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Manufacturing Processes for Automotive Composites

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Abstract - *Manufacturing is an issue for composites in the automotive sector when one considers the high production volumes required. Compression moulding using sheet moulding compound (SMC) or glass mat thermoplastic (GMT) are the two most common composite production processes Long fiber thermoplastics (LFT) have enjoyed a long run of double digit growth and have general acceptance as structural material. Consequently, their introduction has led to an increased penetration of the automotive market for structural thermoplastic composites. Both pellet application (primarily involving complex parts made via injection molding) and direct in-line applications (primarily involving simpler, largely flat parts made vial compression or injection molding) have shared in the growth. The study reviews manufacturing processes for the manufacture of both thermost and thermoplastic automotive composites. Various innovative approaches in formulation and processing of SMC and LFT are also accounted.*

Keywords:- *Composites, automotive, thermoplastics, thermosets, resin, fiber*

I. Introduction

Polymer matrix composites (PMCs) are being used extensively in automotive applications due to their superior specific modulus and strength. Composites provide excellent resistance to static and dynamic loads, and resistance to chemical environments, improved vibration damping and noise reduction. By introducing them into mass transit applications, composites help to increase fuel efficiency and decrease maintenance costs due to their low weight. Various components have been designed and manufactured for ground transportation including structural roof panels in high-speed railway coaches, bus structures, front cabins of high-speed locomotives, and non-structural interior panels. The year 1953 was a milestone for the automotive industry. In January, the Chevrolet Corvette debuted at the GM Motorama. Since those early days, composite materials have been used for many automotive applications. **[1]**

Composite materials are increasingly being used in the Railway Industry where the resulting performance improvements and achievable cost reductions are significant. Weight savings of upto 50% for structural and 75% for non-structural applications provides many advantages such as, reduced power consumption, lower inertia, high-speed, less track wear and the ability to carry greater pay-loads. Factors like recycling and emphasis on low cost and fuel efficiency have enabled natural fiber such as jute based composites to enjoy wider applications in automobiles and railway coaches. Use of natural fibers in automobiles is mainly limited on upholstery applications due to the shortcomings of natural fiber composites, low impact strength and poor moisture resistance. These drawbacks may be overcome either by pre-treatment of the fibers or by improving the chemistry while impregnating the fibers with the matrix material. **[2]**

II. Manufacturing Processes

The choice of manufacturing process depends strongly upon the required rate of production. A typical truck application might have a volume of between 5,000 and 20,000 parts per year, whilst for cars it might be 80,000 - 500,000 parts per year, or even more. Other aspects that have to be considered are tooling costs, scrap production and cycle time. Compression moulding using sheet moulding compound (SMC) or glass mat thermoplastic (GMT) are the two most common composite production processes used. Both have become highly automated over recent years and are currently used for cars and trucks with cycle times in the order of a few minutes. Many of the problems originally encountered with these materials, including high density, surface finish and paintability, have now been addressed. A third process for medium volume composite production is resin transfer moulding (RTM). It can be used for structural applications and is of growing interest because of its potential for automation, good tolerances and good achievable mechanical properties. The surface finish of RTM parts is also quite good. The D-LFT (Direct Long Glass Fibre Thermoplastic) process is also worthy of mention. This combines good structural characteristics with complete process automation. Created in 1989 by Ron Hawley (Composite Products Inc.), it is now considered one of the most promising processes for structural parts.

2.1 Sheet Molding Compound (SMC)

Modern industries demand structural materials that are lightweight, strong and versatile. Material that resist corrosion and temperature extremes and which deliver freedom of design and low system costs. The ideal solution appears in the form of SMC (Sheet Moulding Compound) a fiber reinforced thermoset. The SMC primarily consist of a thermosetting resin matrix (normally UP –unsaturated polyester), reinforcement (normally glass fibre) and inorganic filler. Additional ingredients such as cure initiators, process additives, low-profile additives, mould release agents and thickeners are used to enhance the process ability of the material and the end-performance of the part. A typical SMC formulation is: Resin 28%, Reinforcement 29%, Inorganic Filler 40%, other Additives 3%) **[3]**

Thermosetting resins form the matrix and chemical backbone of SMC, imparting the required blend of properties. Unsaturated polyester (UP) or vinyl ester (VE) are the resins most commonly used, and they undergo a cross-linking reaction when cured under heat and pressure. VE resins are used when there is a high technical requirement, for example where sustained heat and chemical resistance is needed. Good heat resistance is a characteristic of all thermosets and they differ from thermoplastics in that once the compound cures to a rigid solid, it will not soften at elevated temperatures or become brittle at lower temperatures. This means that SMC parts retain their original properties and dimensional accuracy over a broad range of temperatures.

