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Manufacturing and Measuring Mechanical Properties of Continuous Functionally Graded Beam

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Abstract

In this study, glass-filled epoxy functionally graded material (FGM) was prepared by adopting the hand lay-up method. The vertical gravity casting was used to produce a continuous variation in elastic properties. A 30 % volume fraction of glass ingredients that have mean diameter 90 µm was spread in epoxy resin (ρ = 1050 kg/m^3). The mechanical properties of FGM were evaluated according to ASTM D638. Experimental results showed that a gradually relationship between Young's modulus and volume fraction of glass particles, where the value of Young's modulus at high concentration of glass particles was greater than that at low concentration, while the value of Poisson's ratio at high concentration of glass particles was lower than that at low concentration. The manufacture of this FG beam is particularly important and useful in order to benefit from it in the field of various fracture tests under dynamic or cyclic loads.

Keywords: Epoxy-Glass, Functionally Graded Composite, Hand lay-up, Vertical Gravity Casting, Tensile Test.

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1. Introduction

Recently a new generation of composite materials as known: functionally graded materials which have an essential position in the classification of the composite material. In the beginning of the development of the FGMs, the idea was eliminating the sharp interface between the constituents in conventional composite and replace it with a gradually one, which leads to changing in chemical composition in the interface region of this composite [1]. There are many important applications in several fields especially in aerospace, biomedical, energy, defense and many other applications [2]. There are two types of FGMs constituents' structures, that were can be manufactured as a continuous or step wise gradient [3]. Stabik et al. [4] presented the methods of producing polymeric FGMs such as gravity casting, fast discharge, selective laser sintering, pressing and UV photopolymerization. It was noted that the experience of polymer gradation materials constituents to evolve which could make new products with unique characteristics. Butcher et al. [5] produced a continuous glass-filed epoxy functionally graded composite. The structural gradation of the Young's modulus was measured by Ultrasonic technique. They showed that the elastic properties were a function of position. Rousseau et al. [6] fabricated a continuous FGM made of solid glass spheres filled epoxy resin. The spatial gradient occurs according to the variation in volume fraction of glass particles from 0 to 0.52. The elastic properties of FGMs were measured using Ultrasonic pulse-echo technique. Kirugulige et al. [7] prepared a FGM samples made of epoxy/glass composite by continuously variation the solid soda-lime particles volume fraction in the matrix. A 40 % volume fraction of glass was used and the Ultrasonic pulse-echo was employed to measure the FGM characteristics. Farouq et al. [8] investigated the mechanical properties of a stepwise functionally graded material. The hand lay-up method was adopted to produce a five layer of epoxy/glass composite with 40 % wt. of glass particles. Elastic properties of each layer then extracted according to ASTM D882-02. Siddhartha et al. [9] presented the fabrication of functionally graded composite made of epoxy and cement kiln dust with different percentage (0 % and 10 %) wt. cylindrical sample was produced by mechanical stirring method in glass tube (Ø 12 mm) diameter. The mechanical properties measured by using tensile test according to ASTM D 3039.76. Sigh and Siddharth [10] produced a FGM based on glass fibers and efficient polypropylene manufactured along a new production route. Polypropylene was used for producing FGMs and homogenous one filled with 15 % wt. of glass fiber. Gradation is also tested using ignition loss test. Liu et al. [11] determined the Young's modulus and glass transition temperature of step wise FGM. Polyurethane and epoxy were used as a constituent of the FGM with diaminodiphenyl methane (DDM) as a crosslinking agent. Huang et al. [12] used the tubular braided carbon fiber and epoxy resin to prepare an FGM. The FGM samples had distinct braiding angles and constant angles for non-FGM samples. The mechanical properties of FGM were obtained by tensile test according to ASTM D3039-95a. Seaglar and Rousseau [13] created a FGM made of virgin epoxy matrix reinforced with a 42 µm mean diameter glass particles. Ultrasonic wave speed was used to obtain the mechanical properties. In the absence of additional mixing, the glass spheres initially distributed evenly in the epoxy, dispersed gradually to the bottom side of the mold simultaneously with the thermosetting response processing. In this work producing a continuous FG beam made from epoxy resin reinforced with glass particles, where (30 %) volume fraction of glass powder was used. Elastic properties of the manufactured FGM will be extracted by implementing tensile test.

