

Effect of Hybridization on the Tensile Properties of S-glass Fibre/Nanoclay/Epoxy Composites

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Abstract

Three groups of composites were fabricated: glass fibre/epoxy composites A, B, C, D, E, and F, which contains 0, 10, 20, 30, 40 and 50 wt. % glass fibre reinforcements respectively. Nanoclay/epoxy composites A, B, C, D, E, and F with 0, 1, 2, 3, 4, and 5 wt.% nanoclay content respectively. Hybrid composites A, B, C, D, E, and F, containing equal amount epoxy (60 wt.%), 39, 38, 37, 36 and 35 wt.% glass fibre and 1, 2, 3, 4, and 5 wt.% nanoclay content respectively. Sample A is the control with 100% epoxy. Tensile properties of S-glass fibre/nanoclay/epoxy hybrid nanocomposite E, which contains 60 wt.% epoxy, 4 wt.% nanoclay and 36 wt.% glass fibre was found to be the overall best performing composite in mechanical Tensile Propertytest when compared with the rest of the composite fabricated.

Keywords: Hybrid-composite, nano-composite, epoxy, nanoclay, S-glass fibre, tensile properties

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Introduction

Man's unending quest for improvement has led to the continuous search for better and more durable materials this led to the development of many new materials in the 20th century [1]. Composite is one such material [2], which has revolutionized the concept of high strength and lightweight materials [3]. A composite material is made by combining two or more materials often with ones that have very different properties [4]. The two materials work together to give the composite unique properties [5]. However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other [6]. Composites are not new to humanity, as natural composites exist in both plants and animals [7].

Wood is a composite; it is made from long cellulose fibres (a polymer) held together by amuch weaker substance called lignin [8]. Cellulose is also found in cotton, but without the ligninto bind it together; it is much weaker [9]. The two weak substances lignin and cellulose together form a much stronger one [10]. The bone in our body is also a composite. It is made from hard but brittle material called hydroxyapatite (which is mainly calcium phosphate) and a soft and a flexible material called collagen (which is a protein) [11]. Collagen is also found in hair and fingernails [10] on its own, it would not be much use in the skeleton but it can combine with hydroxyapatite to give bone the properties that are needed to support the body [11].

Most composites are made of just two materials [1]. One is the matrix or binder [6] it surrounds and binds together the fibres or fragments of other material, which is called the reinforcement [12]. The first modern composite was fibreglass [5].

It is still widely used today for boat hulls, sports equipment, building panels and many car bodies [4]. The matrix is plastic and the reinforcementis glass that has been made into fine threads and often oven into sort of cloth [6]. On its own, theglass is very strong but brittle and it will break when bent sharply. The plastic matrix holds the glass fibre together and protects them from damage by sharing out the forces acting on them [11]. The urge to improve the properties of composite materials has prompted material scientists to investigate composites with lower reinforcement size [3], leading to the developments of nanocomposites and hybrid composites [10]. This research work x-rayed the effect of hybridization on epoxy/glass fibre/nanoclay composites.

Materials and Methods

Materials

The materials used for this research work, their specification and Source/manufacturer are listed in Table 1 whereas the equipment/apparatus used for this research work, their model/standard, capacity and manufacturer/source are listed in Table 2.



Table 1: List of materials and chemicals

S/N	Material	Specifications
1.	Montmorillonite Clay	≥ 20 nm, 10- 400 GPa, 1.72 gm/cm^3 (682608-500G)
2.	E-glass Fibre (fabric form)	300 GSM Specific gravity 2.6 gm/cc
3.	Epoxy Resin	Araldite LY 506 Specific gravity $1.15\text{-}1.20 \text{ gm/cc}$
4.	Epoxy Resin Hardner	Aradur HY 951 Specific gravity $0.97\text{-}0.99 \text{ gm/cc}$
5.	Mould Releasing Agent	Poly vinyl alcohol (PVA)

Table 2: List of equipment

S/N	Instrument	Model/standard	Capacity	Manufacturer/Source
1	Instron Analyser for TensileTest.	AUST/MT/004	5KN	Instron, 825 University Avenue Norwood MA 02062-2643
2	Open Glass Moulds	-	-	Locally fabricated
3	Motorized Stirrer	-	1000r/min	-

Methods

The methods for preparation of the various composites are shown

Mould design and fabrication

The moulds used for fabricating all the composites were made of silicate glass and have the same dimensions of $200 \times 200 \times 3$ mm dimension were fabricated locally using inert glass material. The glass sheets were marked and diamond glasscutter used to cut out the glass block from the sheet whereas the edges of the moulds were held together with adhesives.

