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Experimental Investigation of the Mechanical and Structural Properties of a Functionally Graded Material by Adding Alumina Nanoparticles Using A Centrifugal Technique

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Abstract:

In this work, functionally graded materials were synthesized by centrifugal technique at different volume fractions 0.5, 1, 1.5, and 2% V_f with a rotation speed of 1200 rpm and a constant rotation time, $T = 6$ min. The mechanical properties were characterized to study the graded and non-graded nanocomposites and the pure epoxy material. The mechanical tests showed that graded and non-graded added alumina (Al_2O_3) nanoparticles enhanced the effect more than pure epoxy. The maximum difference in impact strength occurred at (FGM), which was loaded from the rich side of the nano-alumina where the maximum value was at 1% V_f by 133.33% of the sample epoxy side. The flexural strength and Young modulus of the functionally graded samples were enhanced by 43.69% and 52.74%, respectively, if loaded from the alumina-rich side. On the other hand, when loading (FGM) from the epoxy side, the amount of decrease in bending resistance was 122.4% while the improvement in bending modulus was 81.11% compared to pure epoxy. Scanning electron microscopy (SEM) revealed the fracture surface of the impact samples and the gradient scattering of nanoparticles in the epoxy matrix. Numerous applications can be used to manufacture the functionally graded material by centrifugal casting method, including for the manufacture of gears and all bending applications such as leaf springs.

Keywords: Centrifugal casting, Flexural properties, Functionally Graded Materials (FGMs), Impact test.

Introduction:

One of the most significant and present material studies is functionally graded materials (FGMs). These materials can fabricate components, showing gradual engineered transitions in composition and microstructure according to the definition. Such spatial inhomogeneity is markedly inspired by functional performance requirements, which vary with a single component position¹.

It is worthy of mentioning that Polymer Graded Materials (PGMs) are considered a specific type of graded material where one of the compounds is used as a matrix, usually (thermoplastic or thermoset resin). Polymer-graded materials are being investigated less than other graded materials. Overall, the polymer matrix is used for various reasons, including low density, resilience to any atmospheric influences and aggressive conditions,

electric and thermal properties, and high specific mechanical strength compared to mass².

In polymeric materials, the gradation of functional properties is investigated by altering the chemical composition, microstructure, size of the grain, and density as a spatial position function. One of the fundamental problems in the designing process of graded materials and composites is controlling the scheduled gradation. To understand the techniques used in information on graded fabrics and at the same time to gain a perfect design of (PGMs), it is better to understand both the morphology and structure of polymeric materials and the relationship between them³.

When the metal matrix is based on (FGMs), the manufacturing methods involve the following: chemical vapor deposition, solidification process, co-deposition, spray atomization, powder metallurgy

techniques, and gravity and centrifugal casting. These methods, particularly the last one, are seen to be the most appealing and cost-effective^{4,5}.

Gravity and centrifugal casting are the most cost-effective and attractive metal matrix-based (FGMs) processes. Centrifugal casting has been used recently in polymer matrix-based (FGMs) composites to achieve a graded distribution of carbon fibre and graphite particles in an epoxy resin⁶.

Additionally, Siddhartha et al.⁷, used a vertical centrifugal casting technique and simple mechanical stirring to fabricate functionally graded materials and homogeneous composites from various materials, including short glass fibre and polyester-based matrix. The results indicate that adding short glass fibre to polyester-based (FGMs) composites significantly increases their tensile and flexural strengths compared to homogeneous composites.

According to Singh AK et al.⁸ homogeneous and functionally graded composites were developed using (epoxy resin reinforced with Titania (TiO₂) particles and were fabricated using a simple mechanical stirring technique first and then a vertical centrifugal casting technique. Among all manufactured composites, unfilled polyester composites have the poorest mechanical properties; whereas (TiO₂) filled FGMs have superior mechanical properties to homogeneous composites.

Kumar MS et al.⁹ used in-situ polymerization to create layered functionally graded epoxy-alumina nanocomposites (FGPNC). Gradation of the composite material was accomplished by adjusting the weight percentage of nano-alumina in the thickness direction. The results indicated that (FGPNC) had a higher flexural modulus and flexural strength under both types of loading conditions when compared to pure layered epoxy.

Shareef, M. et al.¹⁰ prepared Functionally Graded Polymer Nano-composites (FGPNCs) via combining Al₂O₃ nanoparticles with 5 layers of the epoxy matrix using a hand lay-up technique. A three-point bending test used various samples of (FGPNCs) and compared them with the epoxy and isotropic composites. The results show that the flexural modulus and strength of the (FGPNC) for each (FGMs) type and isotropic composite material are more than pristine epoxy.

Many previous studies dealt with the improvement in mechanical properties of composites due to different types of filler added to the thermoset polymer. It's obvious that adequate investigations have been carried out upon the polymer-based functionally graded materials, but to the best of the author's knowledge, the nano Al₂O₃-packed epoxy-based functionally graded materials by centrifugal casting method haven't been synthesized up to now.

