MANUFACTURING AFFORDABLE COMPOSITES USING SOLID EPOXY RESINS

Neptun Yousefi,[1,2] Henry A. Maples,[1,2] Thomas James[3] and Alexander Bismarck[1,2]

[1]Polymer and Composite Engineering (PaCE) Group, Institute of Materials Chemistry, Faculty of Chemistry, University of Vienna, Währinger Straße 42, A-1090 Vienna, Austrian
[2]Polymer and Composite Engineering (PaCE) Group, Department of Chemical Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK
[3]Formax, Cutters Close Industrial Estate, Narborough, Leicestershire, LE19 2FY, UK

Keywords: Laminate; carbon fibres; structural composites

Abstract

We have investigated the use of solid epoxy resins in composite manufacturing. Solid epoxy resins are mainly used as protective coatings e.g. in marine applications, and have had limited use as composite matrices. Solid epoxy formulations are typically much cheaper than liquid epoxy resins commonly used in composite production. The development of a novel manufacturing method with solid epoxies could therefore lower the overall cost of high performance composites.
Different resins were formulated by mixing solid epoxies, hardeners and accelerators at elevated temperatures. These mixtures were then ground into uncured, resin powders. The resin powders were applied directly onto carbon fibers, which were then heated, infused with the melted resin system and cured (curing times of <10 min were achieved by using accelerators). The laminates manufactured without accelerator had competitive mechanical properties (flexural modulus, 80 GPa; flexural strength, 1270 MPa) when compared against other high-performance composites. However, the addition of accelerator led to higher void content in the matrix, which affected the mechanical composite properties. In order to prevent a high void content flow media was successfully introduced into the process.

1. Introduction

The reduction of costs during manufacturing is attracting increased interest [1-3]. The range of low-cost composites could be large, however, in the past cost and feasibility have restricted their production. Present ways to reduce costs focus on automation of the manufacturing process [4-6]. Technologies such as Automated Tape Laying (ATL) and Automated Fibre Placement (AFP) are efficient and low-cost. These processes are used in the aerospace industry due to their advantages [7, 8]. An alternative could be Resin Transfer Moulding (RTM) [9], however, it is limited due to the high cost of the preforming stage.
Here we describe a method to lower the cost of composites by using solid epoxy formulations. In the past, solid epoxies have been used to manufacture composites [10-13]. It was possible to manufacture hierarchical composites, which contained carbon nanotubes by using a filament winding and compression moulding [10-13]. Continuous carbon fibres were pulled through a power suspension. This suspension contained solid epoxy resin powders loaded with carbon nanotubes. A more practical method of manufacturing composites is described in this work. No suspension bath is used, meaning no drying

step is required. The solid epoxy powder is dispersed over carbon fibre layers. The layers are then cured in a simple, low-cost press-claving step.

2. Experimental details

2.1. Materials

Huntsman (Duxford, UK) supplied the solid epoxy resin and powdered accelerator. The solid hardener was supplied by AlzChem (Trostberg, Germany). Unidriectional carbon fibre preforms were kindly provided by Formax (Narborough, UK). EpoxiCure 2 resin and hardener were purchased from Buehler (Düsseldorf, Germany), which were used for the preparation of the composite microsections.

2.2. Formulation of solid epoxy resins

The solid epoxy resin and hardener were weighted and pre-mixed in a sealed container. This mixture was blended at a temperature of 80°C for 5 min by kneading (Plastograph, Brabender, Duisburg, Germany), which was equipped with a mixing unit (W50EHT). The resins containing accelerator were prepared using a lower blending temperature in order to prevent pre-curing of the resins. The resins were milled into a powder and sieved to ensure a uniform particle size. In order to avoid unwanted curing of the solid epoxy resin it was stored at 4°C.

2.3 Differential Scanning Calorimetry analysis of resins

Differential Scanning Calorimetry (DSC, Discovery DSC, TA Instruments, Eschborn, Germany) was used to analyse the thermal properties of the uncured and cured resin. The samples were heated and cooled at 10°C/min in nitrogen atmosphere. All samples were heated from 0°C to 300°C, then cooled back to 0°C and re-heated to 300°C.

2.4 Manufacturing of composites

The surface of a hotplate was coated with release agent (Frekote 700-NC, Henkel, Germany). A polyimide release film placed above the coated area. This area was outlined with masking tape. Then three layer of resin coated fibres were prepared. The dispersion of the resin powder was performed by a vibrating nozzle. A CNC model-making machine (Stepcraft 420, Stepcraft GmbH, Iserlohn, Germany) was equipped with the vibrating nozzle, which was previously fabricated at the workshop of the University of Vienna. The first layer of this three carbon fibre layers was covered with the powdered resin on both sides and placed directly on the polyimide release film. The next two layer were only coated on one side and placed on top of each other. A second polyimide release film was placed on the three carbon fibre layers. In order to obtain a sealed vacuum, vacuum bagging film (Easy Composites, UK) was used. This film was pressed against the sealant tape. A valve and hosetail barb fitting (Easy Composites, UK) were attached to a vacuum pump (Composites Vacuum Pump, Easy Composites, UK) through the vacuum bag in order to degas. After applying vacuum, the hotplate was switched on and slowly heated to the curing temperature. At this temperature the sample was remaining for 8 h in case no accelerator was used. If accelerator was present in the matrix of the resin the sample remained 10 min at the curing temperature before the hotplate was switched off.