Composites preparation

The formulated mixtures of nanoclay/epoxy of 99, 98, 97, 96 and 95-wt.% epoxy with 1, 2, 3, 4 and 5-wt.% nanoclay respectively were prepared. The ratios were mixed using high-speed motorised stirrer. Mould release agent PVA was applied on mould plates in order to have smooth removal of moulded composites after curing. Secondly, epoxy/E-glass fibre composites consisting mixtures of 90, 80, 70, 60 and 50-wt % epoxy with 10, 20, 30, 40, and 50-wt.% E-glass fibre respectively were also fabricated. Finally, hybrid nanocomposites were fabricated with a constant 60 wt.% of epoxy while glass fibre and nanoclay ratios were varied thus: 39, 38, 37, 36, 35 wt.% glass fabric and 1, 2, 3, 4 and 5 wt.% nanoclay, respectively. The glass fibre (in fabric form) was placed on the mould after the initial application of the uniformly mixed formulation, the nanoclay and the matrix system, which contains epoxy and hardener were mixed and spread uniformly. A roller was used to remove some of the entrapped air bubbles in order to reduce the development of voids. Hand Layup method was used to prepare glass fibre/epoxy and glass fibre/nanoclay/epoxy composites by placing one glass fabric (mat) over another and applying the epoxy matrix between the glass fabric alone and the glass fabric with the nanoclay (lamination) respectively while maintaining the thickness of the composite. Casting method was employed for nanoclay/epoxy composites of various ratios. The moulds were left undisturbed for 24 h and the samples were removed and cut into circular, dumbbell, square & rectangular shapes with diamond cutter according to ASTM standards for various recommended physical, mechanical and structural tests.

Glass fibre/epoxy composites fabrication

Hand layup method was employed in the preparation of glass fibre/epoxy composites. The following weight ratio 50:50, 60:40, 70:30, 80:20, 90:10 and 100:0 (control) of compositions were prepared see Table 3. Glass fabric was weighed, Epoxy was measured out and poured into a beaker and epoxy hardener was measured and poured into the same beaker in the ratio of 2:1. The contents of the beaker were subjected to mechanical agitation using a high-speed motorized stirrer at 1000 rev/min. for a period of five minutes for proper mixing. Releasing agent (PVA) was applied on the mould, a little of the epoxy and hardener homogenous mixture were poured in, an E-glass fabric placed, matrix mixture applied again, E-glass fabric placed, matrix mixture poured in, this continued until the glass fabric was exhausted and the remaining mixture was poured, to form the outer covering of the composite. This method was used to fabricate all the varieties of E-glass/epoxy fabric composites produced in this research work.

Table 3: The compositions of epoxy and glass fibre in the composites

S/N	Composite Name	Composite Code	Epoxy (wt.%)	Nanoclay (wt.%)	Glass Fibre (wt.%)
1	EP100GF0NC0	A	100	0.00	0.00
2	EP90GF10NC0	B	90	0.00	10.0
3	EP80GF20NC0	C	80	0.00	20.0
4	EP70GF30NC0	D	70	0.00	30.0
5	EP60GF40NC0	E	60	0.00	40.0
6	EP50GF50NC0	F	50	0.00	50.0