The present paper focuses on fabricated Functionally Graded Nano- Polymer Materials (FGNPMs) using the centrifugal casting technique where the graded of nano-alumina particles occurred through-thickness of samples. In this study, alumina nanoparticle at different volume fraction was used as reinforced material with epoxy matrix. The mechanical properties of various functionally graded materials were compared with neat epoxy and equivalent isotropic nanocomposites. SEM test was used to show the fracture surface of impact samples and the nano-alumina distribution and graded through-thickness.

Materials and Methods:

Utilized material

The thermoset epoxy named Quickmast 105 base was used as the resin matrix which had less viscosity by comparing it to the else thermosets, as well as this material being transformed later to a solid form by adding hardener (Quickmast 105 hardener) addition at a (4:1.47) ratio from the company which manufactured it. Table. 1, contains the (Quickmast 105) technical characteristics which rely upon the datasheet of (DCP) company, whereas the nanoparticles reinforcements being Al₂O₃ produced via Briture Company Ltd. (Table. 2) lists the nano-alumina technical properties.

Table 1. The technical characteristics of Quickmast 105 (from the supplier's data)

Properties	Values
Compressive strength (MPa)	50
Flexural strength (MPa)	82
Tensile strength (MPa)	28
Density (g/cm ³)	1.15
Viscosity (poise)	3-5 at 25°C 1-2 at 35°C
Poisson's Ratio	0.33

Table 2. Properties of alumina nano particle (from data sheet of supplier)

Properties	Values
Purity (%)	99.9
Average Particle Size, (nm)	50 -100
Specific Surface Area, (m ² /g)	5 -10
Microstructure Shape	spherical
Poisson's Ratio	0.22
Young's Modulus, (GPa)	347

Preparation of graded and non-graded nanocomposite

Preparation of neat epoxy and homogenous nanocomposites

In this work, alumina nanoparticles were selected as nano-filler materials. Epoxy was also used as a matrix. The entire reinforcement procedure for epoxy resin was performed in a suitable thinner solvent to prepare a uniform mixture.

To prepare pure epoxy models to produce identical states as compared to other models, an appropriate amount of epoxy resin was placed in an appropriate amount of solvent. After 15 minutes of mixing with a magnetic stirrer, the mixture is transferred to an airtight flask. The solvent must be evaporated using a vacuum pump to create a vacuum state. During this stage, a proportion of the stoichiometry of the hardener, in this case (4 epoxy) / (1 hardener), was added and uniformly combined for about 15 min as well as the gases and any air bubbles removed by a vacuum pump. This mixture was placed in a mold for 48 hours for processing purposes.

To prepare the homogeneous nanoparticles, amounts of reinforcements 0.5, 1, 1.5, 2, 2.5 % V_f of alumina nanoparticles were dispersed in an appropriate amount of the specified solvent for 15 min. The synthesis results were consistently completed by a magnetic stirrer for about 15 min and sonicated at 75% amplitude for 15 min; with on for 50 seconds and off for 10 seconds. The required amount of epoxy was added to this mixture in the same manner as indicated previously and mixed mechanically by a mechanical stirrer. The stoichiometric ratio of the hardener was increased to a mixture and it was mechanically stirred and vacuumed by a vacuum pump to remove air bubbles. Finally, the consistent mixture was poured into acrylic molds for curing for 48 hours.

Functionally graded polymer nanocomposite (FGNC) preparation

To obtain specimens by using centrifugal casting methods, within the initial stage, the mold walls were covered with wax to facilitate the exit of the sample from the mold after the solidification process. The procedure for manufacturing FGNCs was divided into two different steps; The first step was to prepare the nano-filler mixture and the molten matrix via suitable dispersal and mixing techniques as the process that used in the homogeneous nanocomposite, and then pour the sequentially molten mixture into 6 mm thick acrylic molds. The molds were mounted in the centrifuge apparatus in the second step, as shown in Fig. 1, with a certain centrifugation speed and time. The mold surface formed the specimen's outside surface, while the specimen's inner surface was formed by centrifugal force and gravity. Note that the high mixing speed leads to the entry of air bubbles into the mixture. Air

bubbles play an important role in determining the mechanical properties of the manufactured model, so it became necessary to get rid of them as much as possible by using a vacuum. In this work, the effect of different volume fraction 0.5, 1, 1.5, 2 $V_f\%$ with rotational speed $N = 1200$ r.p.m rotational time $T = 6$ min were studied.

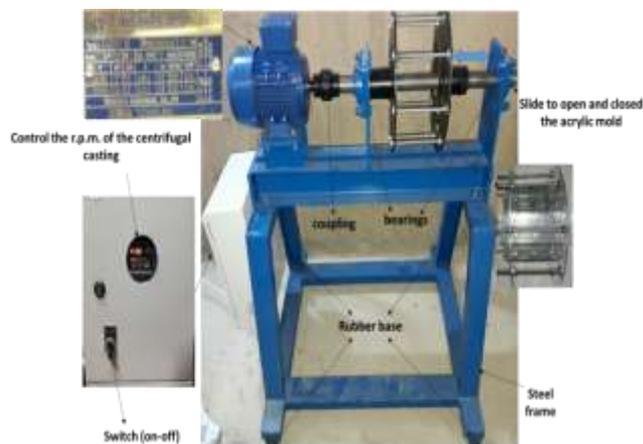


Figure 1. Centrifugal casting apparatus used in this work.

