Processing Techniques of Polymer Matrix Composites – A Review

H.V.Divya[1], L. Laxmana Naik[2], B.Yogesha[3]

[1] Assistant Professor, Department of Industrial & Production Engineering,
[2] Associate Professor, [3]Professor, Department of Mechanical Engineering. Malnad College of Engineering,
Hassan. Visvesvaraya Technological University, Belagavi, Karnataka, India.
Email ID: by@mcehassan.ac.in Ph.No.+919844102636

Abstract— In the present scenario development of suitable processing techniques for polymer matrix composites is one of the major challenges with respect to the energy efficient criterion of natural and synthetic fibers with the compatibilization of reinforcements in a matrix polymer. Over the last decade, intensive research and development has been carried out in order to establish suitable processing techniques for the fabrication of high performance polymer matrix composites. This article highlights the brief overview on classifications, properties, applications and various techniques adapted to manufacture polymer matrix composites.

Keywords—Processing technique, Polymer Matrix Composites (PMCs), fiber, reinforcement.

INTRODUCTION

Materials have become a symbol of the progress of human civilization, and have become milestones for dividing eras of human history [1]. The relative importance of the structural materials most commonly used, i.e. metals, polymers, composites, and ceramics, to various societies throughout history has fluctuated. Ashby M.F. [2] presents a chronological variation of the relative importance of each group from 10,000 B.C. and extrapolates their importance through the year 2020. The information contained in Ashby's article has been partially reproduced in Figure 1. With the enlargement of modern industry, the production of light materials with high strength is required for our day-to-day applications [3, 4]. For some applications composite materials are considered to be more suitable than conventional materials as they have desirable mechanical, thermal and wear properties. [5-7]. Polymer matrix composite material is the one that uses organic polymer as matrix and fiber as reinforcement. Strength and modulus of fiber are much higher than the matrix material normally. PMCs are very popular due to their low cost and simple fabrication methods [8]. In this paper an attempt is made to through light on various techniques adopted by researches across the globe to manufacture PMCs.

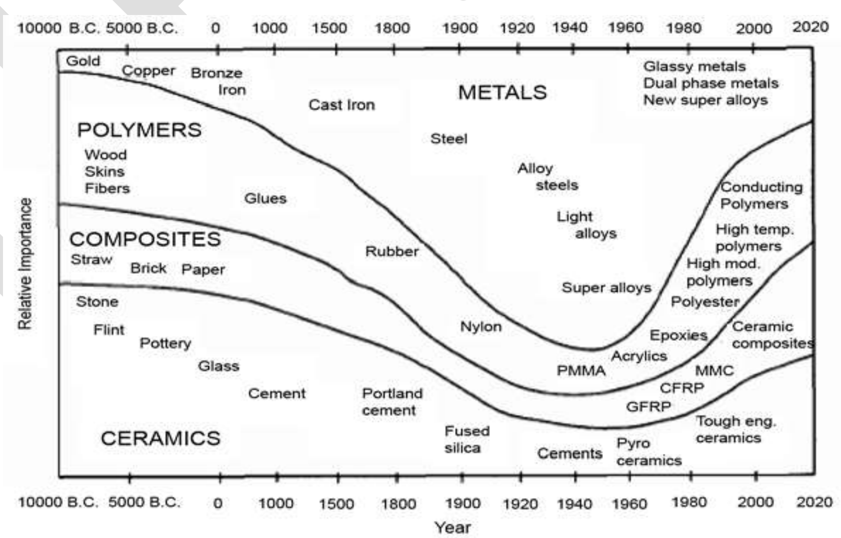

Fig. 1. Relative importance of material development through history.

OVERVIEW ON PMCs

The classification of polymer materials is very large and these materials can be grouped into: thermoplastic and thermosetting materials (polyethylene, polypropylene, polyvinyl chloride, polystyrene, phenolics, polyester etc.); elastomers (natural rubber, butadiene styrene, silicone etc.); polymeric fibers (fabric polymeric fibers, aramid fibers); coating materials (paints, lacquers, enamels etc.); adhesives (polymeric adhesives, natural-glu adhesive, casein, rosin); films (polypropylene, polyethylene, cellophane, cellulose acetate films); sponge or foam (polyurethane, rubber, polystyrene, sponge polyvinyl chloride) [9] [19] [20].

