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Effect of Strain Rate on the Mechanical Properties of Epoxy-Glass Fabric Reinforced Nano Composites

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***Abstract*—**The effect of rate of strain on the tensile and bending strength of nano graphene filled epoxy glass fiber nano composites was studied. The nano composites are developed and processed using vacuum molding technique. Higher loading of functional graphene in nano size up to 2 wt. % is used for the processing. The nano graphene has been varied from 1 to 2 wt. %. The mechanical properties has been studied and evaluated through tensile and flexural properties as per ASTM D 638 and ASTM D790 standards respectively. The Mechanical behavior of the composite materials was studied under the influence of different rates of strain (Tensile: 5, 25 and 50 mm/min and Flexure: 1.33, 2 and 4 mm/min). Further, the effect of higher loading of nanographene was also studied from the experimentation it is found that the mechanical behavior of composites studied is a function of rate of strain. The increase in strain rate has increased the strength of composite under tensile and bending loads which may be due to increase in strain energy of materials due to effect of higher strain rate. Furthermore, higher loading of nanographene has negative response on the strength of composite studied. This may be due to the agglomeration and improper distribution of these particles in the network of glass fabrics and epoxy

Keywords- Strain rate, Nanographene, mechanical, glass-epoxy, tensile, flexure

1. INTRODUCTION

The mechanical behavior of polymer composites is most significant in defining the selection and adoptability of polymer composites in the field of structural applications. The light weight and high strength to weight ratio of polymer composites define their performance better than the metal based ones. The polymer composites are recommended to aerospace applications, aircrafts and such related fields because of their thermal stability and mechanical response. In addition, performance of polymer composites is improved by modification. The best method to improve the tensile and flexural strength of polymer composites is by reinforcing the base polymer with fibers and fillers [1]. Epoxy is most economically used polymer resin for base materials in composites. Further, the size of fillers and geometry of fiber may affect the behavior of composites [2]. There may be a glass fabric which is one among the reinforcement used for the improvement of structural stability of the composites. The usage of nano fillers is most significant in improving the properties of reinforced polymers. Some of the polymers used for the structural applications in thermo set category are Epoxy, Polyester, Polyvinyl chloride, Polyethylene etc. Fillers in nano scale such as graphene, alumina, MoS_2, TiO_2 are few possible potential fillers used for the development of polymer composites [3]. The response of polymer composites in different strained states defines the structural stability of polymer composites. The research bench has focused its attention towards the processing and development of epoxy based glass fabric composites which are used in automobile components. Further, the effect of rate of strain on the mechanical properties of polymer composite is under serious discussion in the research bench. The effect of rate of strain on the tensile behavior of different polymers such as PA66, PA6 and HDPE composites filled with glass fibers, graphite fibers and chopped glass strand mats have been studied and systematically reported. They revealed that the effect of rate of strain enhanced the flexural strength and modulus of composites. Because of effect of reinforcement the strength of composite has promoted [3- 8]. Further they reported the behaviour of the glass fabric/polyester composite system with strain rate effect Increase in rate of strain increased the strength of composites. Sahin and Yayla [9] studied the effect of testing parameters and their effect on mechanical properties of polypropylene random copolymer. They stated that the tensile properties of materials are fairly rate sensitive. The tensile properties such as stress at yield point, modulus of elasticity and y strain increases as an effect of increased strain rate. Zhou and Mallick [10] investigated the effect of the temperature and strain rate on the tensile behaviour of unfilled and talc filled polypropylene. They proved that the effect of increase in strain effectively improves the strength of the filled polymer composites. Investigation on the Influence of rate of strain and temperature on mechanical properties of polycarbonate, polycarbonate/thermoplastic polyurethane blends and talc filled polypropylene composites have been studied [11]. The different behaviour was noticed from their investigation. As the strength of composite increases due to increase in rate of strain, the effect of temperature and rate of strain on strength of composites is very much significant. The influence of nanaographene filler loading on the mechanical behaviour of the multiwall carbon nanotube filled epoxy composites was studied by Ervina et al [12]. They found that the insertion of nanographene has enhanced the tensile behaviour of nanotube filled epoxy composites. The cock et.al [13] studied the behaviour of nanogaphene filled epoxy under the influence of high strain rates and reported that the high rate of strain has increased the modulus and strength of filled composites.