2. Experimental work

2.1. preparation of the mold

Fabricate an acrylic sheet to make 300 × 90 × 10 mm (length, width and thickness) mold as shown in Fig.1, that was used to produce an epoxy-glass FGM by adopting the gravity casting technique. A transparent acrylic sheet 4 mm thickness was cut out by using CNC laser cutting machine into six pieces, then assembly these pieces together to constructing the mold. To avoid sticking of the epoxy/glass sample into the mold; the release of compound was used to lubricate its inside surfaces. Universal Acetoxy silicon type SL-545 was applied to cover the joints of the mold from outside to prevent the leakage of the composite from the mold during the pouring.

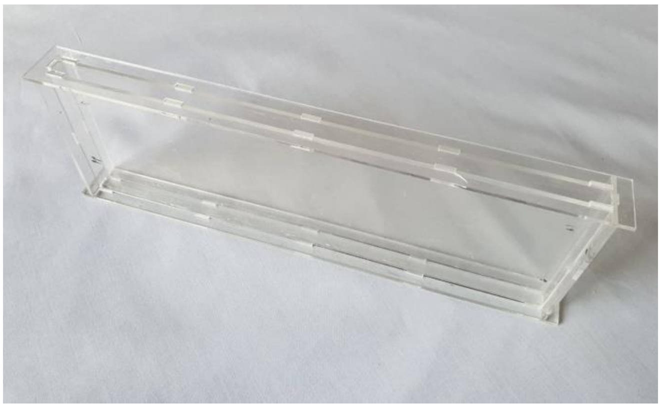


Fig. 1 assembling of the acrylic mold.

Hand lay-up was adopted for fabricating the composite materials, where all processes relate to this method was done by hand. There are many ways and materials that can be used in producing the molds: it can be made from metal, plastic, glass, wood and composite depending on the temperature of curing, pressure and the productivity. To avoid sticking the epoxy into the inside of the mold petroleum jelly was used as a release agent.

2.2. Preparation of the FGM

2.2.1 Rule of mixture and sample calculation

$$V_f = v_f / v_c \quad (1)$$

$$V_m = v_m / v_c \quad (2)$$

$$V_f + V_m = 1 \quad (3)$$

$$v_c = v_f + v_m \quad (4)$$

$$w_c = w_f + w_m \quad (5)$$

$$w_c = \rho_c \times v_c \quad (6)$$

$$w_f = \rho_f \times v_f \quad (7)$$

$$w_m = \rho_m \times v_m \quad (8)$$

$$\rho_c \times v_c = \rho_f \times v_f + \rho_m \times v_m \quad (9)$$

$$\rho_c = \rho_f \times V_f + \rho_m \times V_m \quad (10)$$

Where V_f , V_m : Volume fraction of reinforcement and matrix.

v_f , v_m , v_c : Volume of reinforcement, matrix and composite respectively.

ρ_f , ρ_m , ρ_c : Density of reinforcement, matrix and composite respectively.

w_f , w_m , w_c : Weight of reinforcement, matrix and composite respectively.

By considering a 30 % volume fraction of glass sphere, and using the above equations to calculate weights of the FGM constituents. Slow curing epoxy resin (ρ = 1050 kg/m^3) involves two-part base and hardener (1:2) mixing ratio. The base was mixed with the hardener and stirred for 40 min. At the same time, a mixture of epoxy/glass particles was prepared.