Testing: Laser particle size analyzer

The alumina nanoparticle size was determined statistically by using a laser particle size analyser Battersize 2000. The sample was initially properly distributed and sonicated in the deionized water for 10 min.

Density

This work used two types of density measurements; the first type was about dividing the weight of nano- alumina particles by the volume of these nanoparticles in a cylindrical flask that contain liquid solvent to calculate the density of the nanoparticles.

The second was measuring the density of nanocomposite and FGM samples theoretically and practically. As shown below, the composite's theoretical density (ρ_{th}) has been calculated by using the rule of mixture (ROM)¹¹:

$$\rho_{th} = V_p \rho_p + V_e \rho_e \quad 1$$

Where V_p is the volume fraction of nanoparticles, ρ_p is the density of nanoparticles, V_e is the volume fraction of epoxy matrix, and ρ_e is the density of epoxy matrix.

It is possible to obtain the density experimentally for epoxy and the samples of (FGPNC) by using the rule of Archimedes. The analyzer Matsu Haku HIGH Precision Density Tester GP-120S has been used to perform the density test, which was measured according to Archimedes' law by using the following formula¹²:

$$\rho_c = \frac{W_a \rho_w}{(W_a - W_w)} \quad 2$$

Where ρ_c : Density of composite, ρ_w : Density of water, W_a : Weight of object in the air, W_w : Weight of the object in the water

The following equation is used to calculate the percentage of void content of prepared samples.

$$\text{Void Content (\%)} = \left(\frac{\rho_t - \rho_e}{\rho_t} \right) * 100 \quad 3$$

Where: ρ_e : experimental density g/cm^3 , ρ_t : theoretical density g/cm^3 .

Flexural test

The thickness gradient is delivered to functionally graded nano polymer samples; The property hardness changes through the thickness direction. The three-point bending properties of elegant epoxy nano- alumina composite, FGM with 2% V_f , constant rotational speed $N = 1200$ rpm, and different times of rotation 1, 2, 4 and 6 min were determined. The samples were bearing onto the universal testing machine from both sides of the epoxy and nanocomposite and one side of the homogenous composite models. The dimensions of the bending test specimen comply with ASTM D790. The length of the sample L was 60 mm, while the width W was 10 mm, and the thickness B was 6 mm. To determine the flexural strength, strain, and modulus, the following equations were used^{13, 14}:

$$\sigma_f = \frac{3PL}{2WB^2} \quad 4$$

$$\varepsilon_f = \frac{6DB}{L^2} \quad 5$$

$$E_b = \frac{mL^3}{4WB^3} \quad 6$$

where σ_f is the stress of bending, ε_f : the strain of bending, E_b : bending modulus, P is the maximum load, D is the deflection, and m is the slope tangent to the first linear region of the load and deflection curve. Each sample type was tested with at least five samples. The diameters of the support cylinder and the nose of the loading were 10 mm.

Impact test

Impact testing was measured using ASTM D256 standard uncut Charpy-Impact test equipment with a rectangular-shaped specimen with dimensions $55 \times 10 \times 6$ mm³. Each group was repeated five times, and average values were used. Impact testing was performed with a 1.5 J (1.5 Nm) sled. The impact force was calculated by dividing the absorbed energy by the original cross-sectional area of the sample. In such a test, the impact strength and fracture toughness computation relied upon calculating the needed fracture energy¹⁴. The impact strength is found by using this formula:

$$G_c = U_c / A \quad 7$$

Where: G_c : is the material impact strength J/m^2 . U_c : is the absorbed energy J . A : is the specimen's cross-sectional area m^2 .

Scanning Electron Microscope (SEM)

Scanning electron microscopy SEM was utilized to demonstrate the fracture surfaces of the shock-tested specimens; Based on synthetic crystal technology, an instrument Tescan Corporation, Mira3 model was used for this test. To prepare the specimens, it is better to cut the fractured sample into a rectangular block $5 \times 10 \times 6$ mm³ and then spread a thin layer of gold using a sputter-coating unit (EM Technologies LTD company, UK) to avoid charging.

Results and Discussion:

Particle size

The particle size measurements for nano Al_2O_3 are shown in Fig. 2. In this figure, the maximum size of the Al_2O_3 nano particles is 630.6 nm; this depicts the more extensive agglomerated area and the lousy dispersal into water. The device treats the agglomerated or gathered structures as one molecule and measures its total size and this is in agreement with the work of Reem A.¹⁵.

