Effects of EPON on Mechanical and Thermal Properties of Epoxy Resins

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Keywords: EPON, epoxy resin, flexural modulus, fracture toughness and glass transition temperature.

Abstract : Low cost composite materials are widely used in civil and structural engineering applications. This project uses EPON to plasticize a commonly used resin, epoxy resin to lower the cost of the composite and to find out the mechanical and thermal properties of the plasticized epoxy resin to see if it is suitable for the said applications. Three point bending tests were carried out to evaluate the flexural properties of the plasticized resins. Differential scanning calorimetry and dynamic mechanical thermal analysis are used to evaluate the thermal properties of the plasticized epoxy resin. The study with epoxy and EPON showed that the mechanical properties of the epoxy composite were lowered but its ability to dissipate energy increased because of its improved thermal properties. As EPON is much cheaper that epoxy resin, the composite produced is therefore cheaper and provided the service requirements were not so demanding, it can be used in the said applications.

Introduction

The emergence use of fibre composite materials and technologies in civil and structural engineering has created opportunities in the development of 'smarter' new polymers and polymer additives. The composite research centre of the University of Southern Queensland developed projects for creating new materials suitable for civil and structural engineering applications. One of the difficulties faced by the centre in using composites is the brittleness of thermosetting resins, even though the mechanical properties of these resin-based composites are good. This means that most civil engineering structures manufactured from thermosetting resin based composites are strain- rather than strength-limited. Consequently, a major focus of polymer research work was conducted at the centre to improve the toughness of thermosetting resins. There are many well-established techniques used to toughen these resins. These approaches are always cost-prohibitive for civil engineering composites. This study uses EPON to plasticize and reduce the brittleness as well as lowering the cost of the resins. Different percentage by weight of EPON was added to epoxy resin in steps of five percent.

Materials

The resin used is Hyrez 201, part 'A' of the centre-developed epoxy resin, Hyrez 202. It is a blend of different commercially available epoxy resins developed and mixed by the centre. It is a resin normally used for composite preparation. The hardener used was developed by the centre and is a blend of three hardeners. This results in a gel time and cost compatible with civil engineering applications. EPON is a plasticizer for epoxy resins.

Flexural and Fracture tests

Three point bending test will be used in this project. In this test, the area of uniform stress is quite small and concentrated on the centre loading point (Shackelford, 1992). The standard used is ISO 14125:1998(E) because the results can then be compared with the work of others. (ISO 14125, 1998). The centre uses a universal machine MTS Alliance RT/10 at 10kN couple with the software TESTWORK 4. The dimensions of the specimens of resins were 250mm x 10mm x 4mm and tested at a crosshead speed of 4 mm/min. Fracture tests were conducted at room temperature, in the three-point bending mode at a crosshead displacement rate of 4 mm/min, using the MTS alliance RT/10 mentioned above. The standard used for values of K_{IQ} is ISO 13586:2000 (ISO 13586, 2000). The linear elastic fracture mechanics (LEFM) approach, for single- edge-notch bending (SENB) geometry was employed to determine of fracture toughness because the resin used can readily meet the requirements for LEFM (Redjel, 1995).

Differential Scanning Calorimeter

This was used to monitor the cure kinetics. In all experiments, resin samples of approximately 20mg were used and were sealed into aluminium pans to prevent evaporation. Experiments were performed in standard mode by scanning the temperature of the samples at 10°C/min from 12°C to 250°C under nitrogen atmosphere.

Dynamic Mechanical Thermal Analysis

Dynamic mechanical thermal analysis (DMTA) is an important technique used to measure the thermal properties of elastomers. Polymeric materials, which are viscoelastic in nature, are subject to time, frequency and temperature effects on mechanical properties which can be analysed by this method. The dimensions of the samples used for analysis are 60 mm x 10 mm x 4 mm. The mode used here is 'dual cantilever'; the sample is clamped at both ends and flexed in the middle. For this study, the temperature change was 3°C per minute. While heating, the composite is deformed (oscillated) at constant amplitude (strain) with a fixed frequency of 1 Hz and the mechanical properties measured.

