Flexural Properties of Glass and Graphite Particles Filled Polymer Composites

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Abstract

The effects of reinforcing polymers with glass and graphite particles on enhancing their flexural properties are investigated.

Five composites were fabricated using the same polymer matrix material with different volume fractions of reinforcement particles. They comprise glass particles and graphite particles each having volume fractions of 20% and 30% as well as a hybrid composite having 10% glass and 10% graphite.

Three-point bending tests using a Universal Testing Machine were carried out on specimens of the above mentioned composites, as well as specimens of the polymer matrix material to determine their flexural properties.

The experimental test results indicate that the flexural stiffness of all the composites were markedly higher than that of the matrix material.

As for the flexural strength, composites with 20% glass, 30% graphite and the hybrid composite maintained higher flexural strength than the matrix material.

Keywords: Polymer composites, Flexural properties, Glass and graphite particles

Introduction

A composite is basically a system composed of two or more different individual phases with distinctive characteristics. All composites have two basic components, the matrix or host, and the reinforcement or filler. The matrix is the element giving shape to the composite, and performs as a load transfer medium to the filler. The filler is designed to optimize selected mechanical properties of the composite [1].

The mechanical and physical properties of polymers can be significantly enhanced by adding various types of fiber or particle reinforcements.

Some of the primary advantages of composite materials are high strength to weight ratio, high bending stiffness, corrosion resistance, excellent fatigue characteristics (comparable to metals) and good thermal insulation properties [2].

Particle reinforced polymeric composite materials are being used increasingly in a variety of modern engineering applications and this trend is likely to continue due to the fact that these materials possess a number of highly desirable engineering properties that can be exploited to design structures with high demand on their performance. To cope with the obvious limitations of polymers, for example, low stiffness and low strength, and to expand their applications in different engineering areas, different types of particulate fillers are often added to process polymer composites, which normally combine the advantages of their constituent phases. Particulate fillers modify the mechanical and thermal properties of polymers in many ways [3-5].

Particle filled polymer composites have become attractive because of their wide applications and low cost. Incorporating inorganic mineral fillers into plastic resin improves various physical properties of the materials such as mechanical strength, modulus and heat deflection temperature [6].

The objective of this work is to investigate the flexural (bending) properties of polymer composites reinforced with glass and graphite particles. It involves studying the effect of volume fraction and type of reinforcement particles on the flexural strength, stiffness (modulus of elasticity) and failure strain of the composites as compared to the polymer matrix material.

The flexural strength (σ), flexural stiffness (E) and failure strain (ε) are calculated by the following relationships [7]:

where, P is the applied load, L is the span of the specimen, b is the width of specimen and h is the thickness of specimen.

where, is the slope of the initial linear portion of the load-deflection curve.

where, δ is the deflection at mid span of the specimen.

Materials and Methods

Materials

The matrix material used in this work is a thermoset epoxy resin type Conbextra Ep-10 supplied by Fosroc Chemicals Company [8]. It is characterized by its low viscosity which facilitates its mixing with reinforcement materials, low creep characteristics under sustained loading, resistance to repetitive dynamic loads, non-shrinkage which ensures complete surface contact and bond, resistance to a wide range of chemicals, high tensile, compressive and flexural strength.

The hardener used with this epoxy resin is Metaphenylene Diamine, which is a liquid material with low viscosity and transparent color. It is added to the resin in a ratio of 1:3 [9]. The reinforcement fillers used are glass and graphite particles.

Fume silica (Aerosil 200) supplied by Evonik Industries [10] was used to prevent the precipitation of the reinforcement particles. A small amount of this material (1% of total volume fraction) was added to the composite.

Specimen preparation

Hand lay-up molding was employed for fabricating the matrix material as well as the composites. The mold used in this work for casting process was made of galvanized steel with dimensions of (200, 80 and 4 mm).

The mold was cleaned and a sticker fablon was placed on the inside walls of the mold to prevent the sticking of the polymer material inside the mold.