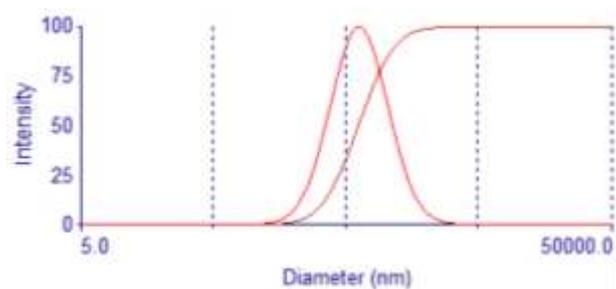


Figure 2. Particle size of Al_2O_3 nanoparticles

Density and void content

During the manufacturing of composite materials, either the air or the volatiles might be trapped between filler and matrix, and they will form voids. The existence of voids affects several of the composites' mechanical properties and performance while functioning. These voids were a source of stress within the material, resulting in failure mechanisms such as crack initiation and propagation and catastrophic part failure. Comparing the theoretical and experimental densities of composite materials allows for determining their void content. The theoretical density of the composites was first calculated using the rule of mixtures and then experimentally verified using Archimedes' technique.

The effect of alumina nano particle addition on the density of epoxy composites at various volume fractions is depicted in Fig. 3. The addition of nano

alumina particles increased the density of the epoxy matrix, demonstrating the value of nano fillers as particulate reinforcement. The increase in density suggests that particle breakage has little effect on the composites. It is believed to enhance particle-matrix bonding.

Additionally, Fig. 3 indicates an increasing porosity as the volume fraction increases, particularly for small nano particle sizes of composites, due to the decrease in the inner-particle spacing caused by the increased contact surface area, this is in agreement with the work of Naguib¹⁶.

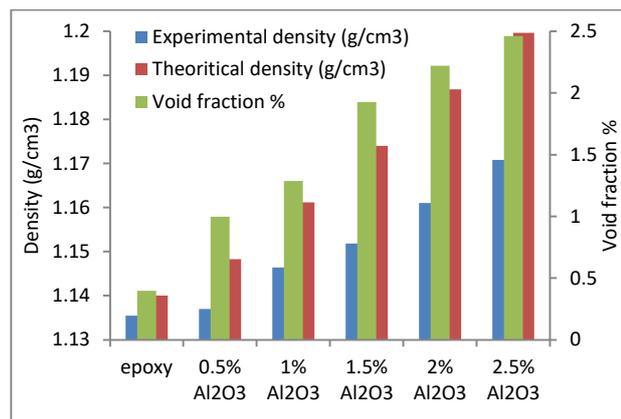


Figure 3. The theoretical, experimental densities and the corresponding content of void of the neat epoxy and alumina nano-composite at different volume fraction.

From Figs. 3, 4, a comparison between homogeneous composites and graded composites declares that the first has more void-fraction than the latter; this may attribute to the fabrication technique used to prepare the composites. The presence of alumina nano particles can affect the density of homogeneous composites and (FGMs). Whereas (FGMs) exist in more significant quantities than their homogeneous counterparts, (FGMs) also have a lower void fraction than homogeneous composites. This is because centrifugation effectively omitted agglomerates during synthesis, resulting in increased dispensability and a lower void fraction.

Thus, one can assert that for a given sample size, in comparison to monolithic composites, gradation in the volume fraction of particles can reduce the functionally graded polymer composite weight in one way or another. Centrifugal casting samples were rotated at 1200 revolutions per minute for 6 minutes. As a result, the ratio of voids to bubbles if any is thrown towards the periphery surface for centrifugal action, where they rapidly collapse; thus, the void fraction decreases automatically. To fabricate homogeneous composites, either manual stir casting or gravity methods are used; as a result, the likelihood of

inherent voids is increased. Thus, it can be concluded that the centrifugal technique is more efficient at minimizing the void content than the gravity method. The void fraction increases with particle loading in each preceding case, resulting from poor interaction/adhesion between the alumina nano particle and the epoxy matrix materials. This is consistent with references¹⁷⁻¹⁹.

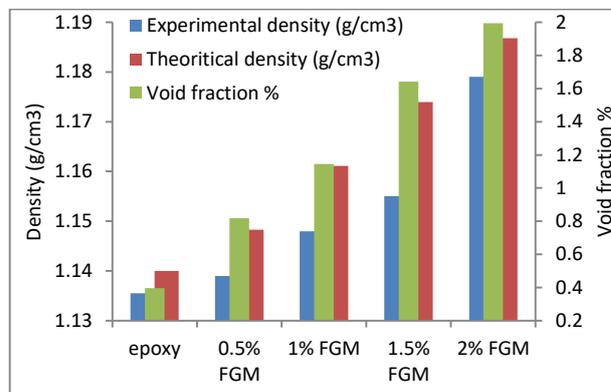


Figure 4. The theoretical, experimental densities and corresponding void content of the neat epoxy, FGM's (Al₂O₃) and equivalent alumina composite

Flexural test results for isotropic composite

Fig.5, shows the data on the flexural properties of the pure epoxy and different concentrations of nano alumina particles. The flexural stress shows a straight increase with the nano filler content until 2% V_f after that can be seen stability in the ultimate stress value of alumina composite because alumina particles display a constructive outcome on the flexural stress.

