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Review Paper on Processing Technique of Polymer Matrix Composites: Current and Future Trends

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Abstract: Composite material shows energetically convenient manufacturing with low weight feature. The strength and other mechanical properties of PMC depend upon the orientation of fibers and method, they are fabricated. The product and their industrial applications also taken into consideration while manufacturing whether it is shaft of racing car or it is wings of flying aircraft or etc. The main microscopic objective of production are to ensure that the fibers are well wetted, uniformly distributed and correct aligned. Practical consideration, relating to capital cost, speed of production and component size and shape are often of eminent importance. Therefore, many researchers explored the every possible technique to enhance the performance of product and optimize the process. This study reviews the research work carried out in this field.

Key words: Polymer matrix composites, optimize, size, shap, wings, India

INTRODUCTION

Polymer matrix composites materials are processed in many ways as per the requirement of the industry. Every processing technique has its own beauty and limitations. Materials are developed with the help of different design technique. Starting from hand lay-up technique to recently developed carbon-carbon composite technique, advancement of design has an important role for quality product. In this present study, last 20 years research is discussed to study the processing technique.

Review of procesing technique of poly matrix composites: Rachal and James (1990) investigated problems with composite having high melting point thermoplastic resin and hence, invented a method of consolidating a fiber reinforced thermoplastic poly (arylene sulfide) by vacuum bagging. Layup is first placed between substrate made of stainless steel and enveloped with a flexible air impermeable (aluminum foil). This arrangement is then placed in oven and heated up to melting point of resin or softening point. Heating is being carried out by impinging heated gas against layup. Suction is applied between the flexible foil and metallic sheet and so achieves good wet out of reinforcing fiber and resin. After that cool air source causes impinging gas being cooled against layup, there by to form consolidated composite.

They also confirmed the thermal stability of substrate and flexible foil. By this advantageous technology, 2-20 composite can simultaneously be produced and venting of gas from layup be assisted. Partially automated and speedy process of production was also objective of invention. Chen and Li (1993) studied the effect of silica coating on the surface of carbon or graphite fiber and the interface in a carbon/magnesium composite manufactured by vacuum pressure infiltration: the mechanical properties of the materials were also studied.

For the coating process, the fibers were passed through a toluene solution, containing a silicon-based organ metallic compound and chloride following which hydrolysis and pyrolysis of the organ metallic compound occurred to form a thin and uniform silicon dioxide coating on the surface of the fibers. The air-stable silicon dioxide coating, facilitates wetting and bonding between carbon or graphite fibers and liquid magnesium. The carbon and graphite fiber-reinforced magnesium composites were fabricated by vacuum/pressure infiltration processing. Special attention was focused on analysis of the structure of the coating which was deposited by the solution immersion process with the aid of analytic instruments such as SEM, EDAX, TEM, XPS and SAM. Manufacturing processes of C/Mg composites, the interface chemical reaction and the mechanical properties were also studied.

Vodermayer *et al.* (1993) researched on the manufacture of high performance fiber-reinforced thermoplastics by aqueous powder impregnation. In their experiment, carbon fiber roving's are impregnated on a

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laboratory scale, using an aqueous polymer powder dispersion process to produce unidirectional fiber-reinforced thermoplastics having a fiber content of up to 65% by volume. The fiber/matrix ratio is calibrated optically and/or by an adjustment of the material, tool and process parameters. Roving impregnation can now be economically achieved at higher production velocities with reduced damage to the fibers. In order to optimize the impregnation process, the most important material parameters powder size and concentration in the dispersion are denied by model calculations and experimentally examined to establish their influence on the intended fiber volume content.

Yumitori *et al*. (1994) investigated the role of sizing resin in carbon fibre-reinforced polyethersulfone, using surface-treated type a carbon fibre sized with different polymeric coatings. To investigate their influence on the adhesion of the carbon fibre to the matrix, the single embedded filament fragmentation test was used. Sized carbon fibres showed higher interfacial shear strength than the unsized ones. Analysis by time-of-flight secondary ion mass spectrometry suggests that this arises from a strong interaction between sizing resin, the fibre and the matrix.