The glass powder then added slowly a little bit. Pour the pure epoxy resin first into the mold, and then leave it for 50 min. the epoxy/glass mixture was then poured into the mold and was enough to fill it. The mold was sealed, held in a vertical position for 10 min. and turn upside down again before being kept in an ambient temperature for more 10 min. dissociated the mold after 24 h and extract the FGM as shown in Fig. 2.

By using image-J software the percentage of glass particles were obtained in the FGM, where a 1.5 × 1 cm pieces were cut out from the FGM beam in the direction of gradient and tested under microscope. Table 1 illustrated the glass percentage in the FGM beam.

Fig. 3 clarifies the high and low glass continents in the FGM.

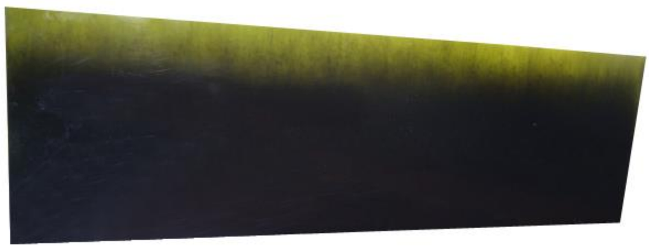
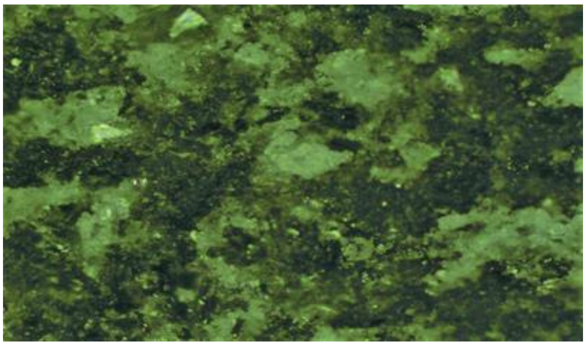


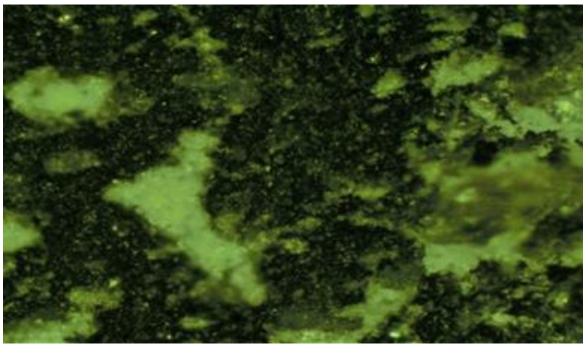
Fig. 2 Functionally graded material.

Table 1. volume fraction of glass particles.

Position	Volume fraction
15	0.02729
30	0.08551
45	0.11395
60	0.2132
75	0.2615
90	0.298



(a)



(b)

Fig. 3 Glass continent **(a)** high, **(b)** low.

2.3. Determining the elastic properties

2.3.1. Sample preparation

In the present study, standard FGM tensile test samples were machined from the functionally graded beam according to ASTM D638 to extract the elastic properties as shown in Fig. 4. Standard dog bone (dumbbell-shaped) type I was selected where the thickness of the specimen is 7 mm, the overall length is 165 mm, the gauge length is 57 mm, the width of the narrow side is 13 mm and the fillet radius is 76 mm.

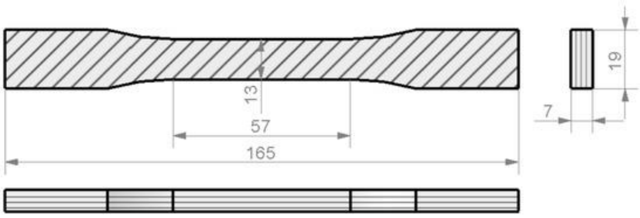


Fig. 4 Tensile test sample ASTM D638.

After manufacturing the FGM composite by the hand lay-up vertical gravity casting method, FGM specimen was cut into four equal pieces Fig. 5.