As illustrated in Fig. 5, adding 2% V_f of alumina nano particles to neat epoxy increased the ultimate flexural stress by (22.68 per cent) the increase in flexural stress for the samples containing 2% V_f alumina nano particles was attributed to a decrease in the matrix's crosslinking degree and a physically improved interaction between the polymer matrix and the filler²⁰.

Additionally, Fig. 5 demonstrates that Al₂O₃ nano particles effectively increase Young's modulus, while epoxy resin decreases the elongation at break. At a 2% volume f of particles, a 52.74 per cent increase in elastic modulus was observed, while the elongation at break decreased to 85.5 per cent. Rigid alumina nano particles act as a constraint on the deformation of a local matrix in response to the applied load, thereby increasing the stiffness of composites. Due to the interface between the particles and matrix imperfect bonding, the bending strength at break may be reduced due to stress concentration and void content effects.

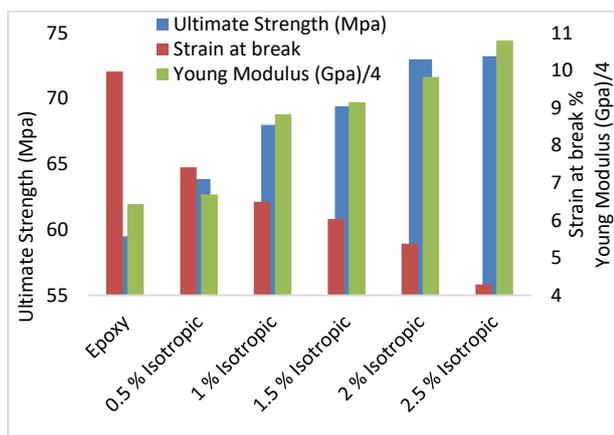


Figure 5. Effect of alumina nano particles on Young's modulus, ultimate strength and strain at break.

Flexural test results for FGM at different volume fractions

Fig.6, shows the comparison of Young's modulus between neat epoxy, alumina nano composite isotropic and FGMs at different volume fractions of nano alumina particles with a constant speed of rotation $N=1200$ r.p.m and constant time of rotation $T=6$ min for both sides of nano alumina and epoxy. The results indicated an incensement in the flexural modulus with an increasing volume fraction of the functionally graded polymer composite above the samples of the neat epoxy if they are loaded from both the side of neat epoxy and alumina side. Due to the presence of nano particles, it was observed that Young's modulus of the ungraded composites was significantly higher than that of pure epoxy. Additionally, the results demonstrate a 52.74 per cent increase in the flexural modulus of the FGM samples when loaded from the nano alumina rich side at 2% V_f . In comparison, when FGM samples were loaded from the epoxy rich side at 2% V_f of Al_2O_3 , the flexural modulus was increased by 81.11 per cent.

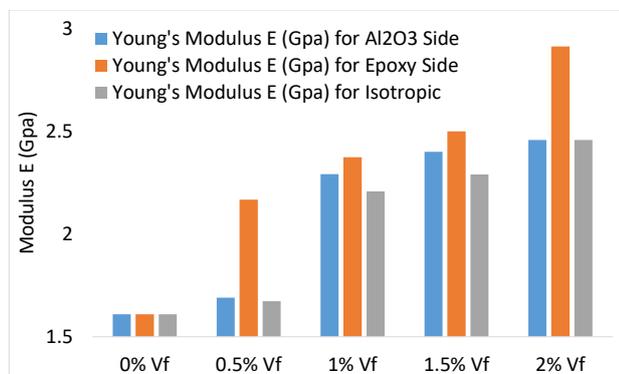


Figure 6. The Young's Modulus for neat epoxy and (FGMs) at difference volume fraction and constant speed ($N=1200$ r.p.m) and time ($T=6$ min) for both sides; nano alumina side and epoxy side

Fig.7, shows the comparison of flexural strength between neat epoxy, alumina nano composite isotropic and FGMs at different volume fractions and constant speed $N=1200$ r.p.m and constant time ($T=6$ min) for both sides; epoxy side and nano alumina side. The results indicate that the flexural strength of the functionally graded polymer composite is reduced by 122.4 per cent when loaded from the neat epoxy side. The flexural strength of ungraded composites is greater than that of pure epoxy due to the presence of alumina nano particles. Simultaneously, when the epoxy samples were loaded from the nano alumina rich side, a slight increase in flexural strength 43.69 per cent was observed compared to the neat epoxy samples. Pure epoxy has the lowest modulus and strength in this regard, lowering the modulus and strength of graded composites.