Table 4: The compositions of epoxy and nanoclay in the composites

S/N	Composite Name	Composite Code	Epoxy (wt.%)	Nanoclay (wt.%)	Glass Fibre (wt.%)
1	EP100GF0NC0	A	100	0.00	0.00
2	EP99GF0NC01	B	99	1.00	0.00
3	EP98GF0NC02	C	98	2.00	0.00
4	EP97GF0NC03	D	97	3.00	0.00
5	EP96GF0NC04	E	96	4.00	0.00
6	EP95GF0NC05	F	95	5.00	0.00

Nanoclay/epoxy composites fabrication

Nanoclay/epoxy composites with percentage weight composition of 99:1, 98:2, 97:3, 96:4, 95:5, and 100:0 (control) was fabricated with open moulds see Table 4. The moulds were cleaned and mould release agent applied on them. Proper weight percent of epoxy resin was measured and poured into a beaker and proper weight nanoclay was measured out and added to the beaker. The contents were mechanically agitated using high speed motorized stirrer at 1000 rev/min, for five minutes for proper mixing, then Epoxy hardener was measured and poured into the same beaker and the agitation continued for another about five minutes for homogenous mixing. The uniform mixture was then poured into the moulds and allowed to cure overnight. The composites were removed from the mould and the process repeated using with the various compositions as listed above.

Glass fibre/nanoclay/epoxy hybrid nanocomposites fabrication

10 g grams of glass fabric/nanoclay/epoxy hybrid composites with percentage weight composition of 60:39:1, 60:38:2, 60:37:3, 60:36:4, 60:35:5, and 100:0:0 (control) was fabricated with open mould see Table 5. For the first composite, 3.9 g of glass fibre of stable length 200 mm was measure out and five even mats of dimension 200 x 200 mm were weaved from them, then moulds were cleaned and mould release agent applied. 6.0 g matrix system containing epoxy resin and epoxy hardener in the ratio of 2:1 i.e. 4.0 g epoxy and 2.0 g hardener were measured separately.

Table 5: The compositions of epoxy, glass fibre and nanoclay in the composites

S/N	Composite Name	Composite Code	Epoxy (wt.%)	Nanoclay (wt.%)	Glass Fibre (wt.%)
1	EP100GF0NC0	A	100.0	0.00	00.0
2	EP60GF39NC01	B	60.0	1.00	39.0
3	EP60GF38NC02	C	60.0	2.00	38.0
4	EP60GF37NC03	D	60.0	3.00	37.0
5	EP60GF36NC04	E	60.0	4.00	36.0
6	EP60GF35NC05	F	60.0	5.00	35.0

The epoxy alone was then poured into a beaker and 0.1 g nanoclay was measured out and added to the beaker. The content was mechanically agitated using high speed motorized stirrer at 1000 rev/min, for five minutes for proper mixing then epoxy hardener was measured and poured into the same beaker and the agitation continued for another five minutes for homogenous mixing. A portion of the uniform mixture was poured into the mould and an E-glass fabric laid up the mixture is poured again and spread with a brush on the mat, another mat placed and the mixture poured in

this continues until all the five the E-glass fabric was exhausted, then the remaining mixture poured. The moulds were allowed overnight to cure properly. The composites were removed from the moulds and the processes repeated with the other compositions.

Composites analysis

The composites fabricated were cut into various samples according to ASTM standards for the various tests, the samples were smoothed and analysed for their tensile properties.

Tensile properties

Tensile properties indicate how the materials react to forces applied under tension. In this work, the stress-strain graphs were plotted appropriately and the tensile strength, modulus, strain at break and other tensile properties were determined.

Result and Discussion

Tensile properties of the various composites fabricated

The tensile properties of all the composites fabricated were tested and the results analysed.