Hinea *et al*. (1995) in their study describes the characterisation of the 3D fibre orientation of a single-gated, injection-molded plaque of short-glass-fibre-reinforced nylon by image analysis and they used this orientation data for the theoretical prediction of the composite elastic properties. Fibre orientations were measured by using a purpose built image, analysis facility which allows 3D data to be obtained. Composite elastic properties were measured by an ultrasonic velocity method and compared with theoretical predictions obtained from the modelling techniques of Wilczynski and Ward.

Hou *et al*. (1996) investigated the relationships between impregnation mechanisms, consolidation quality and the resulting mechanical properties of Carbon fibre Fabric reinforced Polyetherimide (CF/PEI) thermoplastic composites. A compression-molding procedure was applied to simulate the effects of different processing conditions (i.e., pressure, holding time and processing temperature) on the quality of finished samples. Microscopic studies of cross-sections, density measurements and flexural mechanical properties were used to examine the quality of impregnation and consolidation. A qualitative model to describe the impregnation and consolidation processes of this material was developed. It predicts the variations of void content during consolidation as well as the holding time, moulding temperature and pressure required to reach full consolidation. Good agreement between theoretical predictions and experimental data indicates the success of the approach. Finally, aileron ribs for a civil aircraft were successfully manufactured from the CF/PEI material according to the suggested optimum processing conditions.

Mosleh *et al*. (1997) investigated the manufacture and mechanical properties of a homocomposite consisting of an ultra-high molecular weight polyethylene matrix and an ultra-high molecular weight polyethylene reinforcing phase. While the chemical compositions of the bulk and fibers are the same, the fibers have a higher strength and a higher melting temperature due to their high degree of molecular orientation. The composite materials was manufactured by alternatively laying up plies of an ultra-high molecular weight polyethylene fabric or randomly oriented fibers and ultra-high molecular weight resin in a mold followed by compression molding. The molding temperature was chosen to be slightly higher than the melting temperature of the matrix but below that of the fabric or fibers. The fibers were also cross linked using gamma irradiation so as to retain their molecular orientation during compression molding.

Mechanical properties of the composite materials such as the elastic modulus, tensile strength and hardness are improved in a direction parallel to the fiber orientation when compared with the properties of ultra-high molecular weight polyethylene. This composite exhibits a lower friction coefficient and higher wear resistance which are desirable properties in bearing applications. In addition, owing to the biocompatibility of polyethylene, this composite may be acceptable as a bearing material in joint prostheses.

Guo *et al*. (2010) studied the effect of epoxy coating on carbon fibers during manufacture of carbon fiber reinforced resin matrix composites. In their research, they measured the changes in oxygen and nitrogen during manufacture of the carbon fiber reinforced resin matrix composites by using the X-ray photoelectron spectroscopy method. The effects of the change in oxygen and nitrogen on the strength of the carbon fibers were investigated and the results revealed that the change of the tensile strength with increasing heat curing temperature was attributed to the change in the surface flaws of the carbon fibers because the carbon fibers are sensitive to the surface flaws.

The ultimate purpose of these treatments has been to increase the physicochemical interactions between the carbon fibers and resin matrix such as chemical active functional groups, the surface energy and corrode or change the surface microstructure of the carbon fibers. The effect of the surface energy that was calculated using

Kaelble's method on the strength of the carbon fibers was investigated. Furthermore, the surface roughness of the carbon fibers was measured using atom force microscopy. The change trend of roughness was reverse to that of the strength which was because of the brittle fracture of the carbon fibers. The purpose of this research was to report the physicochemical interactions of the carbon fibers and epoxy coatings on the tensile strength of the carbon fibers in order to modify curing process of the carbon composites, quality assurance and characterization assessment of durability.