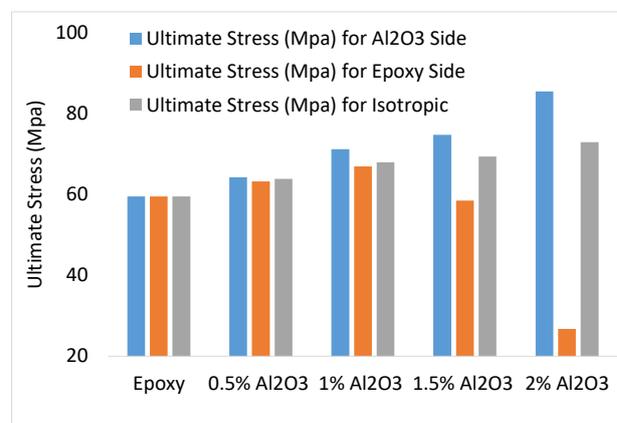


Figure 7. The ultimate stress for neat epoxy and FGMs at difference volume fraction and constant speed ($N=1200$ r.p. m) and time ($T=6$ min) for both sides; nano alumina and epoxy

From Fig. 8, the results indicate that the elongation strain decrease with increasing volume fraction for isotropic composite, and FGMs at a constant speed $N=1200$ r.p.m and time $T=6$ min for both sides (nano alumina and epoxy) due to brittle nature of nano- alumina. The maximum strain at the break at 2% V_f of Al_2O_3 was decreasing by 984.78 when they are loaded from the epoxy side while reducing by about 62.8 when loaded from nano alumina side and the decrement about 85.5 for isotropic composite and this agrees with ²¹.

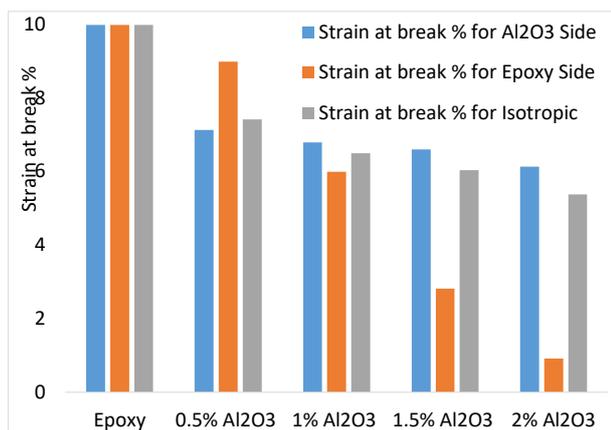


Figure 8. The strain at break for neat epoxy and FGMs at difference volume fraction and constant speed $N=1200$ r.p.m and constant time $T=6$ min for both sides; nano alumina and epoxy.

Impact strength

After obtaining the absorbed energy values from the Charpy test device, they were divided into impacted sections to allow for a more reliable comparison. When a small number of nano-alumina particles were added, the impact energy increased but decreased at high concentrations. The maximum impact strength was found at the particles content 1.5% V_f of nano Al_2O_3 which increased by 95.09% over neat epoxy, as shown in Fig. 9. The brittle nature of particles reasons for decreases in the material's impact strength. The same behavior was obtained in reference^{21,22}.

According to reports, physicochemical interactions between nano particles and the matrix play a significant role in the formation of composites. Composites with high chemical bonds also have better mechanical properties as a result of alumina nano particles with a high modulus that absorbing higher mechanical stresses, an interfacial surface is formed, which increases values of mechanical properties where the nano-alumina particles act as strong stress concentrators, reducing crack propagation by increasing crack deflections (creating multiple crack propagation directions)²³.

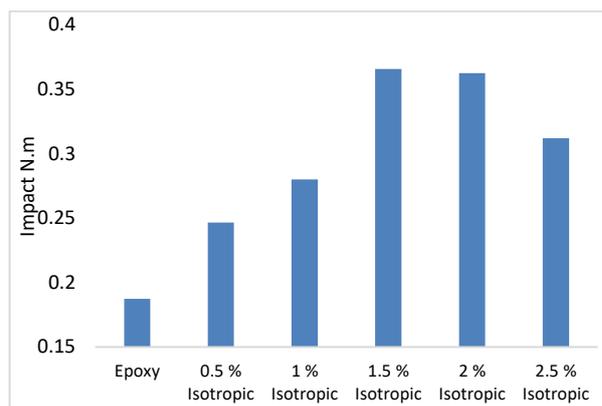


Figure 9. Shows impact strength of neat epoxy and homogenous composite material.

According to Fig. 10, the impact strength of functionally graded composites is greater when loaded from the nano alumina rich side (the maximum value at 1% V_f was 133.33 per cent greater than the epoxy side) because the impact load causes a more excellent elongation to break in pure epoxy on the opposite side. In contrast, the composites loading side improves the resistance to impact, this is in agreement with the work of Khalid²⁴. These two phenomena may be partially responsible for the increased impact strengths of these samples²⁵.

Generally, properties display a flat and constant change starting from one surface to another, thus removing any interface problems. On the other hand, it is noticed that functionally graded composite has higher impact strength in comparison with other types of the composite at different concentrations of nanoparticles within functionally graded material; the purposes have changed because of the changes in microstructural levels and the overall functionally graded material accomplish the multi structural position from their property gradation^{26,27}.