The tensile properties of hybrid composites A, B, C, D, E & F with 0:0:100 wt.%, 1:39:60 wt.%, 2:38:60 wt.%, 3:37:60 wt.%, 4:36:60 wt.%, & 5:35:60 wt.% of clay:glass:epoxy respectively was studied, analysed and presented in Fig. 1. The stress values of the hybrid composites improve as the nanoclay content was increased from 0 to 4 wt.% at an interval of 1 wt.% and glass fibre contents decrease from 39 to 34 at an interval of 1 wt.% as in composites A to E. Composite R with 5 wt. % nanoclay and 35 wt.% glass fibre witnessed a decrease in stress when compared with composite E. Good interaction between the nanoclay, glass fibre and the epoxy matrix led to the increased tensile stress recorded in composites A to E, the reduction in the tensile stress as experienced in composite R was because of the reduction in cohesion between the matrix, and fillers, as clusters of nanoclay were formed in the composite. The highest stress value of 1678.6 MPa was recorded against composite E, which is 39.03% better when compared to the control A. Composite F with stress 1634 MPa, showed a sharp decrease of about 9.12% when compared with composite E. [2] reported similar trends. The highest strain value of 0.082 was witnessed by control composite M. The strain values of the hybrid composites decreased from N to R indicating that the hybrid composites become more brittle in nature as the filler contents were increased. The works of [5, 6] have similar trends.

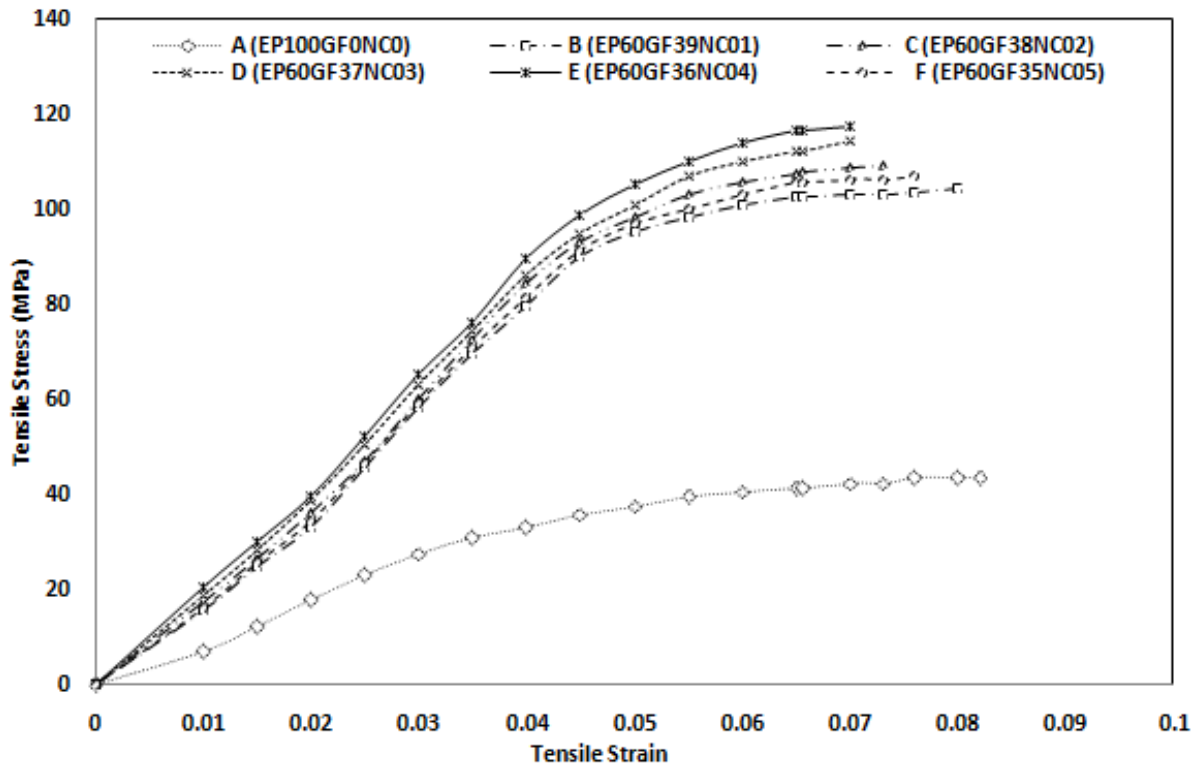


Figure 1: Tensile stress-tensile strain curves of glass fibre/nanoclay/epoxy hybrid composites