From all the above extensive Literature, it is evident that the much work is not carried out on the effect of strain rate of the above said composite material system under mechanical loading. Further, effect of higher loading of nanaographene filler on mechanical properties of glass-epoxy composites was not reported. Therefore, investigation has taken up to explore the importance and the effect of different strain rates on tensile and flexural strength of epoxy, glass-fabric reinforced Nano composites.

2. Material System and Evaluation Method

The materials used in the design and fabrication of Glass-Epoxy (GE) based Nano composites are epoxy, glass fabric as shown in table 1. The data recorded in the table are related to supplier's data. The raw materials used for the fabrication process were epoxy L-12 with compatibility hardener K-6, Glass fabric 360 GSM and nano graphene with a density of 0.7 gr/cc. The material formulation designed for the processing of polymer composites is recorded and tabulated in table 2.

A. *Fabrication of Nano composites*

The epoxy L-12 and the compatible hardener K-6 is used as base material in 1:10 proportion with glass fabric 360 GSM for developing the composites. These composites were dried for period of 5 hrs. to remove any hydrolyzing effects. The hand layup process is used to fabricate composites followed by vacuum bag molding process. The plates of size 500 mm x 500 mm of thickness 4 mm were made and the Specimens were cut in to required size as per ASTM Standards using abrasive water jet machining.

TABLE I. Materials Used In Processing Composite

Particulars	***Form and Size***	***Supplier***	***Melting Point(^{0}c)***	***Density(gr/cc)***
Epoxy	Liquid	GLS Polymers	90	---
Glass fabric	Fabric	GLS Polymers	2450	1.8
Hardner	Powder	Advanced Engineers Limited, Bangalore	----	---
Nano Graphene	Powder	Graphite India Ltd Bangalore	3620	0.7

B. *Evaluation of Mechanical behavior of Graphene reinforced Nano polymer composites*

Tensile and flexural strength of epoxy Nano hybrid composites under the influence of different strain rates were studied according to ASTM methods. The properties under tension were measured using different rates of strain at 5, 25 and 50 mm/min in accordance with ASTM D 638 standards using universal testing machine. The bending behavior was studied as per ASTM D 790 method under the impact of different strain rate of 1.33, 2 and 4 mm/min. using same machine. The standard specimens dimensions for the flexural strength specimen used for the foresaid test are as shown in figure 2.

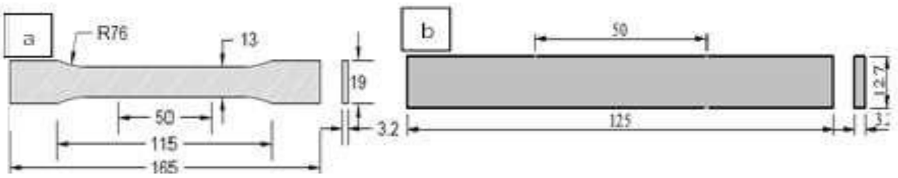

Fig. 2. Standard Specimens as per standards :(a) Tensile strength Test and (b) Flexural strength Test

TABLE II. FORMULATION OF MATERIAL SYSTEM WITH VARIOUS WEIGHT PERCENTAGES

Particulars	***Material ID***	***Epoxy(l12)***	***Glass Fabric(360GSM)***	***Functionalized Nano Graphene***
Neat Epoxy	EP	100	-----	------
Epoxy (L12) with Glass Fabric	GE	67	33	-------
Epoxy (L12) with Glass Fabric+ 1wt% Graphene	GE1	66	33	1
Epoxy (L12) with Glass Fabric + 2 wt% Graphene	GE2	65	33	2

3. Results and Discussion

The behavior of epoxy based nano composites under the influence of different strain rates under mechanical loading were studied and presented in the figure 3(a – d). These behaviors of Nano composites were studied according to ASTM methods. at room temperature It is observed from the response given by the material under the influence of different strain rates that the mechanical behaviors were purely affected under the influence of strain rates. It is proved that the mechanical behavior in tensile and flexural mode was greatly improved with increase in strain rates. This may be purely attributed to the strained state of the material. Higher the strain rate higher will be the strain energy

