THERMAL EXPANSION MOLDING

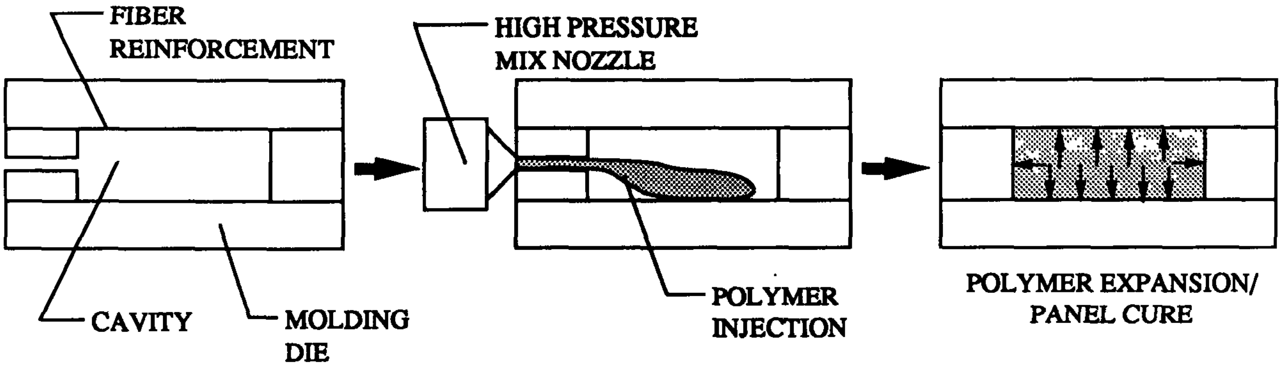


FIGURE 9. REACTION INJECTION MOLDING

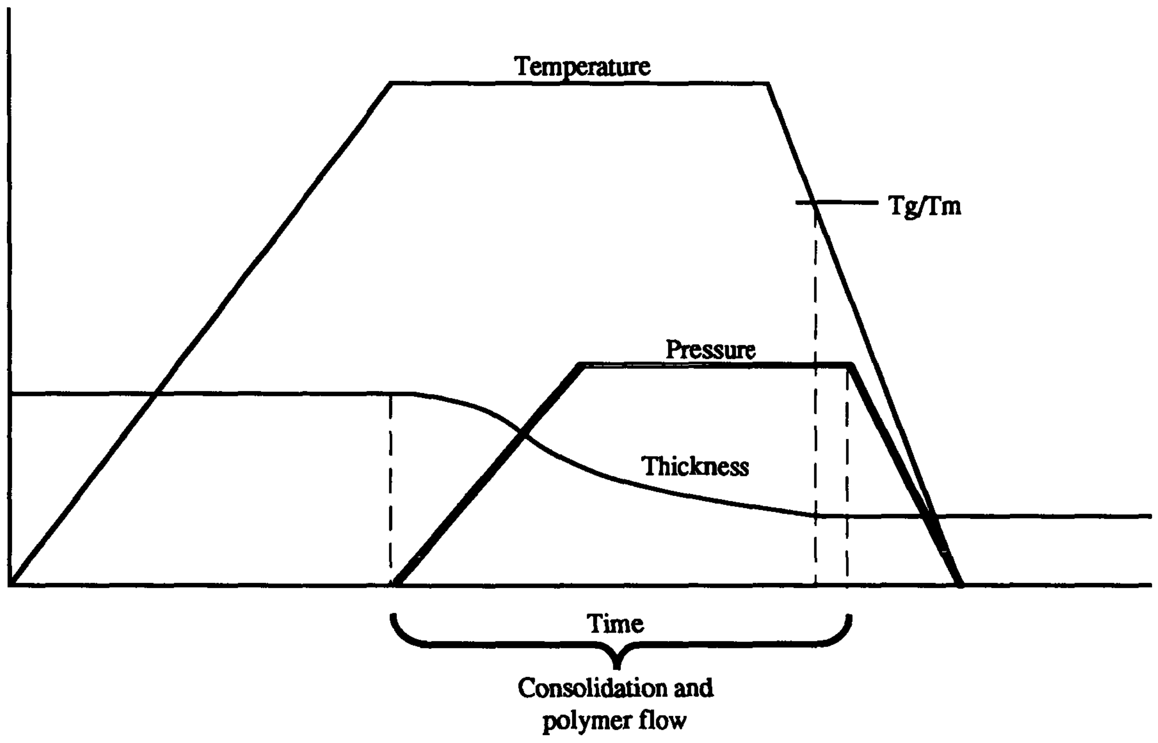
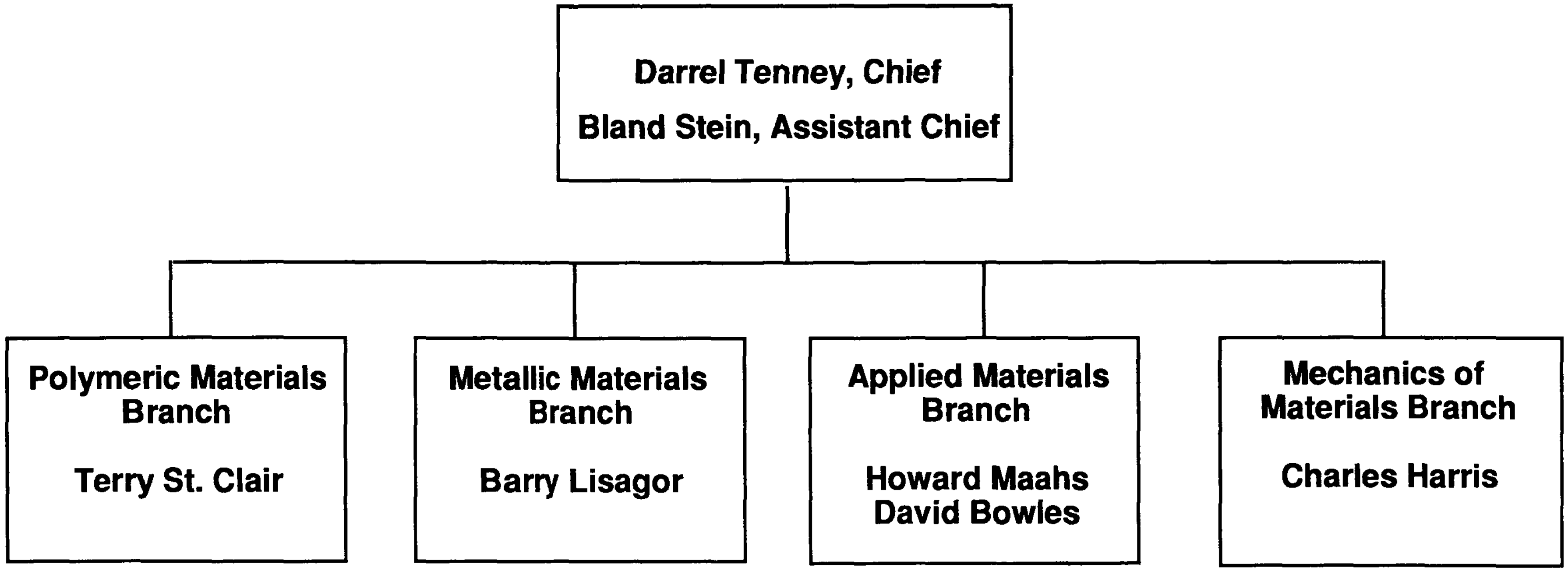


FIGURE 10. TYPICAL CURE PROFILE

MATERIALS DIVISION



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