The properties of the PMC depend on the matrix, the reinforcement, and the interphase. Consequently, there are many variables to consider when designing a PMC. These include not only the types of matrix and reinforcement but also their relative proportions, the geometry of the reinforcement, and the nature of the interphase. Each of these variables must be carefully controlled to produce a structural material optimized for the conditions for which it is to be used [10]. Some of the typically properties exhibited by PMCs are high strength at low weight ; ability to tailor properties to meet wide-ranging performance specifications; moulding to close dimensional tolerances, with their retention under in-service conditions ;good impact, compression, fatigue and electrical properties; ability to markedly reduce part assembly; excellent environmental resistance; ability to fabricate massive one-piece mouldings; low-to-moderate tooling costs; cost-effective manufacturing processes; ability to build in, ex-mould, both colour and texture; excellent chemical and corrosion resistance.

PROCESSING TECHNIQUES FOR PMCs

The basic steps for processing of PMCs include:
1) Impregnation of the fiber with the resin,
2) Forming of the structure,
3) Curing (thermoset matrices) or thermal processing (thermoplastic matrices), and
4) Finishing.

Commonly used processing techniques of polymer-based composites are described in table 1.

Table 1. Processing Techniques for Polymer Composites

Technique	Type of polymer composite processed/manufactured
Resin transfer molding	sisal fiber reinforced polyester composites [12]
	carbon fiber reinforced composites [13]
	phenoxy nanocomposite[14]
	carbon nanotubes reinforced glass fiber epoxy composites[15]
	benzoxazine– epoxy blend [16]
	carbon fabric hybrid multiscale composites [17]
	plain woven carbon fiber reinforced plastics[18]
Injection molding	hybrid composites of jute and man-made cellulose fibers with polypropylene[21]
	cellulosic fiber composite foams [22]
	sisal-glass fiber hybrid biocomposites[23]
	cellulose fiber-reinforced polylactide (PLA) composites [24]
	glass fiber reinforced mixed plastics composites[25]
	polypropylene single-polymer composites with sandwiched woven fabric [26]
	carbon nanotube filled polymer [27]
	polypropylene single-polymer composites [28]
	crayfish protein-PCL biocomposite material [29]
	cork-polymer composites[30]
	polypropylene-based cork–polymer composites [41]
Extrusion	cellulose fiber reinforced composites [32]
	polycaprolactone/multi-walled carbon nanotube composites [35]
	polyethylene/short glass fiber composites [36]
	kenaf fiber/high-density polyethylene (HDPE) composites[38]
	sugarcane bagasse cellulose/HDPE composites [39]
	polypropylene/polyamide-6 composites [40]
	polypropylene-based cork–polymer composites [41]
	functionalized cork-polymer composites [42]

Pultrusion	chemically modified soy-based epoxy resins [31]
	thermoplastic composites[33]
	natural fiber reinforced composites [34]
	a foam/glass fiber reinforced polymer (GFRP) sandwich panel [37]
	glass/UV cured polyester composites [43]
	carbon reinforced polypropylene (CF/PP) pre-impregnated materials [44]
	glass reinforced polypropylene (GF/PP) towpregs [44]
Compression molding	sugarcane bagasse cellulose/HDPE composites [39]
	polypropylene-based cork–polymer composites[41]
	multiscale carbon fiber/epoxy composites[45]
	carbon/PEEK Randomly-Oriented Strands composites [55]
	bioresorbable phosphate glass fiber reinforced composites [56]
Filament winding	E-glass fiber epoxy tubes [46]
	liquid-like multiwalled carbon nanotube (MWCNT) reinforced composites[47]
	glass fiber reinforced polymer and Carbon fiber reinforced polymer composite tubes [48]
	kevlar fiber monofilament/epoxy composite [49]
	epoxy matrix for T800 carbon fiber [50]
Prepreg tape lay-up	carbon fiber/Triple-A polyimide composites [51]
	glass fiber/polypropylene composite laminates [52]
	glass / carbon fiber reinforced thermoset polymer [53] [54] [59]