3. Results and Discussion

The neat epoxy resin had a glass transition temperature (Tg) of 37°C. The uncured Tg of the resin containing hardener remained constant, i.e. no pre-curing happened during the mixing process of the solid epoxy resin and hardener at a temperature of 80°C (Figure 1). At 150°C the curing onset can be observed as seen in the heating curve.

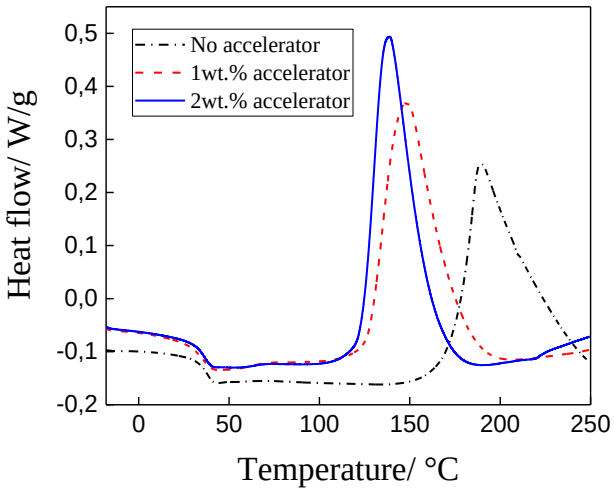

Figure 1. DSC curves of uncured resins containing 0wt.%, 1wt.% and 2wt.% accelerator.

Similar thermal properties were observed for the resins containing 1wt.% and 2wt.% accelerator. Resins containing accelerator had an uncured Tg of 35°C. At 125°C the onset of curing was observed. The early onset temperature was expected since the resin was containing accelerator.

4. Conclusions

A low-cost carbon fiber composite solid epoxy resin has been developed. The resin formulations were performed by mixing solid epoxy resin and hardener at a certain temperature. The addition of an accelerator reduced the curing time of the resins form 8h (without accelerator) to less than 10 mins (with 1 wt% accelerator). The carbon fibers were coated with the powdered resins using a printer. A low-cost and simple press-claving technique was used to cure the composites. Flexural properties of the manufactured composites without accelerator were competitive compared with composites manufactured with liquid epoxy resins. The flexural strength of the composites produced without accelerator were 1270 ± 127 MPa and flexural strength of those produced with accelerator were 1223 ± 3 MPa. The amount and the type of accelerator and the use of flow media made it possible to reduce the void content of the composites. Composites manufactured with this method will be more affordable and could be used for many applications.

Acknowledgments

We thank Innovate UK for funding this research through the ALPA (Affordable Lightweighting through Pre-form Automation) project.

References

[1] Schubel P.J. Cost modelling in polymer composite applications: Case study – Analysis of existing and automated manufacturing processes for a large wind turbine blade. Composites Part B: Engineering. Volume 43, Issue 3, 2012, 953–960.

[2] Shama Rao N., Simha T.G.A., Rao K.P., Ravi Kumar G.V.V., 2015. Carbon composites are becoming competitive and cost effective (white paper), Infosys.

[3] Khan LA., Mehmood AH, Cost-effective composites manufacturing processes for automotive applications. In: J. Njuguna, ed. 2016. Lightweight Composite Structures in Transport Design, Manufacturing, Analysis and Performance. Ch. 5, PP. 93–119.

[4] Mills, A. Automation of carbon fibre preform manufacture for affordable aerospace applications. Composites Part A: Applied Science and Manufacturing, 32(7)2001, 955–962.

[5] Wang S., Li Y., Xiang H., Zhou Z, Chang T., Zhu M. Low cost carbon fibers from bio-renewable Lignin/Poly(lactic acid) (PLA) blends. Composites Science and Technology, 119, 2015, 20–25.

[6] Ding R., Wu H., Thunga M., Bowler N., Kessler MR. Processing and characterization of low-cost electrospun carbon fibers from organosolv lignin/polyacrylonitrile blends. Carbon, 100, 2016, 126–136.

[7] Marsh, G., Automating aerospace composites production with fibre placement. Reinforced Plastics, 55, 2011, 32–37.

[8] Crosky, A., Grant C., Kelly D., Legrand X., Pearce G. Fibre placement processes for composites manufacture. In: 2015, Advances in Composites Manufacturing and Process Design Ch.4, PP. 79–92.

[9] 10.Jacob, A. BMW counts on carbon fibre for its Megacity Vehicle. Reinforced Plastics, 54, 2010, 38–41.

[10] T.M. Herceg, M.S.Z., Abidin, E.S. Greenhalgh, M.S.P. Shaffer, A. Bismarck. Thermosetting hierarchical composites with high carbon nanotube loadings: En route to high performance, Composites Science and Technology, 127, 2016, 134–141.

[11] Herceg T.M., Yoon S.H., Abidin M.S.Z., Greenhalgh E.S., Bismarck A., Shaffer M.S.P. Thermosetting nanocomposites with high carbon nanotube loadings processed by a scalable powder based method. Composites Science and Technology, 127, 2016, 62–70.

[12] Herceg T.M. Nano and hierarchical composites with high CNT loading fractions. Ph.D. Thesis. Imperial College London; 2013.

[13] Abidin M.S.Z. Development of Hierarchical Composites for Structural Applications. Ph.D. Thesis. Imperial College London; 2015.