Effect hybridization on tensile strength of composites fabricated

The tensile strength of the three groups of composites epoxy/glass fibre composites, epoxy/nanoclay composites and epoxy/glass fibre/nanoclay hybrid composites were compared in Fig. 2 and the following deductions made. The results show that tensile strength of glass fibre/epoxy composites vary from 43.56 MPa (control) to 98.93 MPa, tensile strength of nanoclay/epoxy composites ranges from 43.56 MPa (control) to 60.837 MPa while the tensile strength of glass fibre/nanoclay/epoxy hybrid composites ranges from 43.56 MPa (control) to 117.5 MPa. The tensile strength increases with increase in filler loading in all the composites. Glass fibre/nanoclay/epoxy hybrid composites gave the highest tensile stress followed by glass fibre/epoxy and nanoclay/epoxy. The increase in tensile strength as the filler loading increase can be attributed to the glass fibre and nanoclay ability to improve the tensile strength independently. As the glass fibre content increased beyond 40 wt. % the epoxy matrix could no longer wet the glass fibre properly hence the tensile strength decreased as in composite F with 50 wt.% GF: 50 wt.% epoxy. Likewise tensile decreased for nanoclay as in sample composite F with 5 wt.% nanoclay: 95 wt.% epoxy. In the other hand the effect of the glass fibre loading on the tensile strength as can also be seen, the tensile strength varies from 43.56 MPa to 98.93 MPa. The tensile strength increases with increase in glass fibre up to 40 wt.% as in composite E and thereafter decreases as seen in composite F. The increase in tensile strength with increase in glass fibre can be attributed to good

interfacial bonding between the glass fibre and the epoxy matrix giving the glass fibre ability to serve as good reinforcing filler. As the glass fibre content was further increased as in composite F with 50 wt.% GF, the epoxy matrix could no longer wet GF properly hence the tensile strength decreased marginally. This conforms to the works of [4] that recorded tensile strength of GF reinforced epoxy composites variation from 34.13 MPa to 79.47 MPa, and the tensile strength increases with increase in glass fibre up to 30 wt.% and thereafter decreases. Likewise, a study [11] recorded similar trends of results in GF/epoxy composites tensile strength analysis. In like vein, the effect of the nanoclay loading on the tensile strength of the nanoclay/epoxy composites ranges from 43.56 MPa to 60.837 MPa. The tensile strength improves with increase in the quantity of nanoclay added up to 4 wt.% as in composite A to E. Thereafter, the tensile strength decreased as seen in composite F with stress 58.78 MPa. The increase in tensile strength from samples A to E can be attributed to the abilities of nano fillers to mix thoroughly forming no clusters and lumps in the epoxy matrix. When nanoclay content was further increased beyond 4 wt.% as in composite E with 5 wt.% nanoclay content, the tensile strength reduced due to formation of clusters by the nano filler. This conforms to the work of [1] as they recorded similar trends. The effect of the nanoclay and glass fibre loading on the tensile strength of the hybrid nanocomposites ranges from (control) 43.56 MPa to 117.5 MPa. The tensile strength improves with increase in the quantities of nanoclay from 0 to 4 wt.% at an interval of 1 wt.% and reduction of glass fibre contents from 40 to 36 wt.% and interval of 1 wt.% in

composites A, B, C, D and E. The increase in tensile strength with increase in nanoclay can be ascribed to the ability of the nano particle to mix properly in the matrix creating a good interfacial interaction between the nanoclay and other constituents of the hybrid composites as in samples A to E with 1 to 4 wt.% nanoclay contents. As the nanoclay content increased to 5 wt.%, nanoclay clusters were formed reducing the interfacial interaction between the nanoclay and other constituents of the hybrid composites making tensile strength of the composite to reduce to 114.38 wt.% as seen in samples F. These comply with the report of [10] which reported that nano particles loading in composite materials are most effective in little quantities.

