Effect of Nanoparticle in FRP Composites on Evaluation of Loading Rate Sensitivity

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Abstract: Alumina/epoxy nanocomposites were synthesized using 50 nm alumina nanoparticles. The resulting nanocomposites display a room temperature brittle-to-ductile transition in flexural test (3-point bend test) with an increase in the ILSS value with increase of loading speed. Formation of double layer at the interface region because of a common surface, which is created by molecular mobility (physico-chemical bond) of matrix affect the interfacial interaction zone. Nevertheless, the most striking result is that mirror, mist and hackle region observed in fractography analysis.

Key words: Polymer nanocomposites, loading rate, fractography, SEM

1. Introduction

Functionализation of nanoparticles with polymer chains opens new avenues in nanostructure materials and composites by tailoring the interactions of the nanoparticles with its constituents. Polymer nanocomposites incorporating alumina nanoparticles are a novel class of composite materials that are unique mechanical properties, while maintaining if not enhancing, the neat polymer properties. When designing polymer nanocomposites as structural materials for use, undergo different loading conditions such as static/quasi-static, creep, impact and fatigue [1]. Alumina/epoxy based polymer nanocomposites are widely used in aerospace applications, trigger to meet high durability conditions that conventional composite materials compete to meet [2]. Nanostructures constitute a bridge between molecules and infinite bulk systems. The physical and chemical properties of nanomaterial can differ significantly from those of the atomic-molecular or the bulk materials of the same composition. Jacob and co-workers [3, 4] explored the assessment of loading rate on the mechanical behavior of polymer composites. This is a summarization of the published work related to the effect of strain rate on tensile, shear, flexural properties of composite materials. The strain-rate sensitivity is less pronounced at higher conditioning time. It may be assumed that the failure mechanisms are loading rate sensitivity phenomenon [5]. Hence, in recent years introducing rigid nanofillers as alumina into epoxy resin to form polymer-matrix nanocomposites has become a popular method for improving mechanical properties of epoxy-based composites materials [6-10]. Zhao.Su. et al reported APTES-Al₂O₃/epoxy nanocomposites exhibits increase in fracture energy at 10-15 phr due because of good adhesion level. Debonding, plastic void growth and plastic deformation of matrix are the key reason of increase of fracture energy [11]. Current interest in alumina/epoxy nanocomposites has been generated and maintained because nanoparticles filled polymers exhibit unique combinations of properties not achievable with conventional composites. In the present study, glass fiber reinforced composites filled with alumina nanoparticle have been prepared. Alumina nanoparticle was well dispersed in epoxy polymer matrix to achieved high mechanical performance. The results show that it is possible to improve the interlaminar shear strength with the loading rate variations. Clearly, no follow-up work in this area will be commendation for better understanding of effect of nanoparticle in FRP composites in assessment of loading rate sensitivity.

2. Experimental Methods
2.1. Materials

Experiments were performed using alumina nanoparticles-epoxy based glass reinforced polymer nanocomposites. Alumina particles with an average size of 10μm and < 50 nm were purchased from Sigma Aldrich of was selected as the reinforcement materials. Experiments were performed using samples that had fabricated as per ASTM standard 2344-10 having dimensions 60x 40x4 mm³. Epoxy-alumina nanocomposites were prepared via magnetic stirrer and sonicator methods. 1hpr of alumina nanoparticles was added to epoxy at 70°C to reduce resin viscosity and then thoroughly stirred on a magnetic stirrer for 10 min followed by sonicating with sonicator to break any aggregates. The directionality of woven roving in GFRP composites was 0°/90°, and the fabric had plain weave architecture. After curing, the laminate was cut into the required size for 3-point bend (Short- Beam Shear) test by diamond cutter. Thirty six specimens were tested from two conditions panels with six loading speed (3 specimens each) for each test. The results were then compared with the data obtained from unconditioned specimens.

2.2. Mechanical Testing

The shear stress induced in a beam subjected to a bending load, is directly proportional to the magnitude of the applied load and independent of the span length. Thus the support span of the short beam shear specimen is kept short so that an inter-laminar shear failure occurs before a bending failure. The shear stress induced in a beam subjected to a bending load, is directly proportional to the magnitude of the applied load and independent of the span length. Thus the support span of the short beam shear specimen is kept short so that an inter-laminar shear failure occurs before a bending failure.