Boszer and Palm *et al.* (1997) studied and concerned that the polymer bag used for isolation during curing in autoclave has many drawbacks, regarding many complex shapes. Due to bridging at the flange, bag must stretch or break or tear. Folding, adjusting or refolding is done to overcome the above drawback but this makes it labor intensive. Hence, they invented a conformal vacuum bag method in which first similar shaped silicon rubber is cured on reference object having dimensions essentially the same as the article to be produced. The reference object makes a impression on sheet. In their research, they used this shaped sheet to envelop the work piece while curing in autoclave. They also propounded the reinforcement of silicon rubber bag if still there is possibility of tearing or bridging and hence, ensured a better and automated curing procedure for uninterrupted manufacturing.

Qiu *et al.* (2001) fabricated and characterized the three-dimensional cellular-matrix, composites reinforced with woven carbon fabric. A low-density three-dimensional cellular-matrix, composite reinforced with woven carbon fabric (3DCMC) was fabricated by means of a pressure-quenching molding technique with nitrogen gas as the blowing agent. Epoxy resins in the interstices of yarns in the 3DCMC samples were vacated during the foaming process and needle shaped voids were also generated between fibers in yarns. The average density of the 3DCMC samples was about 103 kg m^{-3} and their density reduction was 28-37% compared with a regular matrix composite with the same preform. The 3DCMC has 32-42% higher specific tensile strength, 14-37% greater specific tensile modulus, a lower specific flexure strength but 35% higher specific tangent modulus in 3-point bending, a 30-40% higher specific impact energy absorption at an impact velocity around 120 m sec^{-1} and a similar specific energy absorption at about 220 m sec^{-1}. Meanwhile, the 3 point bending and impact test results of 3DCMC showed that they have different fracture mechanisms from that of 3DRMC.

Sandler *et al.* (2002) produced poly (ether ether ketone) nanocomposites containing vapour-grown Carbon Nanofibres (CNF) using standard polymer processing techniques. Evaluation of the mechanical composite properties revealed a linear increase in tensile stiffness and strength with nanofibre loading fractions up to 15% wt. while matrix ductility was maintained up to 10% weight.

Electron microscopy confirmed the homogeneous dispersion and alignment of nanofibres. An interpretation of the composite performance by short-fibre theory resulted in rather low intrinsic stiffness properties of the vapour-grown CNF. Differential scanning calorimetry showed that an interaction between matrix and the nanoscale filler could occur during processing. Such changes in polymer morphology due to the presence of nanoscale filler need to be considered when evaluating the mechanical properties of such nanocomposites.

Tuckera *et al.* (2003) in their research introduced a method in which curing taking place outside the die. This results in very low pulling forces as the passage of the fibers through the die and the consequent compaction of the fiber pack to a final fiber volume is lubricated by the low viscosity uncured resin as a result, the cost is reduced and the ability to manipulate the shape of the pultrudate during formation. The die, therefore is only required to impart a profile to the fibre/resin bundle and to remove excess resin from the fiber bundle. In the feasibility study described in this research, the process of curing relies primarily on irradiating the resin-coated fibres with Ultra-Violet (UV) light as the profile exits the die. The process is assisted by the low viscosity of the uncured resin.

The capital costs of an industrial machine will be considerably lower than current pultrusion machines because the mechanical forces used in operation at low. It is likely that the process will consume less energy than current machines. Aside from these advantages, a novel process has been developed whereby a 3D space frame can be made from a composite material.

Diaz and Rubio (2003) investigated the developments of detail parts and assemblies in an aircraft from reinforced thermoplastic. Thermoplastic composites technology, intends to achieve improved properties and low cost process and many advantages like short manufacturing cycle, recycling and no curing cycle, etc. They mentioned the trends of technology, used thermoplastic composite for aircraft industry, R and D project (before 90'sec) to EADS CASA project (current technology). They included the description of elementary material and feeding material RTL (reinforced thermoplastic laminates) in recent technology and future trends in aeronautic industry. Rubber forming process was technically described. Important aspects was silicon rubber (displaceable) and forming operation. Developments include supplementary forming process as welding is quite favorable with thermoplastic matrix. Welding of detail parts permits to obtain assemblies with weight reduction and cost saving. This study also describes the automation of the process to reduce labor cost and improve the manufacturing process. In recent, EADS CASA uses rubber forming to fabricate constant thickness part as ribs and panel.