APPLICATIONS OF PMCs

Just as with most new materials, the development of high performance polymer composites has driven by military and later aerospace, marine, automotive and many more. PMCs are used for manufacturing;

i) Aerospace structures: The military aircraft industry has mainly led the use of polymer composites. In commercial airlines, the use of composites is gradually increasing. Space shuttle and satellite systems use graphite/ epoxy for many structural parts.

ii) Marine: Boat bodies, canoes, kayaks, and so on.

iii) Automotive: Body panels, leaf springs, drive shaft, bumpers, doors, racing car bodies, and so on.

iv) Sports goods: Golf clubs, skis, fishing rods, tennis rackets, and so on.

v) Bulletproof vests and other armor parts.

vi) Chemical storage tanks, pressure vessels, piping, pump body, valves, and so on.

vii) Biomedical applications: Medical implants, orthopedic devices, X-ray tables.

viii) Bridges made of polymer composite materials are gaining wide acceptance due to their lower weight, corrosion resistance, longer life cycle, and limited earthquake damage.

ix) Electrical: Panels, housing, switchgear, insulators, and connectors [11] [57], and many more.

CONCLUSION

The more efficient processing methods for manufacturing PMCs are important in order to obtain more commercially viable products. Further the researchers are introducing and investigating a hybrid processes (merging manufacturing technologies into a single continuous process) as an efficient solution for shortening process chains and improving performance of processed materials [58]. The merging manufacturing technologies to process composite materials will have to face a lot of changes within the next decades and it certainly will remain as an interesting field of activity.

REFERENCES:

[1] Wang, R. M., Zheng, S. R., & Zheng, Y. G. (2011). Polymer matrix composites and technology. Elsevier.

[2] Ashby M. F. (1987). Philosophical Transactions of the Royal Society of London, A322: 393.