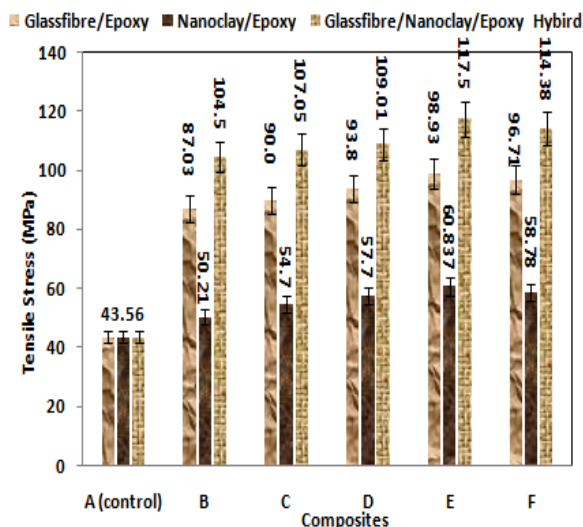


Figure 2: Comparison of the effect of filler loading on tensile strength of glass fibre/epoxy, nanoclay/epoxy and glass fibre/nanoclay/epoxy hybrid composites

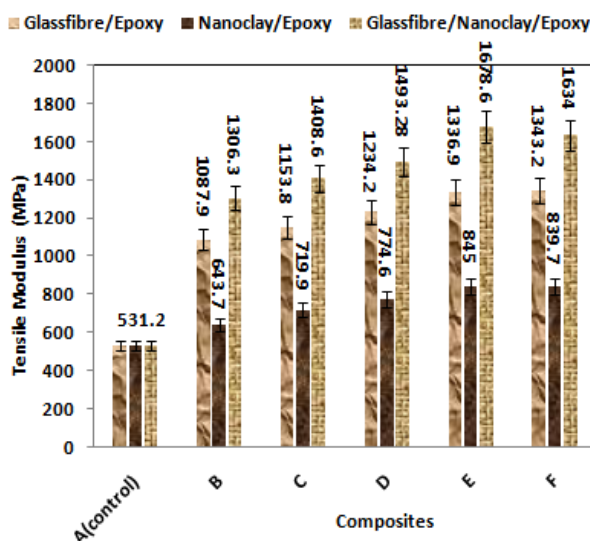


Figure 3: Comparison of the effect of filler loading on tensile modulus of glass fibre/epoxy, nanoclay/epoxy and glass fibre/nanoclay/epoxy hybrid composites

Effect of hybridization on the tensile modulus of composites fabricated

The Fig. 3 compares the tensile modulus of glass fibre/epoxy composites, nanoclay/ epoxy composites and glass fibre/nanoclay/epoxy hybrid nanocomposites. The tensile modulus of elasticity varies from (control) 531.2 MPa to 1678.6 MPa. The optimum tensile modulus of 1343.2, 845.0 and 1678.6 MPa was recorded against glass fibre/epoxy composites, nanoclay/epoxy composites and glass fibre/nanoclay/epoxy hybrid composites respectively. The tensile modulus increases with the in fillers content in the three scenarios until saturation point is reached. The saturation point is the point at which the matrix (epoxy) could no longer properly wet the fillers (nanoclay and glass fibre) in composite, at the point nano clusters begins to form. These are experienced in glass fibre/epoxy composites F, nanoclay/epoxy composites F and for the hybrid composites F. The hybrid composites were reported to give best tensile results when compared to glass fibre/epoxy composites, nanoclay/epoxy composites. The effects of glass fibre loading on the tensile modulus for various epoxy composite varies from 531.2 to 1343.2 MPa. The tensile modulus increased from sample A (control) with 531.2 MPa to composite F (50 wt.% GF) with 1343.2 MPa. The composite becomes stiffer as the glass fibre contents were increased from 0 to 40 wt.% at interval of 10 wt. % as in composites A to E. The works of [8] as well as that of [7] which recorded similar trends with maximum tensile modulus of 1314 MPa and 1252.5 MPa for 50 wt.% of glass fibre respectively. The effect of nanoclay loading on the tensile modulus for various formulations of epoxy/nanoclay composites varies from 531.2 MPa to 845 MPa. The optimum tensile modulus of 845 MPa was obtained for the sample E with 4 wt.% of nanoclay, the tensile modulus decreases to 839.7 MPa for composite F with 5 wt.% nanoclay content. The improvement in tensile modulus with increase in nanoclay from sample A to E was because of homogenous mixing of the nanoclay in the matrix system leading to a good interfacial relationship between the nano filler and the epoxy matrix. As the filler content increased, further, clusters of nanoclay begins to form hence reduces the cohesion between the epoxy and nanoclay causing the tensile modulus of composite F to decreased. The works of [6] reported similar results and trends. The effect of nanoclay and glass fibre loading on the tensile modulus of epoxy/glass fibre/nanoclay hybrid nanocomposites varies from (control) 531.2 to 1678.6 MPa. The minimum tensile modulus was obtained from sample A (control) with 100 wt. % epoxy whereas the maximum tensile modulus was obtained from composite E with 4, 36 and 60 wt.% of nanoclay, glass fibre and epoxy respectively, the tensile modulus decreases on addition of more nanoclay as in composite F with 5 wt.% nanoclay content. The improvement in tensile modulus with increase in nanoclay content from sample A to E was caused by homogeneity in matrix mixing which led to good cohesive relationship between the nano filler,