The basic properties obtained from a DMTA test include elastic modulus (or storage modulus, E'), viscous modulus (or loss modulus, E'') and damping coefficient (tan δ) as a function of temperature, frequency or time. Results are typically provided as a graphical plot of E', E'', and tan δ versus temperature. DMA identifies transition regions in plastics, such as the glass transition, and may be used for quality control or product development (Wikipedia, 2006). E', the storage modulus is the elastic component of the composite and related to the sample's stiffness. E'' is the loss modulus and is the viscous component of the material and is related to the sample's ability to dissipate mechanical energy through molecular motion. The ratio of the 2 modulus is equal to damping coefficient or tangent δ or loss tangent, indicating the ability of the material to dissipate energy and $\tan\delta = \frac{E''}{E'}$.

Results and discussions

Figure 3 illustrates the flexural strength of epoxy resin plasticized with varying percentage by weight of EPON. Also plotted on the figure is the flexural strength of epoxy resin plasticized with varying percentage by weight of CTBN obtained by other researcher (Raju et al., 2004).

The trend of the two graphs of flexural strengths was the same; the higher the percentage by weight of plasticizer, the lower the flexural strengths.

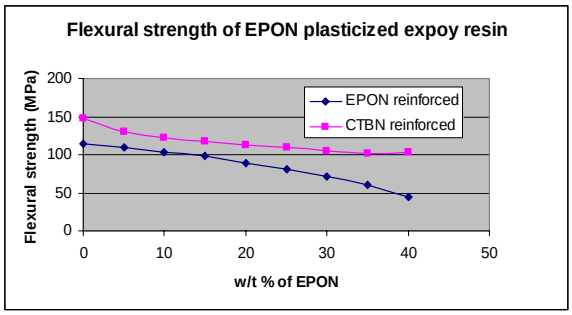

Figure 1: Flexural strength vs. percentage of EPON

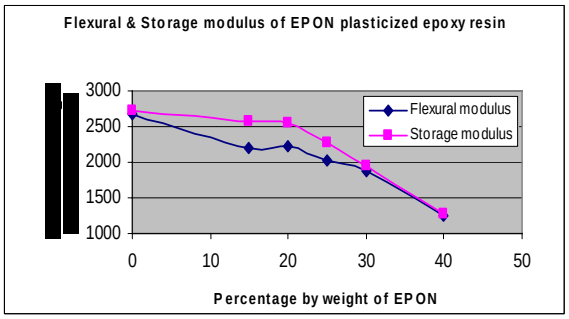

Figure 2: Flexural/Storage modulus vs. percentage of EPON

Figure 2 shows the flexural (static) modulus and storage (dynamic) modulus of epoxy resin plasticized with varying percentage by weight of EPON. Both values decreased with increasing percentage by weight of EPON. Figure 3 depicts the loss tangent of epoxy resin plasticized with varying percentage by weight of EPON. Tan δ is very low and increases slightly with increasing EPON proportion. This means the resin is very elastic and the viscous part of the dynamic modulus, mostly induced by the butadiene, stays very low.