Figure 3(a) depicts the behavior of neat epoxy composites in Tension under the effect of different strain rates. The tensile strength of the neat epoxy increase as strain rate increases. The strength of neat epoxy in tension with a strain rate of 5 mm/min was 28.45 N/ mm^2. As the strain rate is increased to 25 mm/min, the material responded with the tensile strength of 32.46 N/ mm^2 which is 14% increase. Similar observations were made with increase in strain rate up to 50 mm/min. a slight increase in tensile behavior was noticed even at this strain rate. This is mainly due to the strain energy of the material [8, 9]. At lesser strain rates, the strain energy is less. But the strain energy of composites increases with increase in strain rate. This increases the tensile strength of epoxy composites. Further, the effect of strain rate further increases the percentage elongation [13]. This may be due to the fact that at lower strain rate, the advancement of crack is slow. This allows all the energy to be released slowly till the composite reaches the failure point. All the voids in connected with the crack rapidly communicate to reach the failure point [5]. The effect of tension will reaches all the coroners of the composites under lower strain rate. But at higher rate of strain, the effect of tension may free from some of the voids which may decline the tensile strength. Furthermore, at higher strain rate the path of the crack is almost linear whereas under lower strain rate, the crack path was branched indicating that the tension has reached all the zones of the composites. This may weaken the structure of the composites thereby fail to resist the applied load during tension. This may declines the tensile strength of the composites. Figure 3 (b) shows the strength of the Glass fabric - Epoxy composites tension which is significantly high compared to the strength of neat epoxy. The strength of glass- epoxy composites at lower strain rate was 190.76 N/mm^2 which is 570.5% higher compared to that of pure epoxy. But as the strain rate increased, the tensile strength of the composites appreciably increased. The tensile strength of 217.44 N/mm^2 was obtained as an effect of higher rate of strain of 50 mm/min. the glass fabric epoxy composites exhibits ductile nature which is very much sensitive to the strain rate and this ductility of the composites studied is increased proportionately with strain rate This may be purely the effect of addition of glass fabric in to composite system [2, 3]. But the advancement of the crack in glass epoxy composites even at higher and lower strain rates is proportionally declined due to structural stability of glass epoxy based composites due to the existence of glass fabric [4]. Here the resistance against the crack development was due to the distributed fabric across the composites. Therefore, not much variation in tensile strength was noticed in case of glass – epoxy composites even though the tremendous enhancement of tensile strength compared to neat epoxy. In addition, the strain energy stored in glass – epoxy composites proportionately good to offer resistance against the crack due to tension. The effect of rate of strain on the strain energy of the composites is studied and recorded in table 3.