The polymer matrix material was prepared by mixing the epoxy resin with the hardener in a 3:1 ratio at room temperature; a glass rod was used for gently stirring the mixture to avoid the formation of bubbles in the polymer. Then the mixture was poured into the mold. Finally, the mold was kept on a level plane and a galvanized steel cover plate was placed on top of the mold to ensure obtaining a constant thickness of material.

In addition to the polymer matrix material, five composite materials were prepared. Composites 1, 2, 3 and 4 contain 20% glass particles, 30% glass particles, 20% graphite particles and 30%

graphite particles respectively. While composite 5 is a hybrid which contains 10% glass particles and 10% graphite particles.

For preparing composite materials, the epoxy resin was mixed with the hardener and poured into the mold in the same procedure described above. Then, the reinforcement filler powder with the desired volume fraction was mixed with 1% fume silica and added to the epoxy resin and mixed in a similar manner.

All cast materials were left in the mold for 24 hrs at room temperature to complete their solidification. Then, the cast materials were removed from the mold and placed in an oven at 50°C for three hrs to perform curing [9].

Finally, the cast materials were cut into flexural specimens according to ASTM standards as shown in Fig.1 [7].

Instrumentations

A Universal Testing Machine Type Gunt WP300 was used for conducting flexural tests on specimens of the matrix material and the five composites. For each material 5 replicates were tested. The flexural test performed in this work is the three-point bending test in accordance with ASTM D-790 standard [7]. In this test, the specimen is simply supported on two cylindrical bars 100mm apart (span of specimen) and the load is applied at mid-span via a third cylindrical bar fitted to the Universal testing machine moving grip. Load is applied until failure of the specimen took place. The test rig also incorporates a data acquisition unit and a computer display of the load-deflection curve of each specimen tested. The test rig is shown in Fig.2.

Results and Discussion

The flexural test results of the matrix material and the five composites are presented in the form of stress-stain curves as shown in Fig.3. It is noted that the matrix material followed a ductile behavior to failure, with a formation of a definite "knee" in the curve indicating substantial yield, while all the composites followed a similar (almost identical) brittle behavior to failure. The initial linear elastic stress-strain curve is followed by a non-linear behavior prior to brittle failure. This is in agreement with results of previous investigations [11and12]. The onset of nonlinear deflection coincided with the formation of micro-porous zone (or crack) in the composite material. Brittle behavior of particulate composites is attributed to filler particles which act as stress concentrators [11].

The flexural modulus, ultimate flexural strength and failure strain of tested materials are presented in Table-1. It is noted that all composites possess markedly a higher modulus of elasticity than the matrix material. The increase in the modulus of elasticity of composites 1-5 as compared to the epoxy resin matrix material is 28%, 36%, 40%, 136% and 60% respectively.

These results imply that the enhancement in flexural modulus of elasticity of composites is a function of filler volume fraction and stiffness; it increases with the increase in filler volume fraction and its stiffness.

The effect of filler volume fraction is verified by comparing stiffness of composites reinforced with the same filler but with different volume fractions. The stiffness of composite 2 (30% glass) is higher than that of composite 1 (20% glass) by 6%, while the stiffness of composite 4 (30% graphite) is higher than that of composite 3 (20% graphite) by 68%.

As for the effect of filler stiffness on composite stiffness, it is observed that composites reinforced with the graphite particles have higher stiffness than those reinforced with equivalent volume fraction of glass particles, knowing that graphite is much stiffer than glass. The stiffness of composite 3 is higher than that of composite 1 by 9%, and the stiffness of composite 4 is higher than that of composite 2 by 84%.

Previous investigations [12-16] confirmed that the modulus of elasticity of particulate composites increases with the volume fraction of filler, because hard filler particles have much higher stiffness than the polymer matrix material, and also due to better surface area for interaction between the filler particles and the polymer matrix.

The effect of filler type and volume fraction on the flexural strength of composites is not as evident as it was for composite stiffness. The ultimate flexural strength of composites 1, 4 and 5 increased by 18, 6 and 58% respectively in comparison with the matrix material, while composites 2 and 3 suffered from reduction in flexural strength of 20 and 14% respectively.