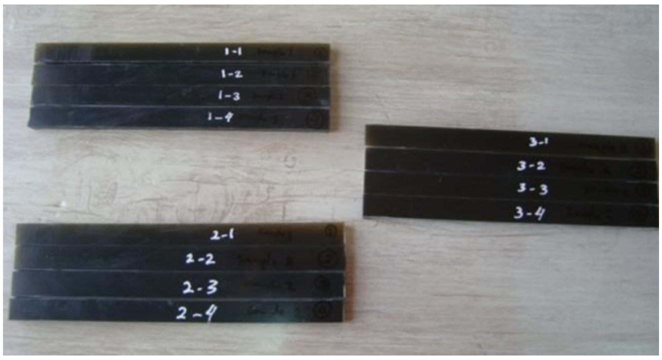


Fig. 5 Cutting the FGM into equal strips.

A standard tensile test samples were machined by a milling machine into the proper shape and dimensions to specify the code of testing plastic materials Fig. 6 and 7.

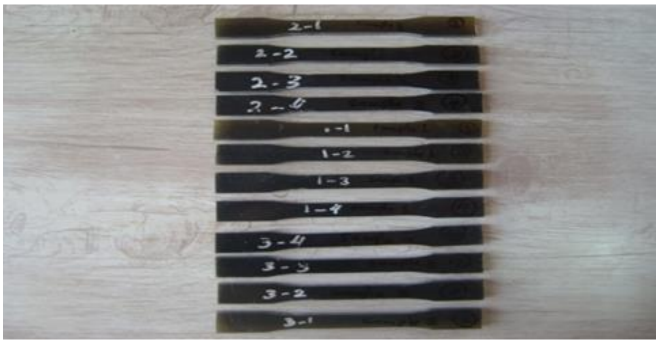


Fig. 6 Standard tensile test specimens.

Fig. 7 Pure epoxy samples.

2.3.2. Tensile test

The Young's modulus of the FGM was determined by performing tensile test. By using INSTRON device with test speed 5 mm per min. Fig. 8 shows the tensile testing machine, also the Poisson's ratio calculated by computing the lateral and longitudinal strain of the samples.

Fig. 8 Tensile testing machine.

3. Results and discussion

The stress strain curve was plotted for each sample separately Fig. 9. Then, curve processing to finding the tilted slope in the elastic deformation zone, which represents the elastic modulus of the material. Table 2 illustrated the values of Young's modulus for each sample.

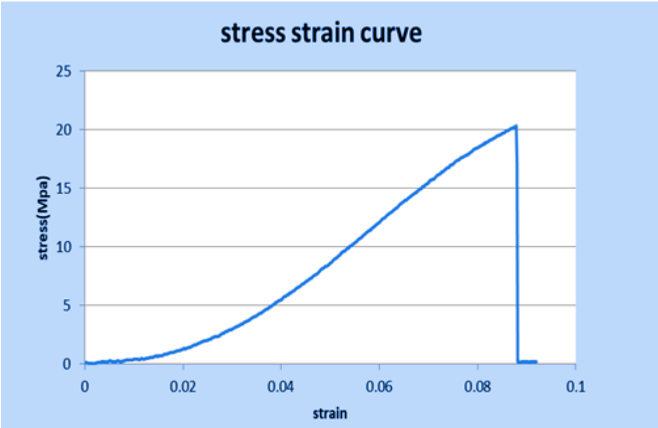


Fig. 9 Stress strain curve for FGM.

Table 2. Young's modulus of FGM samples.

Sample number	Young's modulus (MPa)
0 - 1	1153
0 - 2	1102.95
2 - 1	1107.3
3 - 1	1154
1 - 2	1772.2
2 - 2	1999
3 - 3	2231.8
2 - 3	2229.5
1 - 4	2921.8
3 - 4	2315.5

Fracture shape of tensile test specimen pointed that the fracture mode was brittle with right angle Fig.10. So, there was no clear yield point in the stress strain curve and the ultimate strength is the fracture strength.

