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Mechanical and fracture performance of carbon fibre reinforced composites with nanoparticle modified matrices

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Abstract

The microstructure and fracture performance of carbon-fibre reinforced polymer (CFRP) composites with an epoxy resin cured with an anhydride hardener containing silica nanoparticles and/or polysiloxane core-shell rubber (CSR) particles were investigated in the current work. Double cantilever beam tests were performed in order to evaluate the fracture energy of the CFRP composites, while the single edge notched bend (SENB) specimen was employed to evaluate the fracture energy of the bulk polymers. Tests were conducted at room temperature and at -80°C. The transferability of the toughness from the bulk polymers to the fibre-composite systems is discussed, with an emphasis on the toughening mechanisms.

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Keywords: Composites; Epoxies; Nanoparticles; Toughness

1. Introduction

Epoxy polymers find use primarily as adhesives and as the polymer matrices of composite materials. They are amorphous and highly-crosslinked thermoset polymers. This means they are inherently brittle materials, although they possess many desirable engineering properties, such as a relatively high modulus and good high temperature creep resistance. This greatly limits their use as a structural material. The toughness of epoxy polymers has typically been improved by the addition of either soft rubbery particles (Rowe et al. 1970, Kinloch et al. 1983, Yee and

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Pearson 1986, Bagheri et al. 2009) or rigid inorganic particles (Kawaguchi and Pearson 2007, Park et al. 2005, Johnsen et al. 2007). Recently toughening of epoxy polymers has been reported on a range of other materials including block copolymers (Fine and Pascault 2006, Hydro and Pearson 2007, Chong and Taylor 2013), graphene (Chandrasekeran et al. 2014) and carbon nanotubes (Gojny et al. 2004, Hsieh et al. 2011). These new materials can confer added functionality to the epoxy polymer such as improved electrical and thermal properties.

The concept of hybrid toughening refers to the use of two or more toughening agents to try to achieve some synergistic effect in the toughness of the overall nanocomposites. Kinloch and co-workers (Kinloch et al. 1985, Young et al. 1986) produced some of the early work on hybrid toughening of an epoxy modified with CTBN rubber and glass microspheres. Since this early work there have been several other groups reporting on these systems, notably the group of Pearson (Liang and Pearson 2010, Marouf et al. 2009) and later work by the group of Kinloch and Taylor (Hsieh et al 2010, Chong and Taylor 2013, Carolan et al. 2016).

The present work investigates the effect of incorporating silica nanoparticles and/or CSR nanoparticles on the mechanical and fracture properties of an anhydride-cured epoxy polymer. The mechanical and fracture properties are measured both for the bulk polymer and also when used as the matrix for carbon-fibre reinforced polymer (CFRP) composites. The properties at room temperature and low temperatures are measured and the transferability of toughness from the bulk polymers to the fibre-composite materials is discussed with an emphasis on elucidating the toughening mechanisms.

2. Experimental

2.1 Materials

A standard diglycidylether of bis-phenol A (DGEBA) epoxy resin was used in the current work as the base resin for all of the polymer systems studied. The DGEBA resin, 'LY556' was obtained from Huntsman UK and had an epoxide equivalent weight (EEW) of 185 g/eq. To aid in the infusion of the carbon fibre mats, the base resin formulation was further altered by the addition of a reactive diluent, (1,6-hexanediol diglycidylether, DER 734, EEW = 160 g/eq) from Olin Epoxy, Germany. The addition of the reactive diluent lowers the viscosity of the resin allowing for much easier processing of the material. This resin was cured stoichiometrically with an anhydride curing agent, accelerated methylhexahydrophtalic acid, (Albidur HE600, EEW = 169 g/eq) from Evonik Hanse, Germany. The silica nanoparticles were obtained predispersed in DGEBA at 40 wt%, (Nanopox F400, Evonik Hanse, Germany). The CSR nanoparticles were also obtained predispersed in DGEBA resin at 40 wt%, (Albidur EP2240A, Evonik Hanse, Germany. To manufacture the bulk epoxy polymers the DGEBA epoxy resin was mixed with the resin containing the silica nanoparticles and/or the resin containing the CSR nanoparticles and the reactive diluent in a ratio to achieve the desired nanoparticle concentrations. The reactive diluent was added at a concentration of 25 phr of epoxy resin. This mixture was then thoroughly mixed mechanically at 60°C for 15 minutes followed by degassing in a vacuum oven at 60°C for a further 15 minutes. Following this, a stoichiometric amount of the curing agent was added and mixed and degassed following the procedure already described. The resin mixture was then poured into a pre-heated steel mould coated with a PTFE based release agent (Frekote 700-NC, Henkel, UK). The bulk polymer plates were cured at 90°C for one hour followed by a post cure for a further two hours at 120°C. Bulk specimens were then machined from these plates as required. To manufacture the composite laminates 10 layers of a biaxial textile fabric (Toray T700Sc 50C) provided by Saertex GmBH, Germany were laid up in ±45° configuration on a flat heated vacuum assisted resin infusion tool. The carbon fibre mat was then infused over a period of 8 minutes and subsequently cured under vacuum for 7 hours at 110°C with a post cure ex-vacuum for 13 hours at 120°C and 2 hours at 160°C.

2.2 Mechanical testing

Tensile tests were conducted on both the unmodified and nano-modified epoxy polymers to determine the tensile modulus in accordance with ISO 527-2 (1996). Dumbbell specimens with a gauge length of 30 mm were machined directly from 3 mm thick cast plates. A displacement rate of 1 mm/min was used and the tests were carried out both at room temperature (nominally 20°C) and -80°C. The strain was measured directly on the test specimen using a clip