SMC is made as a continuous sheet. The resin paste is transferred to a doctor box where it is deposited onto a moving carrier film passing directly beneath. The doctor box controls the amount of the resin paste applied. Simultaneously, glass fibre rovings are fed into a rotary cutter above the resin-covered carrier film. Fibres are chopped to length (generally 25mm, or 50mm) and randomly deposited onto the resin paste. The amount of glass is controlled by the cutter and by the speed of the carrier film. Downstream from the chopping operation, a second carrier film is coated with resin paste and is laid, resin side down, on top of the chopped fibres. This stage of the process creates a resin paste and glass fibre 'sandwich' which is then passed through a series of compaction rollers where consolidation of glass fibres with the resin paste takes place and then the air is squeezed out of the sheet. Before the SMC can be used for moulding it must mature. This maturation time is necessary to allow the relatively low-viscosity resin to chemically thicken. The SMC will be kept in a maturation room at a controlled temperature (normally 48 hours at 30°C) and typically requires two to five days to reach the desired moulding viscosity. Sheet moulding compounds are transformed into finished parts by a processing technique known as compression moulding.

A pre-weighed charge of material is placed into a matched metal tool which is located between two platens within a large press. The tool is heated up to 140-165°C dep ending on the formulation and other factors. Hydraulic rams then compress the material under a pressure of around 100 bar of projected area. It's the combination of heat and pressure that softens the SMC and forces the material to flow throughout the mould cavity. The curing agent within the compound is stable at room temperature but is activated by the heat of the mould. Cure time depends on the type of resin in the matrix, the level of curing agent and the thickness of the component. Thick sections take longer to heat through and can generate excessive exothermic temperatures, which is why tool temperature is generally lower and the moulding cycle longer for thicker parts. When the cycle is complete the tool is opened and the part removed ready for finishing operations such as de-flashing, machining and painting. **[4]**

2.2 Long Fiber Thermoplastics (LFT)

Long fiber thermoplastics (LFTs) are being used extensively in automotive and transportation industry due to their superior specific strength and modulus resulting in substantial weight savings, combined with relative ease of fabrication and handling. The matrix in thermoplastic composites is generally comprised of polypropylene (PP), polyethylene (PE), polyamide (PA) or other polymers. E-glass fiber is a commonly used reinforcing material. By introducing them into mass transit applications, composites help ton increase fuel efficiency and decrease maintenance costs due to their low weight.

In general, some of the advantages of using LFT over metals include high impact resistance, superior toughness, improved damping and corrosion resistance in conjunction with ease of shaping and recyclability. The use of a thermoplastic matrix provides the molder the ability to modify and enhance the properties of the resin by blending additives, fillers and fire retardants depending on the nature of the application In the past, the tendency was to use LFT for more simple applications such as covers or backing, or for parts in unexposed areas, but with the arrival of new material systems optimised for the specific application, and with the ongoing development of the processing and process engineering, it has now become possible to mass produce highly stressed structural parts and innovative module systems with a high level of functional integration. Currently, short glass fibers are predominantly used as reinforcement in polypropylene in the automotive industry. But the full strength of the reinforcing short fibers is not realized due to their low fiber aspect ratio. The aspect ratio

(ratio of fiber length (ℓ) to dia (d)) of fibers in LFTs is of an order of magnitude greater than that of short fiber, often exceeding ℓ/d of 2000 and, thus, takes full advantage of the strength of the reinforcing fiber. **[5]**

The quality and mechanical properties of an LFT material are defined by the basic materials (the matrix system and the type of fiber) but also to a very large extent by the process induced flow orientations and the fiber lengths in the finished part. The orientation and real fiber length are influenced significantly by the particular processing method and the variation of process parameters. The mechanical properties of real components are broadly scattered as a result of the process-specific plasticizing and flow processes of the melt, the resultant fiber length reduction and the orientation of the fibers

Table 1. The advantages & disadvantages of composites with thermoplastic matrices (as opposed to thermoset matrices)

ADVANTAGES	DISADVANTAGES
High durability (impact resistance) - Strong damage tolerance	Reduced Compression Strength & stiffness
Low moisture sensitivity (except PA)	Interphase problem like (fiber– matrix adhesion, especially for unipolar thermoplastic)
Unlimited shelf life without the need for cooling	Difficult to impregnate due to high melting viscosity
Low emissions ('fogging')	Creeping (at higher temperature)
Thermal post – processing possible (welding, re-forming etc.)	Processing induced crystalline structure (for partially crystalline thermoplastic) -shrinkage and warpage
Short Cycle times (no hardening reactions)	Paintability and glueability
Simple Recycling	High processing temperature and pressure

2.3 Direct Reinforcement Fabrication Technology (DRIFT) Impregnation process

The DRIFT impregnation process is a hot melt pultrusion process. The fiber is pulled from a creel and heated at or above melt temperature. A single or twin-screw extruder compounds the resin. The heated roving is than impregnated with the melted resin in a die by opening the fiber bundles over special spreader surfaces. This allows complete impregnation of continuous fibers with thermoplastics polymers at very high production rates, providing a high quality, low cost thermoplastic composite. The hot-melt impregnation technology enables to produce products in various forms such as continuous rods, tapes, pultruded shapes, or pellets of any length for injection and/or compression molding. This manufacturing process can be used to combine a wide variety of thermoplastic resins and reinforcing fibers. Fiber levels as high as 60% by weight are easily produced**. [6]**