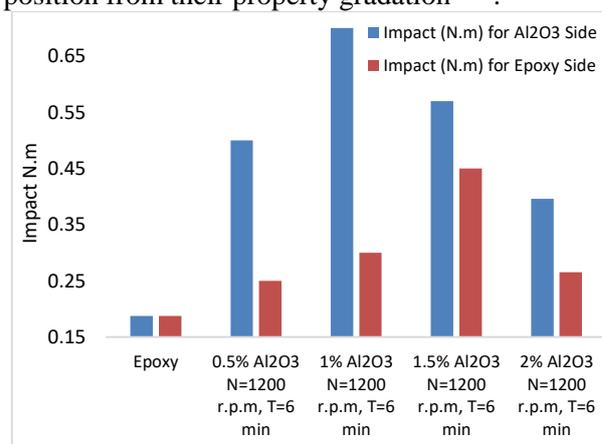


Figure 10. Impact strength of FGMs alumina particles at different volume fractions and constant speed $N=1200$ r.p.m and constant time $T=6$ min

Dispersion and morphology analysis

The impact behavior of epoxy composite can be explained in terms of the morphology observed by SEM. The fracture surface morphologies and dispersions of alumina nano particles with different magnification are shown in Fig. 11 (A-D). The improvement of the impact behavior of FGM can be explained by a close look at the fracture surfaces of the damaged specimens.

Fig.11 (A-D) shows a sample FGM with 0.5% V_f of nano Al_2O_3 and rotational speed $N=1200$ r.p.m, which was centrifuged for 6 min and loaded from the epoxy side. Generally, for the cases in Fig. 11A and Fig. 12A, fractography consists of three zones: the upper zone clearly shows the highly-dense of alumina nano particles in the sample where the particles are heading towards the centrifugal force. This middle zone represents the transition region, while the bottom part of this fractography shows the epoxy matrix which has a few alumina nano particles. As speed or rotational increases, the alumina nano particles are directed toward the surface.

Fig. 11B, shows a magnification of the upper zone, which presents a homogeneous appearance without any phase separation. However, this phenomenon can be considered good compatibility between the alumina nano particles and the epoxy matrix. This morphology, in addition, presents a rough and coarse surface that has a large number of propagated cracks, crack deflection and shear deformation. Fig.11 (C-D) shows the transition region's magnification, which illustrates the nano alumina distribution in the epoxy matrix. However, the dispersion of alumina nano particles of FGM samples was observed and showed that the diffusion was insufficient. Compared with other models, a non-uniform distribution and agglomerates at the content of this nano filler were regarded as the main reasons for the drop in properties.

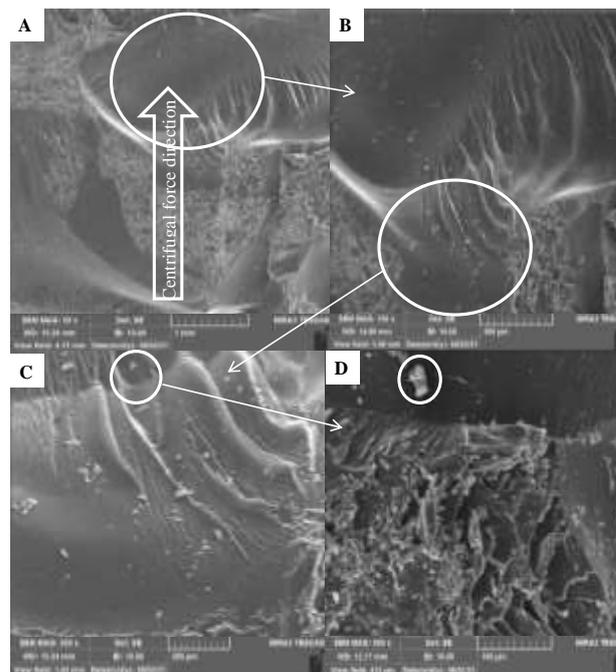


Figure 11. SEM images of the impact fracture surface of FGM of 0.5% nano Al_2O_3 with rotational speed $N=1200$ r.p.m and time $T= 6$ min with different magnification.

The fracture surface of impact test for 2% V_f nano Al_2O_3 FGM with rotational speed $N=1200$ r.p.m and time of rotation $T= 6$ min, which loaded from the epoxy side, was shown in Fig. 12 (A-D). The graded sample was shown in Fig. 12A, while Fig. 12B, shows a magnification of the upper zone containing many reinforcing nano-particles; due to the increase in the rotational speed $N=1200$ r.p.m and the time of rotational $t=6$ min, the alumina nano-particles are trending to the outer surface of the FGM sample as shown in Fig. 12 B. On the other hand, from Fig. 12 (A-B), the FGM sample shows a finer fracture surface. In this case, the failure initiates from the outer region of the sample, which is highly filled with Al_2O_3 nano-particles 2% V_f . The shear deformation can absorb fracture energy when cracks initiate and interrupt crack propagation.

The dispersion of nano-fillers into the matrix is significant, where the non-uniform dispersion and fabrication defect (void) shown in Fig. 12 (C-D) result in an earlier failure of the matrix and prevent it from achieving the desired properties. The dispersion technique was ineffective for higher content and alumina nano-particles.