Fig. 10 Mode of fracture.

By tacking the average of each two readings, elastic modulus and Poisson's ratio corresponding to the volume fraction of glass particles were illustrated in Table 3.

Table 3. Elastic properties of FG composite corresponding to the glass volume fraction.

Sample No.	Volume fraction	Young's modulus (MPa)	Poisson's ratio
1	0.0	1128	0.39
2	0.0272	1130	0.34
3	0.213	1885	0.32
4	0.261	2230	0.31
5	0.298	2618	0.3

The relationship between the elastic moduli and the reinforced particles as pointed in Fig. 11 and 12.

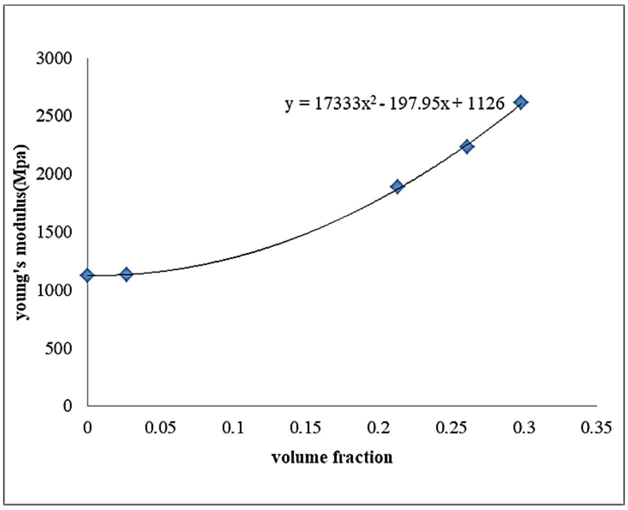


Fig. 11 relationship between Young's modulus and volume fraction.

It is worth noting that the increase in glass content leads to an increase the value of Young's modulus and a decrease in Poisson's ratio, this region which has high glass concentration become stiffer than that with low glass concentration, so, applying load should be in the high glass low epoxy direction and not vice versa. For that, if there are some kinds of voids or cracks embedded inside the material the stress intensity factor will be high in the crack tip comparing with glass low epoxy high region.

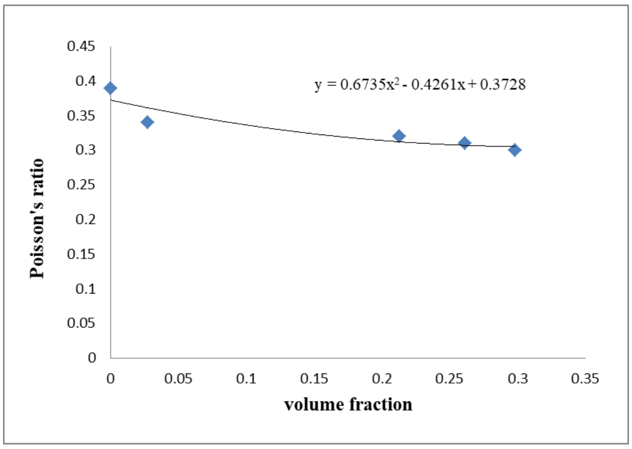


Fig. 12 relationship between Poisson's ratio and volume fraction.

4. Conclusions

A continuous functionally graded material was manufactured by adopting vertical gravity casting. Epoxy resin reinforced with 90 µm glass sphere was used in producing the FG composite. The mechanical properties of that FGM calculated experimentally according to ASTM D638. The Young's modulus results show that increasing in the glass particles volume fraction leads to increasing in Young's modulus and decreasing in Poisson's ratio. After manufacturing this important sample, which has a functional gradation in the properties of the material, it can thus be used in the analysis of fracture problems or vibration problems.

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