[3] Emamy, M., Khorshidi, R., & Raouf, A. H. (2011). The influence of pure Na on the microstructure and tensile properties of Al-Mg 2 Si metal matrix composite. Materials Science and Engineering: A, 528(13), 4337-4342.
[4] Kaneko, S., Murakami, K., & Sakai, T. (2009). Effect of the extrusion conditions on microstructure evolution of the extruded Al–Mg–Si–Cu alloy rods. Materials Science and Engineering: A, 500(1), 8-15.
[5] Lloyd, D. J. (1994). Particle reinforced aluminium and magnesium matrix composites. International Materials Reviews, 39(1), 1-23.
[6] Kaczmar, J. W., Pietrzak, K., & Włosiński, W. (2000). The production and application of metal matrix composite materials. Journal of Materials Processing Technology, 106(1), 58-67.
[7] Chapman, T. R., Niesz, D. E., Fox, R. T., & Fawcett, T. (1999). Wear-resistant aluminum–boron–carbide cermets for automotive brake applications.Wear, 236(1), 81-87.
[8] Sabu Thomas, Kuruvilla Joseph, Sant Kumar Malhotra, Koichi Goda, and Meyyarappallil Sadasivan Sreekala (2012), Introduction to Polymer Composites, Wiley-VCH Verlag GmbH & Co. KGaA.
[9] Florea, R. M., & Carcea, I. (2012). POLYMER MATRIX COMPOSITES–ROUTES AND PROPERTIES. Int. J. of Modern Manufact. Technol, 59-65.
[10] U.S. Congress, Office of Technology Assessment, Advanced Materials by Design, OTAE-351 (Washington, DC: U.S. Government Printing Office, June 1988).
[11] Lekakou, C. and Bader, M.G. (1999) Composites Part A, 29, 29–37.
[12] Sreekumar, P. A., Saiter, J. M., Joseph, K., Unnikrishnan, G., & Thomas, S. (2012). Electrical properties of short sisal fiber reinforced polyester composites fabricated by resin transfer molding. Composites Part A: Applied Science and Manufacturing, 43(3), 507-511.
[13] Van Velthem, P., Ballout, W., Daoust, D., Sclavons, M., Cordenier, F., Henry, E., ... & Bailly, C. (2015). Influence of thermoplastic diffusion on morphology gradient and on delamination toughness of RTM-manufactured composites. Composites Part A: Applied Science and Manufacturing, 72, 175-183.
[14] Van Velthem, P., Ballout, W., Dumont, D., Daoust, D., Sclavons, M., Cordenier, F., ... & Bailly, C. (2015). Phenoxy nanocomposite carriers for delivery of nanofillers in epoxy matrix for resin transfer molding (RTM)-manufactured composites. Composites Part A: Applied Science and Manufacturing, 76, 82-91.
[15] Garg, M., Sharma, S., & Mehta, R. (2015). Pristine and amino functionalized carbon nanotubes reinforced glass fiber epoxy composites. Composites Part A: Applied Science and Manufacturing, 76, 92-101.
[16] Lo, J., Anders, M., Centea, T., & Nutt, S. R. (2016). The effect of process parameters on volatile release for a benzoxazine–epoxy RTM resin.Composites Part A: Applied Science and Manufacturing, 84, 326-335.
[17] Wang, B. C., Zhou, X., & Ma, K. M. (2013). Fabrication and properties of CNTs/carbon fabric hybrid multiscale composites processed via resin transfer molding technique. Composites Part B: Engineering, 46, 123-129.
[18] Kobayashi, S., & Kitagawa, J. (2016). Effect of fine particle incorporation into matrix on mechanical properties of plain woven carbon fiber reinforced plastics fabricated with vacuum assisted resin transfer molding. Composites Part B: Engineering, 85, 31-40.
[19] M R Sanjay, Arpitha G R, B Yogesha (2015) Study on Mechanical Properties of Natural - Glass Fibre Reinforced Polymer Hybrid Composites: A Review" Elsevier, Materials Today: Proceedings, Vol. 2, Issues 4-5, pp. 2959-2967.
[20] Arpitha G R , Sanjay M R , B Yogesha, "Review on Comparative Evaluation of Fiber Reinforced Polymer Matrix Composites. Carbon 4000, 30, 2014.
[21] Khan, M. A., Ganster, J., & Fink, H. P. (2009). Hybrid composites of jute and man-made cellulose fibers with polypropylene by injection moulding.Composites Part A: Applied Science and Manufacturing, 40(6), 846-851.
[22] Ding, W., Jahani, D., Chang, E., Alemdar, A., Park, C. B., & Sain, M. (2015). Development of PLA/cellulosic fiber composite foams using injection molding: Crystallization and foaming behaviors. Composites Part A: Applied Science and Manufacturing.
[23] KC, B., Faruk, O., Agnelli, J. A. M., Leao, A. L., Tjong, J., & Sain, M. (2015). Sisal-glass fiber hybrid biocomposite: Optimization of injection molding parameters using Taguchi method for reducing shrinkage. Composites Part A: Applied Science and Manufacturing.
[24] Graupner, N., Ziegmann, G., Wilde, F., Beckmann, F., & Müssig, J. (2016). Procedural influences on compression and injection moulded cellulose fiber-reinforced polylactide (PLA) composites: Influence of fiber loading, fiber length, fiber orientation and voids. Composites Part A: Applied Science and Manufacturing, 81, 158-171.
[25] Bajracharya, R. M., Manalo, A. C., Karunasena, W., & Lau, K. T. (2016). Experimental and theoretical studies on the properties of injection moulded glass fiber reinforced mixed plastics composites. Composites Part A: Applied Science and Manufacturing, 84, 393-405.