glass fibre and epoxy matrix. Further addition of nanoclay results to nano clusters formation that caused reduction in cohesion thereby decreasing the tensile modulus to 1634 MPa as witnessed in sample F, this confirms the general notion that nanoparticles have greater influence on composite at minute quantities. Similarly, a study [3] recorded similar result in tensile modulus of nanocarbon fibre/polyester composite.

Effect of hybridization on the strain at break of composites fabricated

Strain at break of the three groups of composites glass fibre/epoxy composites, nanoclay/epoxy composites and glass fibre/nanoclay/epoxy hybrid nanocomposites were compared in Fig. 4. The result shows that strain at break of glass fibre/epoxy composites vary from (control) 0.082 to 0.072, strain at break of

nanoclay/epoxy composites ranges from 0.082 to 0.07 while the strain at break of glass fibre/nanoclay/epoxy hybrid composites ranges from 0.082 to 0.07. The strain at break decreases with increase in filler loading in all the composites. Glass fibre/nanoclay/epoxy hybrid composites gave the optimum tensile stress followed by glass fibre/epoxy and nanoclay/epoxy. The increase in strain at as the filler loading can be attributed to the glass fibre and nanoclay ability to serve as good reinforcement. The strain at break for various GF/epoxy composites varies from 0.072 to 0.082. The maximum is obtained for (control) Sample A with 0 wt.% glass fibre and decreases on addition of glass fibre as shown in composite B to F with 10, 20, 30, 40 and 50 wt.% of glass fibre.