Hsiao *et al*. (2004) invested simulation based flow distribution network for vacuum assisted resin transfer molding process. The flow distribution network significantly influence the fill time (as it control the resin infiltration acceleration), fill pattern and highly important for process design. The current process has been to cover the top surface with the resin immediately and penetrate though the thickness. Vents in product, defective part and resin wastage were possible drawbacks.

Difficulties in the flow with ribs and inserts were also encountered. Apart from the conventional ones, science based approach was proposed to design the layout of distribution network. The flow of the resin into the network and panel was simulated. For this, a genetic algorithm was used to optimize the flow distribution network. Good agreement between the flow simulations and the experiment results was observed. This innovative approach successfully optimizes the flow distribution network and can extend the VARTM process for manufacturing of complex structure efficiently.

Guru *et al*. (2006) investigated the production of polymer matrix composite particleboard from walnut shell and improvement of its requirements such as non-flammability, eradication of fungal and insect attack and water resistance features by using fly ash and phenol-formaldehyde. For this purpose, under laboratory conditions, parameters affecting polymer composite particleboard from walnut shell and urea-formaldehyde were specified to be urea-formaldehyde ratio, reaction temperature and reaction period and the effect of these parameters on hardness was investigated.

The optimization results showed that maximum bending strength was 3.8 N mm^{-2} at urea-formaldehyde ratio of 1.0, reaction temperature of 70°C, reaction time of 25 min, walnut shell filler/urea formaldehyde resin of 3 and mean particle size of 0.12 mm. As a result of burning tests although, the maximum flame temperature of composite particle board without fly ash was 535°C, it was 299°C with fly ash of 15% (w/w) according to the filler. Water absorption and increasing in the thickness, exponentially decreased with increasing phenol-formaldehyde/urea-formaldehyde ratio. Benard *et al*. (2005) investigated the adhesion performance of glass/carbon epoxy composites, using excimer laser treatment and also made sure a selective removal of polymer layer without any degradation of fiber reinforcement. They successfully proved that both conical structure and ablation depth of the treated surfaces are dependent on the laser influence and the number of pulse used. They observed that roughness of the composite increased while raising the laser treatment influence and pulse (after 40 pulses) and achieved the highest roughness that is 20 times of untreated sample. In this study, the use of two different adhesive (low and high adhesion performances) responded specific lap shear strength and particular failure mode on varying laser treatment. In last, they concluded the laser treatment can efficiently control the processing parameter and enhance the performance of composite material.

Michael invented a process named *QUICKSTEP* to reduce the manufacturing cost and curing time while sticking with sufficient mechanical and physical properties. They performed tensile test ISL (Interlaminar Shear Test) and Sandwich plates-climbing drum peel test and proved that properties like tensile strength, interlaminar shear strength, degree of curing and glass transition temperature were in range or superior to autoclave ones. Uniform failure (increasing capacity to resist shear force) and lower standard deviation (repeatability) showed the improvement in quickset production. The cure cycle time was reduced by 43% compared to an equivalent autoclave due to rapid heat up and cooling. In innovation, they used as heat transfer rather than air or inert gas.

This caused low viscosity resin but no negative effect on the physical/mechanical properties rather fillet forming of resin between the core and face was improved. Overall, they concluded a product with better fiber matrix adhesion and weight and cost reduction.

Guru *et al*. (2007) investigated the various industrial application of fly ash and marble dust. They took different amount of fly ash, marble dust and polyester as base material, methyl ethyl ketone peroxide as base material, methyl cobalt napthanats as accelerator and produced polyester matrix composite. In the 1st step of the manufacturing of composite material, the amounts of hardener, accelerator and polyester were kept constant and only fly ash/marble dust ratio was changed. The experimental results showed that while fly ash/marble dust ratio up to 1/3 was increased, the strength and hardness of the composite materials increased. In next step, they kept amount of hardener, accelerator and fly ash/marble dust and only polymer was varied and observed almost same three point strength and hardness values. Disposing of fly ash and marble dust creates eminent environmental pollution and of marble dust economic loss also as 10%

loss during fabrication process. Marble dust generally used as reinforcement or raw material and fly ash is highly important for utilization of puzzolanic activity and chemical composition. In their invention, it was seen that the fly ash increases the compressive strength by 31-53% and hence, they originated a novel production process commercially feasible and environmental friendly.