[26] Wang, J., Wang, S., & Chen, D. (2015). Development and characterization of insert injection moulded polypropylene single-polymer composites with sandwiched woven fabric. Composites Science and Technology, 117, 18-25.
[27] Tiusanen, J., Vlasveld, D., & Vuorinen, J. (2012). Review on the effects of injection moulding parameters on the electrical resistivity of carbon nanotube filled polymer parts. Composites Science and Technology, 72(14), 1741-1752.
[28] Mao, Q., Hong, Y., Wyatt, T. P., Chen, J., Wang, Y., Wang, J., & Yao, D. (2015). Insert injection molding of polypropylene single-polymer composites.Composites Science and Technology, 106, 47-54.
[29] Félix, M., Romero, A., Martín-Alfonso, J. E., & Guerrero, A. (2015). Development of crayfish protein-PCL biocomposite material processed by injection moulding. Composites Part B: Engineering, 78, 291-297.
[30] da Silva, S. P. M., Lima, P. S., & Oliveira, J. M. (2016). Rheological behaviour of cork-polymer composites for injection moulding. Composites Part B: Engineering.
[31] Zhu, J., Chandrashekhara, K., Flanigan, V., & Kapila, S. (2004). Manufacturing and mechanical properties of soy-based composites using pultrusion. Composites Part A: Applied Science and Manufacturing, 35(1), 95-101.
[32] González-Sánchez, C., & González-Quesada, M. (2015). Novel automated method for evaluating the morphological changes of cellulose fibers during extrusion-compounding of plastic–matrix composites. Composites Part A: Applied Science and Manufacturing, 69, 1-9.
[33] Babeau, A., Comas-Cardona, S., Binetruy, C., & Orange, G. (2015). Modeling of heat transfer and unsaturated flow in woven fiber reinforcements during direct injection-pultrusion process of thermoplastic composites.Composites Part A: Applied Science and Manufacturing, 77, 310-318.
[34] Van de Velde, K., & Kiekens, P. (2001). Thermoplastic pultrusion of natural fiber reinforced composites. Composite structures, 54(2), 355-360.
[35] Villmow, T., Kretzschmar, B., & Pötschke, P. (2010). Influence of screw configuration, residence time, and specific mechanical energy in twin-screw extrusion of polycaprolactone/multi-walled carbon nanotube composites.Composites Science and Technology, 70(14), 2045-2055.
[36] He, G., Li, J., Zhang, F., Wang, C., & Guo, S. (2014). Effect of multistage tensile extrusion induced fiber orientation on fracture characteristics of high density polyethylene/short glass fiber composites. Composites Science and Technology, 100, 1-9.
[37] Joshi SC, Chen X. Time-variant simulation of multi-material thermal pultrusion. Appl Compos Mater 2010;18:283–96.
[38] Salleh, F. M., Hassan, A., Yahya, R., & Azzahari, A. D. (2014). Effects of extrusion temperature on the rheological, dynamic mechanical and tensile properties of kenaf fiber/HDPE composites. Composites Part B: Engineering,58, 259-266.
[39] Mulinari DR, Voorwald HJC, Cioffi MOH, da Silva MLCP, da Cruz TG, Saron C. Sugarcane bagasse cellulose/HDPE composites obtained by extrusion. Compos Sci Technol 2009;69(2):214–9.
[40] Potente H, Krawinkel S, Bastian M, Stephan M, Pötschke P. Investigation of the melting behavior and morphology development of polymer blends in the melting zone of twin-screw extruders. J Appl Polym Sci 2001;82(8):1986–2002.
[41] Fernandes, E. M., Correlo, V. M., Mano, J. F., & Reis, R. L. (2014). Polypropylene-based cork–polymer composites: Processing parameters and properties. Composites Part B: Engineering, 66, 210-223.
[42] Fernandes, E. M., Aroso, I. M., Mano, J. F., Covas, J. A., & Reis, R. L. (2014). Functionalized cork-polymer composites (CPC) by reactive extrusion using suberin and lignin from cork as coupling agents. Composites Part B: Engineering, 67, 371-380.
[43] Tena, I., Sarrionandia, M., Torre, J., & Aurrekoetxea, J. (2016). The effect of process parameters on ultraviolet cured out of die bent pultrusion process.Composites Part B: Engineering, 89, 9-17.
[44] Novo, P. J., Silva, J. F., Nunes, J. P., & Marques, A. T. (2016). Pultrusion of fiber reinforced thermoplastic pre-impregnated materials. Composites Part B: Engineering.
[45] Zhang, R. L., Gao, B., Du, W. T., Zhang, J., Cui, H. Z., Liu, L., ... & Li, F. H. (2016). Enhanced mechanical properties of multiscale carbon fiber/epoxy composites by fiber surface treatment with graphene oxide/polyhedral oligomeric silsesquioxane. Composites Part A: Applied Science and Manufacturing, 84, 455-463.
[46] Martins, L. A. L., Bastian, F. L., & Netto, T. A. (2013). The effect of stress ratio on the fracture morphology of filament wound composite tubes. Materials & Design, 49, 471-484.
[47] Zhang, Q., Wu, J., Gao, L., Liu, T., Zhong, W., Sui, G., & Yang, X. (2016). Influence of a liquid-like MWCNT reinforcement on interfacial and mechanical properties of carbon fiber filament winding composites. Polymer, 90, 193-203.
[48] Perillo, G., Vacher, R., Grytten, F., Sørbø, S., & Delhaye, V. (2014). Material characterisation and failure envelope evaluation of filament wound GFRP and CFRP composite tubes. Polymer Testing, 40, 54-62.
[49] Li, G., Zhang, C., Wang, Y., Li, P., Yu, Y., Jia, X., ... & Ryu, S. (2008). Interface correlation and toughness matching of phosphoric acid functionalized Kevlar fiber and epoxy matrix for filament winding composites.Composites Science and Technology, 68(15), 3208-3214.