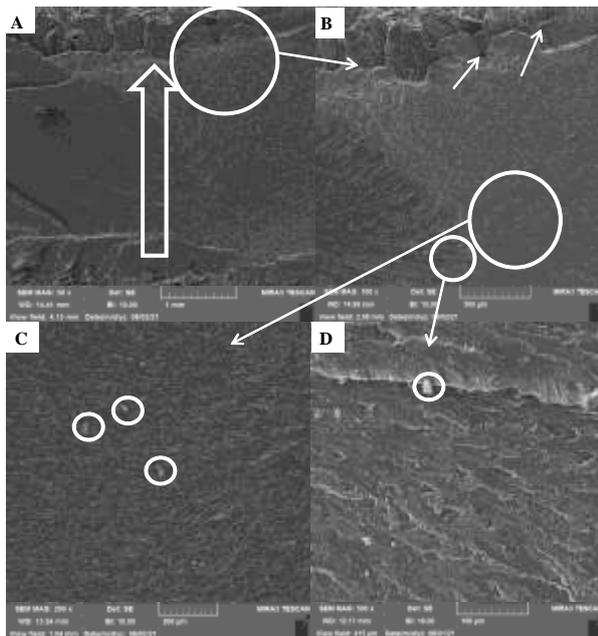


Figure 12. SEM images of impact fracture surface of FGM of 2% V_f of nano- Al_2O_3 with rotational speed $N=1200$ r.p.m and time $T= 6$ min with different magnification.

Conclusion:

A novel synthesis method was achieved for producing continuously graded and non-graded nanocomposites in two phases (epoxy and nano-alumina) by utilizing the technique of centrifugal casting method. The alumina nano particles reinforcement with continuous gradation shape can be an excellent attracting method for developing the mechanical behavior of (FGPNC) over those of the homogenous nanocomposite and neat epoxy. The results indicated that Young's modulus for samples loaded from the nano-alumina composite was less than from the epoxy side for FGM. The samples loaded from the nano alumina side had higher flexural strength than those loaded from the pure epoxy side. The maximum impact strength of the isotropic composite was found at the particle content of nano alumina 1.5% V_f , which increased by 95% over neat epoxy. The impact strength of functionally graded composites was increased when loaded from the alumina rich side; the maximum value at 1% V_f was 133.33% higher than the epoxy side. The SEM of impact fracture at low and high concentrations of nanoparticles. The gradation of alumina nanoparticles through the thickness was evident in the epoxy matrix. By examining the fracture surfaces of impact samples by SEM, it was shown that the 2% V_f of alumina nanoparticles has fine dispersion into the epoxy matrix.

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Authors' declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Babylon.

Authors' contributions statement:

A. M. performed the computations. A. M. and A. F. verified the methods. A.F. supervised the findings of this work. All authors discussed the result and contributed to the paper.

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التحقيق التجريبي في الخواص الميكانيكية والهيكليّة لمادة متدرجة وظيفياً عن طريق إضافة جزيئات الألومينا النانوية باستخدام تقنية الطرد المركزي

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الخلاصة:

في هذا العمل، تم تصنيع المواد المتدرجة وظيفياً بتقنية الطرد المركزي عند أجزاء حجم مختلفة 0.5، 1، 1.5، و 2% V_f بسرعة دوران 1200 دورة في الدقيقة وزمن دوران ثابت $T = 6$ دقائق. تم تمييز الخواص الميكانيكية لدراسة المركبات النانوية المتدرجة وغير المتدرجة والمواد الايبوكسية النقية. أظهرت الاختبارات الميكانيكية أن جزيئات الألومينا النانوية المضافة المتدرجة وغير المتدرجة عززت مقاومة الصدمة أكثر من الايبوكسي النقي. حدث الاختلاف الأقصى في قوة التأثير عند (FGM)، والذي تم تحميله من الجانب الغني من الألومينا النانوية حيث تكون القيمة القصوى عند 1% V_f بنسبة 133.33% من جانب الإيبوكسي. تم تحسين مقاومة الانحناء ومعامل يونك للعينات المتدرجة وظيفياً بنسبة 43.69% و 52.74% على التوالي، إذا تم تحميلها من الجانب الغني بالألومينا. من ناحية أخرى عند التحميل (FGM) من جانب الايبوكسي كان مقدار الانخفاض في مقاومة الانحناء 122.4% بينما كان التحسن في معامل الانحناء 81.11% مقارنة بالايوكسي النقي. كشف الفحص المجهر الإلكتروني (SEM) عن سطح الكسر لعينات التأثير والتشتت التدريجي للجسيمات النانوية في ارضية الإيبوكسي. يمكن استخدام العديد من التطبيقات لتصنيع المواد المتدرجة وظيفياً عن طريق طريقة الصب بالطرد المركزي، بما في ذلك تصنيع التروس وجميع تطبيقات الانحناء مثل النوابض الورقية.

الكلمات المفتاحية: الصب بالطرد المركزي، خصائص الانحناء، المواد المتدرجة وظيفياً (FGM)، اختبار الصدمة.