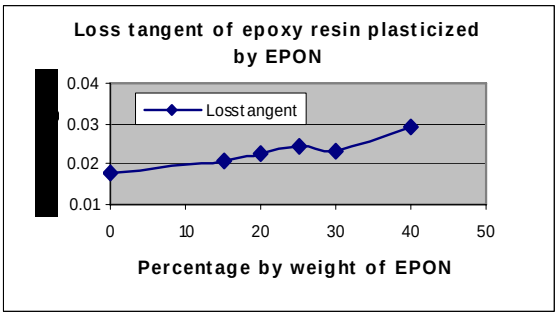

Figure 3: Loss tangent vs. percentage of EPON

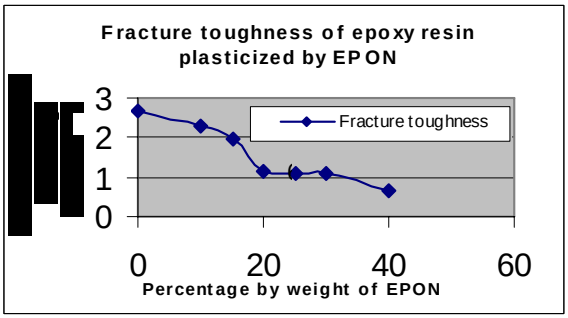

Figure 4: Fracture toughness vs. percentage of EPON

Figure 4 shows the fracture toughness (critical stress intensity) of epoxy resin plasticized with varying percentage by weight of EPON. The fracture toughness (K_{IC}) decreases and flattens from 20 to 30 wt % of EPON. It would have been caused by the transition from cohesive fracture mode to interfacial failure mode (falling from 10 to 15 wt %). The rubber particles did not cavitate in the specimens and a failure appeared at the interface between the resin and substrate (Kang et al., 2001). From these results, one can argue that EPON has plasticizing effect on the material because the fracture toughness decreases. The flattened portion observed from 20 to 30 wt % of EPON in Figure 4 could be explained by the change in morphology of the material. This maintains the fracture toughness value for a range of percentages by weight of EPON; after that fracture toughness decreases further. The flexural and storage modulus (Figure 2) of the epoxy resin plasticized with EPON dropped significantly after the 20 % by weight of EPON because there was a change of morphology at that percentage by weight of EPON. Both phenomena were indicated by the significant drop of T_g with 20% by weight of EPON as depicted in Figure 5, which shows the glass transition temperature (T_g) falls significantly after that percentage by weight of EPON. Raju et al. (2004) discovered that the change of morphology for CTBN plasticized epoxy resin took place at 15 % by weight of the plasticizer. It can therefore be argued that the change in morphology for EPON was not too far from CTBN.

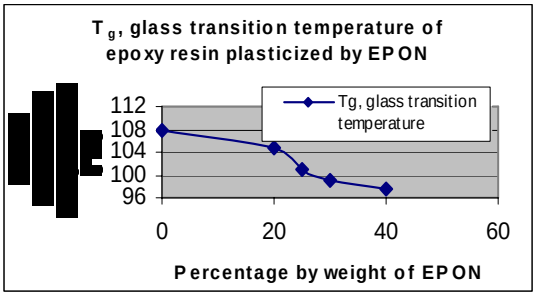

Figure 5: Tg vs. percentage of EPON

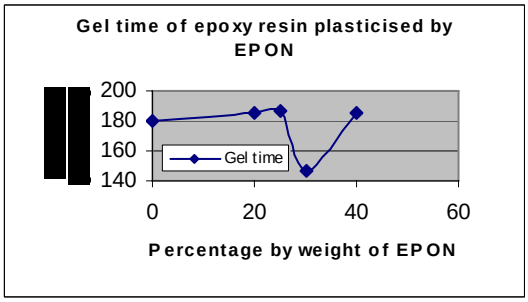

Figure 6: Gel time vs. percentage of EPON

Verdu (1993) discovered that T_g is a function of crosslinking density which increases when T_g increases. The DSC test used for resin crosslinking study shows that less curing energy is required at 20 wt % of EPON, which in this case speeds up the reaction. This effect takes place at 20 wt % of EPON, which confirms the change in morphology. Figure 6 shows the gel time of the epoxy resin plasticised with EPON. The values of the gel time are relatively constant except with 30 % by weight of EPON, in which the gel time was shortened by approximately 40 minutes or lowered by 20%. The experiments were done repeatedly but the results persisted.

Conclusion

Flexural (static) and storage (dynamic) modulus decrease with increasing EPON. The drop is very significant for over 20% of EPON. Fracture toughness decreases with increasing EPON but plateau from 20 – 30 % of EPON before dropping further with more percentages by weight of EPON. Both are due to the change in morphology of the material as indicated by the change in the glass transition temperature at 20% by weight of EPON. Therefore, EPON has successfully plasticized epoxy resin.

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