[50] Chen, W., Yu, Y., Li, P., Wang, C., Zhou, T., & Yang, X. (2007). Effect of new epoxy matrix for T800 carbon fiber/epoxy filament wound composites.Composites Science and Technology, 67(11), 2261-2270.

[51] Ogasawara, T., Ishida, Y., Yokota, R., Watanabe, T., Aoi, T., & Goto, J. (2007). Processing and properties of carbon fiber/Triple-A polyimide composites fabricated from imide oligomer dry prepreg. Composites Part A: Applied Science and Manufacturing, 38(5), 1296-1303.

[52] Alemi-Ardakani, M., Milani, A. S., Yannacopoulos, S., & Borazghi, H. (2015). A rapid approach for predication and discrete lay-up optimization of glass fiber/polypropylene composite laminates under impact. International Journal of Impact Engineering, 84, 134-144.

[53] Gangloff, J. J., Simacek, P., Sinha, S., & Advani, S. G. (2014). A process model for the compaction and saturation of partially impregnated thermoset prepreg tapes. Composites Part A: Applied Science and Manufacturing, 64, 234-244.

[54] Crossley, R. J., Schubel, P. J., & De Focatiis, D. S. (2013). Time–temperature equivalence in the tack and dynamic stiffness of polymer prepreg and its application to automated composites manufacturing. Composites Part A: Applied Science and Manufacturing, 52, 126-133.

[55] Picher-Martel, G. P., Levy, A., & Hubert, P. (2016). Compression moulding of Carbon/PEEK Randomly-Oriented Strands composites: A 2D Finite Element model to predict the squeeze flow behaviour. Composites Part A: Applied Science and Manufacturing, 81, 69-77.

[56] Betanzos, F. B., Gimeno-Fabra, M., Segal, J., Grant, D., & Ahmed, I. (2016). Cyclic pressure on compression-moulded bioresorbable phosphate glass fiber reinforced composites. Materials & Design, 100, 141-150.

[57] Sanjay, M.R., Arpitha, G.R., Naik, L.L., Gopalakrishna, K. and Yogesha, B. (2016). Applications of Natural Fibers and Its Composites: An Overview. Natural Resources, 7, 108-114.

[58] Landgrebe, D., Kräusel, V., Rautenstrauch, A., Albert, A., & Wertheim, R. (2016). Energy-efficiency in a Hybrid Process of Sheet Metal Forming and Polymer Injection Moulding. Procedia CIRP, 40, 109-114.58.

[59] G R Arpitha., Sanjay M R., & Yogesha B. Review on comparative evaluation of fiber reinforced polymer matrix composites. Carbon 2014;4000:30.