Previous investigations [12-16] also reported that the ultimate strength of particle filled composites might be higher or lower than the polymer matrix material. In view of Fu et al [15]; the ultimate strength of a composite depends on the weakest fracture path throughout the material. Hard particles affect the strength in two ways. One is the weakening effect due to the stress concentration they cause, and another is the reinforcing effect since they may serve as barriers to crack growth. In some cases, the weakening effect is predominant and thus the composite strength is lower than the matrix; and in other cases, the reinforcing effect is more significant and then the composites will have strengths higher than the matrix. Prediction of the strength of composites is difficult. The difficulty arises because the strength of composites is determined by the fracture behaviors which are associated with the extreme values of such parameters as interface adhesion, stress concentration and defect size/spatial distributions. Thus, the load-bearing capacity of a particulate composite depends on the strength of the weakest path throughout the microstructure, rather than the statistically averaged values of the microstructure parameters [15].

As for failure strain, it was found that all composites have lower failure strain than the matrix material, and that the failure strain is inversely proportional to the filler volume fraction and filler stiffness. Similar results were reported by several investigators [12, 13 and 16]. Sreekanth et al [13] attribute the reduction of failure strain with the increase of filler content to the interference of filler in the mobility or deformability of the matrix. This interference is created through the physical interaction and immobilization of the polymer matrix by the presence of mechanical restraints, thereby reducing the elongation at break.

Review of flexural properties of all the composites subjected to flexural tests in this work, reveals that Composite5 which is a hybrid composite comprising 10% glass and 10% graphite offers the best flexural properties. The flexural stiffness and strength of this composite are 60% and 58% higher than those of the matrix material.

Conclusions

The flexural properties of polymer composites reinforced with glass and graphite particles have been evaluated. All composites have higher stiffness than the polymer matrix material. The stiffness of the composites is directly proportional to the volume fraction and stiffness of fillers.

The ultimate flexural strength of three of the composites is higher than that of polymer matrix material, while two composites have lower ultimate flexural strength than the polymer matrix material, irrelevant to volume fraction or type of fillers.

The failure strain of all composites is lower than that of the polymer matrix material; the failure strain is inversely proportional to the stiffness and volume fraction of fillers.

The hybrid composite reinforced with 10% glass particles and 10% graphite particles presents the best overall flexural properties. It has the highest ultimate flexural strength as well as an excellent stiffness and a strain to failure comparable to that of the polymer matrix material.

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Table(1): Flexural modulus, ultimate flexural strength and failure strain of tested materials

Failure strain (%)	Flexural strength (M Pa)	Flexural modulus (G Pa)	Material
1.2	25	2.5	Matrix material (epoxy resin)
1	29.5	3.2	Composite 1 (20 % glass)
0.65	20	3.4	Composite 2 (30 % glass)
0.75	21.4	3.5	Composite 3 (20 % graphite)
0.55	26.5	5.9	Composite 4 (30 % graphite)
1.1	39.6	4	Composite 5 (10 % glass and 10% graphite)

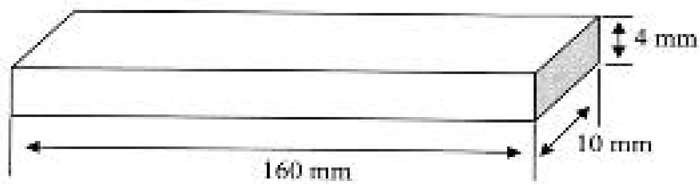

Fig.(1): Standard flexural test specimen

Fig.(2): Flexural test-rig with an exploded view of the matrix material test specimen under three-point bending load