Jiang *et al*. (2007) reviewed the recent progress to model, the CNT/matrix interfaces via a cohesive law established from the Van der Waals force. A simple analytical cohesive law is obtained from the inter-atomic potential and is used to study the effect of CNT/matrix interfaces on the macroscopic properties of CNT-reinforced composites. The interface behavior may significantly influence the mechanical properties of Carbon Nanotube (CNT) reinforced composites due to the large interface area per unit volume at the composite. The modeling of CNT/polymer interfaces has been a challenge in the continuum modeling of CNT-reinforced composites. Goren and Atas (2008) utilized the VARIM technology in their study. They worked on a set up capable of controlling the level of vacuum and the temperature of heating table for excellent curing. Their research on VARIM consisted of a table heated with heating resistance. Table had eight regions having independent control system. They used PLC and touch screen to adjust the temperature up to the 200°C and corresponding time for curing cycle.

In their research, they also made sure manual control of vacuum regulation system using PLC programme. Overall, they designed and implicated a system that has flexible control for changing the cure condition. The originality of the study is to give significant tips to trade/company setter.

Wang *et al*. (2008) prepared Graphite Nanosheets (GNs) in which sonicating expanded graphite were homogeneously dispersed in unsaturated polyester resin using sonication. The dispersion with a curing agent was then subjected to a dc electric field followed by cross linking to fabricate a polymer/GN composite film. X-ray diffraction and scanning electron microscopy revealed that the GNs in the film were oriented parallel to the electric field. UV-VIS measurements indicated that the optical properties of the field-induced composite film showed significant improvement in visible light transmittance compared with those prepared without the electric field. Asuncion invented a jig and an out of autoclave manufacturing process result of which are similar to the process including a curing step in an autoclave. In autoclave time invested in manufacturing was the main concern which included time spent in impregnation, stacking of layer to form structure, applying vacuum and heat (curing) and also high cost of manufacturing. During curing with conventional process (autoclave) applying heat by mean of hot air convection was the spending. This invention used electron beam as curing technique which causes decrease of time and cost necessary for carrying out an automated process. That was so as complete curing is achieved after a single application. Out of autoclave this set up consist a jig, comprised of stacking table on the upper surface of a base where material is laminated. This movable head was provided with automatic compacting and infrared emitter and electron beam emitter. Another aspect of the invention provides layer by layer compacting and partially curing. The above step is repeated until the stacking, the structure and applying the electron beam for curing. No need of partial curing if prepreg tapes are of the shape of the structure.

Fu *et al.* (2009) reduced Carbon Nanotube (CNT) length during the manufacture of CNT/polymer composites and a produce method to simultaneously determine the resulting CNT and interfacial strengths carbon nanotube/epoxy composites with an excellent dispersion of Carbon Nanotube (CNTs) were prepared using a three-roll calandering technique. CNT length after processing of composites is measured and then characterized using a two-parameter Weibull distribution function. Significant reduction of the CNT length is observed as a result of the processing and it is thus suggested that great attention should be paid to the retention of CNT length after processing in order to obtain good mechanical properties. Because of the difficulties in manipulating nanometer sized, CNTs during measurement of CNT strength and CNT-polymer interfacial strength, CNT strength and CNT-polymer interfacial strength have previously been determined using complicated methods with expensive or specially designed equipments. In this research, a simple methodology based on the modified rule of mixtures is proposed to simultaneously determine the CNT strength and CNT-polymer interfacial strength.

CONCLUSION

The reviews of the research on the manufacturing methods of PMC's are presented in this study. The research of last 20 years has been discussed. The purpose of each and every process mentioned and implemented are the same to enhance the properties and to get better output product and also concerning about the efficiency and cost effectiveness of the process. This study would help those who want to start and set up their career in this field.

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