2.4 Glass mat thermoplastics (GMT)

GMT is a board-shaped, semi-finished sheet, typically 3.7 mm thick, in which long (>12.5 – 100 mm) or endless glass fibers are arranged in random form in a thermoplastic matrix. The usual fiber content amounts to 15–40% of the weight. The commercial process for the manufacture of this semi-finished sheet is the molding impregnation in double band presses. The specifically dimensioned pre-cut GMT sheets are further processed on a GMT production line. In addition to typical GMT, certain engineered GMT's are also produced owing to their applicative demands

2.5 Partially consolidated GMT systems for lightweight constructions

Growing market demands for materials for thin-walled structural parts like underbody systems and for structural support materials for so-called direct laminate processes led to the development of a number of partially consolidated GMT systems. These are called lightweight reinforced thermoplastics (LWRT) as they are produced at values of down to 1200 g/m2 as opposed to alternative LFT production methods like extrusion or injection molding, where minimum substances of 2000–2500 g/m2 are used. Current applications are the underbody systems of the BMW 5 and 6 series. LWRT manufacturing methods can also be used for a wide range of alternative reinforcing fibers (aramid, carbon) or natural fibers (sisal, flax, hemp etc). The use of spun matrix filament also enables the application of alternative matrix polymers (PA, PET, PBT etc) with higher heat stability.

2.6 GMT with directed long fiber reinforcement for structural applications

This so-called 'Advanced GMT' combines the advantages of conventional GMT processing of random mats or continuous fiber mats with the high mechanical potential of directed fabrics or unidirectional (UD) layers. In the production of the GMT semi-finished products in the double-band molding press, the fabrics or UD layers are put in different positions or layers continuously or discontinuously. The number and position of the fabrics or UD layers can be chosen in any combination which leads to customized solutions for process ability, features and cost-effectiveness. Cost effective mass production of heavy-duty structural parts with high process ability can be realized with the use of a local reinforcement of Advanced GMT. GMT structural parts can be used in combination with conventional materials like metals due to their excellent stiffness/weight ratio combined with good crash properties, high energy absorption capability and high expansion. Current examples of applications in the automotive industry include instrument panel supports, technical front-ends, door modules, bumper supports, sound absorbing shells, spare wheel pans and – one of the fastest growing applications – complete underbody systems. Only 2% of the GMT produced is used outside of the automotive industry. **[7]**

III. New developments in LFT

3.1 Long fiber reinforced granulates (LFG)

Long fiber reinforced granulates (LFG), pellets and chips of average length 3– 25 mm, prepared by wire coatin g, crosshead extrusion or several pultrusion techniques. The long fiber granulates are suitable for both the classic injection molding process (IM) and the injection compression molding process (ICM) as well as for the extrusion compression molding process (ECM). LFG pellets are fed into the hopper of a plasticator (a single screw, low shear extruder) where they are metered down a barrel, heated above the melting point and extruded in low shear to form a molten charge. The molten charge is extruded to a predetermined size, and shape (usually cylindrical) that is transferred to the compression molding press for the forming operation.

3.2 LFT direct process

The process combines the compounding of a long fiber reinforced thermoplastic material directly with the final part production process. The reinforcing fibers were incorporated and impregnated with the polypropylene matrix directly during the compounding and plastication process of the thermoplastic composites (D-LFT process). Compounds are prepared on compounding extruders and transferred directly to the molding machines. Twin-screw compounding extruders adequately inject continuous roving, or pre- chopped roving – and produce compou nds with adequate fiber wet-out and filament distribution. The process industry has been highly benefitted by this technique. The leaving out of semi-finished products leads to a clear benefit concerning to the material and process costs. Another benefit is the additional heating and plastification process of the matrix is left out, so the thermal stress as well process stabilizers are reduced. Furthermore, the part producer can vary the process conditions and material recipes on a wide scale and can adapt the process quickly and efficiently according to the needs of the specific part.
But certain complexities involved with the process are preparation of the raw materials and the material classification and quality. Furthermore is has to be noted that an in-line compounding system needs higher investment costs and skilled service personnel.

IV. Discussions

There would appear to be significant future opportunities for composites in the automotive industry, especially if one considers their potential advantages compared to metals. Composites can offer benefits in terms of weight reduction, tooling cost savings, and design and styling freedom. The composite industry has experienced continuous innovation and new developments in the processes and application design, in order to continue to meet the requirements at reasonable cost and weight. Above it has been shown that there are various new solutions in the pipeline, which will address the current and emerging needs in the coming years. Many of the new developments are based on thermoplastics, striving to match the key advantages of thermosets, while maintaining the process and postmould advantages and looking to future requirements on recycling, safety, cost and weight.

The ability to tailor SMC to precisely meet processing and end-use needs is a major benefit over metals. Speed to Market, an essential requirement for automotive OEMs as well as producers of consumer electrical goods, is supported when designing in SMC. A wide variety of standard material grades is available; alternatively – by varying the type and percentage of ingredients in their formulations - the compounder can custom-formulate SMC materials to meet specific needs.The growth in LFT market over the last 10 years has been 10-15% and is expected to grow at higher rates. The growth trend of GMT seems to be constant over years, but D-LFT has experienced very high demands over the last 5 years. Market demand of LFG pellets has also considerably increased over the years.

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