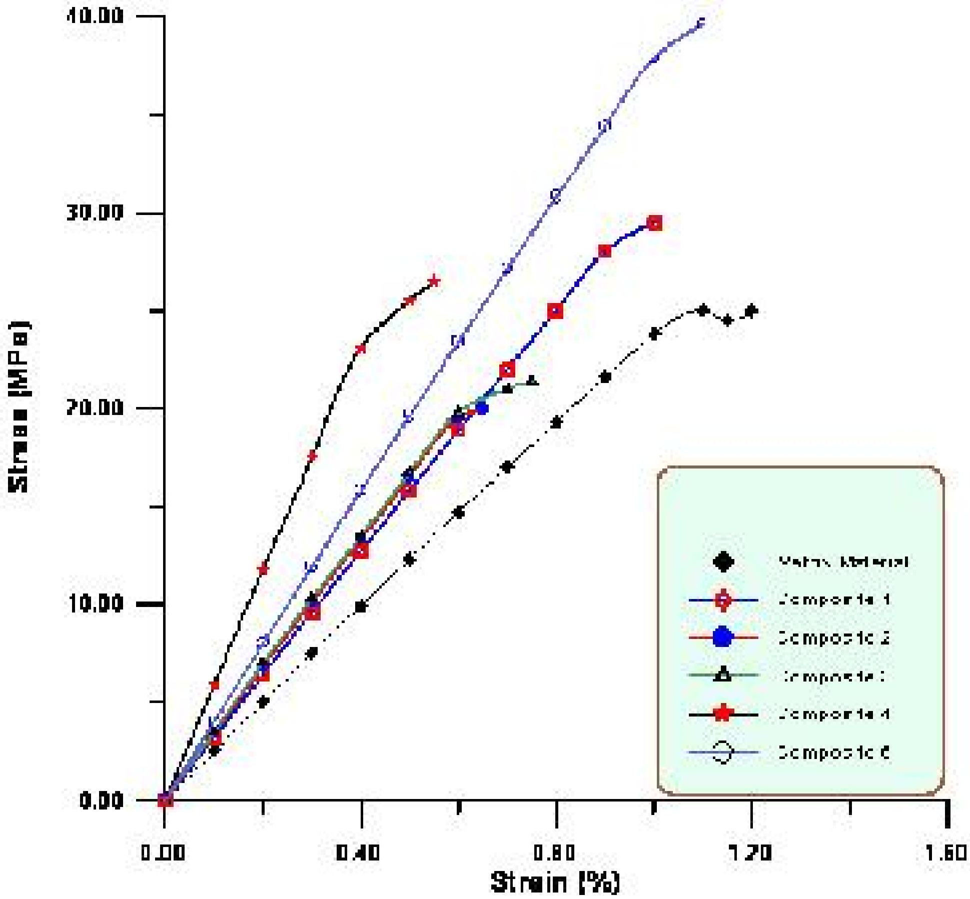

Fig.(3): Typical flexural stress-stain curves of tested materials

خواص الأنحناء لمواد مركبة بولميرية معززة بدقائق الزجاج والكرافيت

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الخلاصة

أجريت هذه الدراسة لمعرفة تأثيرتعزيز المواد البوليمرية بدقائق الزجاج والكرافيت في خواصها الأنحنائية.
حضرت خمسة مواد مركبة باستعمال المادة البوليمرية نفسها مادة أساس ومعززة بكسور حجمية مختلفة من دقائق المادة المالئة، وهي تشمل دقائق الزجاج ودقائق الكرافيت وبكسر حجمي مقداره 20% و30 % لكل منها فضلا" عن الى مادة مركبة هجينة تحتوي على 10% زجاج و 10% كرافيت.
أجريت أختبارات الأنحناء ذي النقاط الثلاث باستخدام جهاز أختبار جامع على عينات من المواد المذكورة أعلاه أضافة عن المادة المالئة لتحديد خواصها الأنحنائية.
أظهرت نتائج الأختبارات العملية أن جساءة الأنحناء لجميع المواد المركبة كانت أكبر بشكل ملحوظ من المادة الأساس.
أما بالنسبة الى متانة الأنحناء، فأن المواد المركبة ذات ال 20% زجاج وال 30% كرافيت والمادة المركبة الهجينة امتلكت متانة أنحناء أكبر من المادة الأساس.

كلمات مفتاحية: مواد مركبة بوليمرية، خواص انحناء، دقائق زجاج وكرافيت