2.3. Micrograph Study

The specimens were focused in JEOL scanning electron microscope. At the best compromise between the tendency for the specimen to charge and to obtain optimum resolution, an accelerating voltage of 15KV was used for all micrographs. To enhance the contrast, which was particularly important for the relatively shallow topography of the basic longitudinal texture, the specimen normal had to be tilted away from the incident electron beam toward the collector by 20 to 25°. During experiments, various loading (striking) speed were performed i.e. (1, 10,100,200,500) mm/min. The alumina nanoparticles size has an effect on the loading rate sensitivity of the composites when this is dispersed around epoxy polymer matrix.

3. Results and Discussions

The relationship between the interlaminar shear strength and loading rate of glass epoxy/alumina fiber reinforced composites at room temperature is shown in Fig 1(a) and (b), where the change in stress-strain curve during both the experiments are plotted in Fig 2(a) and(b).
Fig 2 (a): Average stress-strain curves for the woven GFRP composite with nanoparticle

Fig 2(b): Average stress-strain curves for the woven GFRP composite without nanoparticles

The increase of ILSS value with loading speed observed in 1% alumina/epoxy glass fiber reinforced composites at room temperature. Indeed, the stress-strain curve of alumina/epoxy nanocomposites shows ductile behavior which increases with increase in loading speed. Nevertheless, the most striking result is that mirror, mist and hackle region observed in fractography analysis shown in Fig 3. The increase of percentage value of ILSS with loading rate of alumina epoxy nanocomposites in compared to epoxy glass fiber reinforced composites shown in Fig 1.

The improved in interlaminar shear strength (ILSS), which the nanocomposites exhibit, are due to the behavior of the interfacial interaction zone (IZ) which surrounds the nanoparticle [12, 13]. This is a region in which the structure and properties have been altered because of presence of filler material. Formation of double layer at the interface region because of a common surface, which is created by molecular mobility (physico-chemical bond) of matrix affect the interfacial interaction zone. Thus with the low volume fraction of filler, which may then affect the entire matrix due to their large surface to volume ratio, through an interaction zone. The dispersed nanofillers are able to improve the ILSS vale with the loading rate to maintain or even improve ductility because they are much smaller than the critical crack size of polymer matrix and need not initiate failure with no decrease of strain-to-failure value. The loading rate sensitivity of the polymer composites was appeared to be nonlinear and contradictory value at some point shown in Fig 1(b). This phenomenon may be attributed by, weak adhesion, fiber/matrix debonding and matrix cracking visualise in fractography result. It seems that greater the strain rate and the loading velocity, the greater the mechanical properties [14]. This mechanical behavior of composites depends on the ability to interface (region of stress concentration develops) to transfer stress from the matrix to the reinforcement fiber [15]. The mechanical behavior displayed by these nanocomposites is seen in the stress-strain curves presented in Fig 2 (a),(b). In this graph GFRP laminates at various loading rate at room temperature is compared with 1% alumina/epoxy nanocomposites that displays ductile behavior increases with loading rate. When sample loading with nanoparticles, there is a transition from brittle to ductile behavior is observed. And at other loading speeds that don’t behave ductile manner, because of pre-existing flaws or, inclusions which is the cause of damage and degradation of composite laminates [16].

The much rougher fracture surface with fine mirror, mist and hackle marking appear in the nanocomposites [16, 17, 18]. This is an example of morphology of brittle tensile failure at a microscopic level as shown in Fig 3(a).
This shows nanoparticles dispersed glass/epoxy composites which has been loaded in short beam shear test (flexural loading). Failure initiated at the central region near upper face of glass fiber. At the marked “O” point where small pin-head sized defect was located on the laminate surface. At the area immediately adjacent to this becomes flat means fracture behavior is flat. A slow movement of fracture surface observed in this region, it means enough energy for propagation of crack. As the crack extends the propagation of crack speed increases producing rugged fracture topography. This leads to formation of radial lines. These radial lines used to infer the crack growth direction (Fig 4). The movement from featureless region to rugged region is referred as mirror, mist and hackle development in the brittle matrix. This failure mode was observed at 1mm/min loading speed during the test. The relative proportions of this region are dependent on loading condition, environmental parameters and toughness of the matrix. The interfacial debonding observed in the mirror zone was not seen in the hackle zone.

4. Conclusion

Polymer nanocomposites were synthesized, fabricated and tested with different loading speed. When an interfacial interaction zone (IZ) exists between nanoparticles and polymer matrix at room temperature, the percentage increase of ILSS value with loading rate was obtained. Here the mode of yielding changing from brittle-to-ductile transition. Presence of mirror, mist and hackle region in the polymer matrix around the edge of glass fiber require both the understanding and integrity of composite material.

REFERENCES