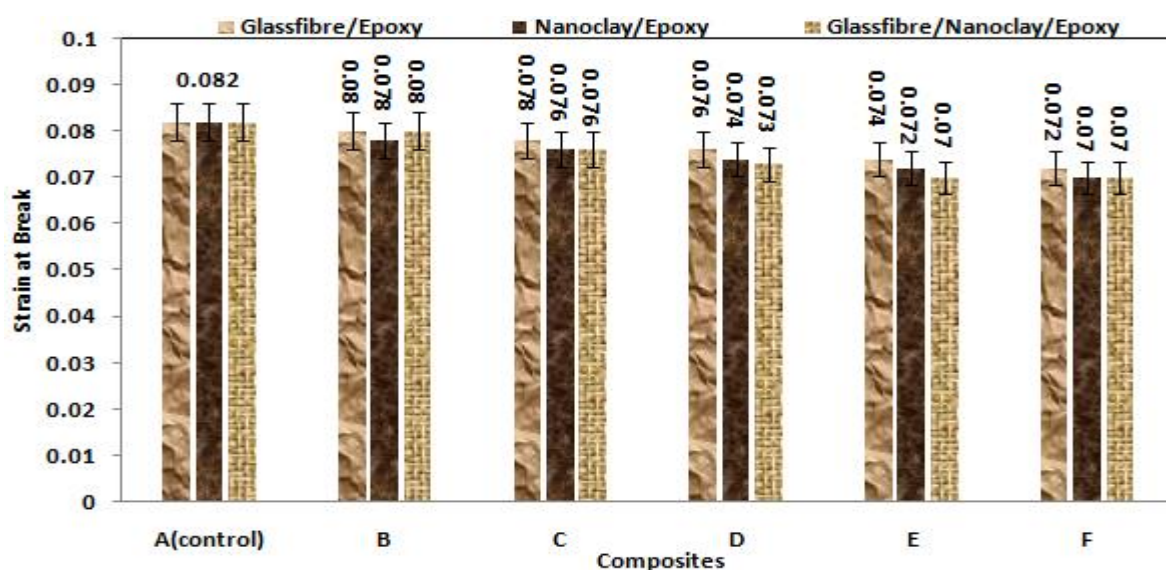


Figure 4: Comparative studies on strain at break for the three groups of composites formulated

The decrease in strain at break (elongation) can be attributed to increase in brittleness and reduction in ductility of the composites as the glass fibre content increased from 10 to 50 wt.%. A study [4] reported similar results with maximum strain at break of 0.79 and minimum 0.68 reported for glass fibre composites respectively. The strain at break for various nanoclay/epoxy composites varies from 0.07 to 0.082. The maximum strain at break of 0.082 was obtained for (control) sample A with 0 wt.% of nanoclay. The strain at break decreases with increase in nanoclay content from 1 to 5 wt.%. The decrease in strain at break as the nanoclay content increase as in composite samples A to F was because the increase nano filler makes them to be more brittle and less elastic, in the other hand, the association between the nano filler and epoxy matrix reduces on increments in nanoclay quantities hence reducing the elongation at break. A study [12] reported similar results against graphene oxide/epoxy composite. The strain at break for various epoxy/glass fibre/nanoclay hybrid nanocomposites varies from 0.070 to 0.082. The maximum strain of 0.082 is obtained for the control sample A with 0 wt.% of

nanoclay. The strain at break decreases with increase in nanoclay contents from 1 to 5 wt.% as in composites A to F respectively. The reduction in strain at break of the composites as the nanoclay content increase as in samples A to F is because the composites become more brittle and less elastic as the fillers i.e. the nano filler and glass fibre increased. In the other hand, the increasing association between the nano filler, glass fibre and epoxy matrix caused the strain at break be decreasing from control sample A to composite F; works of [2, 7, 11] show similar trend.

Conclusion

The essence of this research is to maximize the tensile properties of epoxy/glass fibre composites by inculcating Nanoclay and glass fibre into the composites. Nanoparticle is known to maximize the acceptable properties of material like the tensile, flexural, compressive, hardness, impact etc just to mention a few. Hand layup method was used in the fabrication of both glass fibre/epoxy laminates and glass fibre/nanoclay/epoxy hybrid nanocomposites whereas casting method was used for the fabrication of

the nanoclay/epoxy composites. High speed motorizes stirrer of 1000 rpm was employed for proper mixing. The overall best performing composite is hybrid nanocomposite E, which contains 60 wt. % epoxy, 4 wt.% nanoclay and 36 wt.% S-glass fibre, it possesses the following character; 117.5 MPa tensile strength, 1678.60 MPa tensile modulus, 0.070 Strain at break. The best tensile properties of S-glassfibre/epoxy composites were obtained from composite E, which contains 40 wt.% glass fibre reinforcement, it possesses the following qualities 98.93 MPa tensile strength, 1336.90 MPa tensile modulus and 0.072 Strain at break. The optimum tensile properties of nanoclay/epoxy composites were obtained from composite E, which contains 4 wt. % nanoclay. It has the following behaviour; 60.837 MPa tensile strength, 845.00 MPa tensile modulus, 0.072 strain at break.

Conflict of interest: Authors declared no conflict of interest.

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