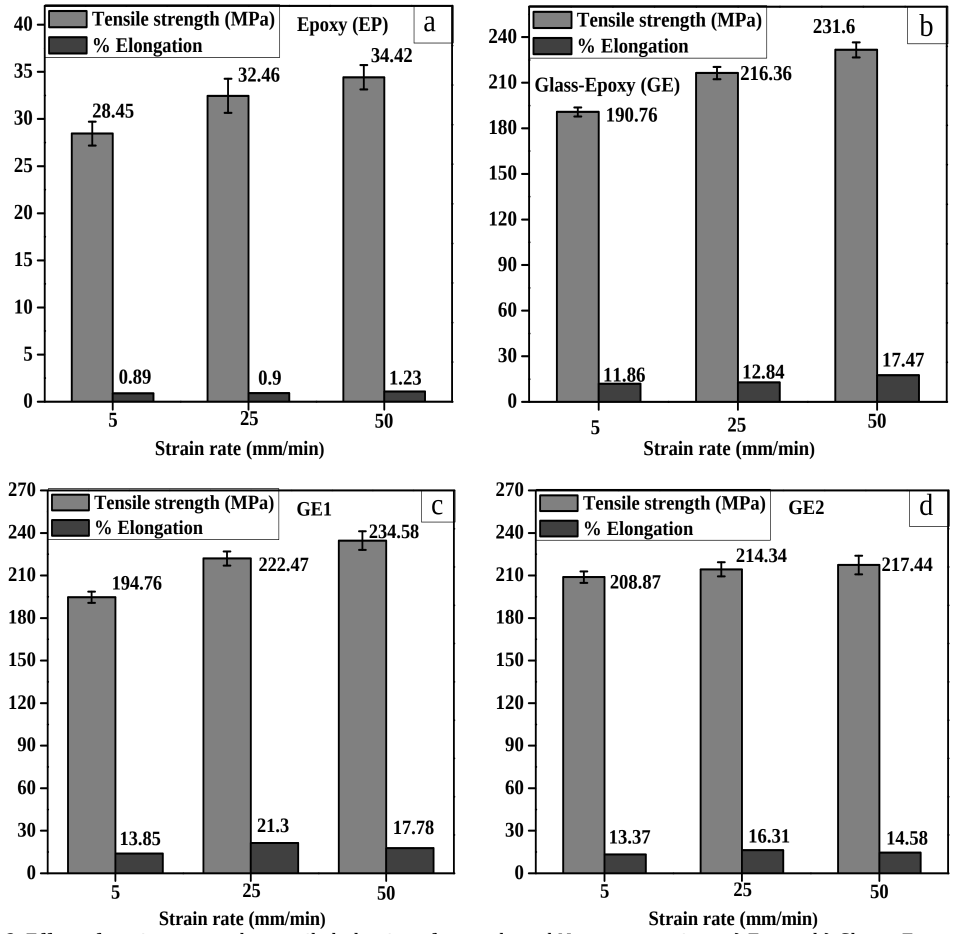

Fig 3. Effect of strain rate on the tensile behavior of epoxy based Nano composites: a) Epoxy, b) Glass –Epoxy composites, c) Glass – epoxy/ 1 wt. % nano graphene and d) Glass –epoxy / 2 wt. % nano graphene

Similar observations were made with glass – epoxy composites filled with 1 wt. % nanographene (Figure 3 (c)). But the tensile strength of glass-epoxy nano composites has enhanced with further addition of 1 wt. % of nano graphene. The effect of nanographene plays a major role in improving the structural stability of the above said composites. The fiber matrix interface has been improved with addition of nano graphene]12,13] Further, the glass fabric network was strengthened due to the addition of the Nano graphene. But the ductility of the composites was retained as that of glass – epoxy composites. This supported the glass-epoxy composites to exhibit highest strength due to the effect of different strain rates [13]. At the higher strain rate of 50 mm/min, the epoxy -glass fabric nano composites exhibits the tensile strength of 234.58 N/mm^2 which is 581.5% in- crease over neat epoxy and 2% increase over glass – epoxy composites. The effect of addition of higher loading of nanographene (2 wt. %) slightly reduced the tensile strength of the composites [5, 8]. This may be due to the decrease in strain energy due to decrease in ductility of composites. The strain decreases due to addition of nanographene which is proportional to stress as per the Hooke's law. Hence, the tensile strength of the compo- sites decreases [12, 13].The best tensile strength was obtained for 50 mm/min strain rate and the glass- epoxy with 1 wt. % nanographene exhibited the best tensile strength among the composites studied.

TABLE III. STRAIN RATE AND ITS EFFECT ON STRAIN ENERGY OF NANO COMPOSITES IN TENSION

Particulars	*Strain rate (mm/min)*	*Ultimate stress (σ)*	*Max.Strain (ε)*	*Volume (mm³)*	*Strain energy (N - mm) (1/2 * σ * ε * v)*
Epoxy	5	28.45	0.0089	4673.6	591.68
	25	32.46	0.009	4673.6	682.67
	50	34.42	0.0123	4673.6	989.32
Epoxy + Glass fabric	5	190.76	0.1186	4673.6	52868.08
	25	216.36	0.1284	4673.6	64917.76
	50	231.6	0.1747	4673.6	94548.14
Epoxy + Glass fabric + 1 wt.% Nanographene	5	194.76	0.1385	4673.6	63033.45
	25	222.47	0.213	4673.6	110731.86
	50	234.58	0.1778	4673.6	97464.01
Epoxy + Glass fabric + 2 wt.% Nanographene	5	208.87	0.1337	4673.6	65257.28
	25	214.34	0.1631	4673.6	81691.85
	50	217.44	0.1458	4673.6	74082.99

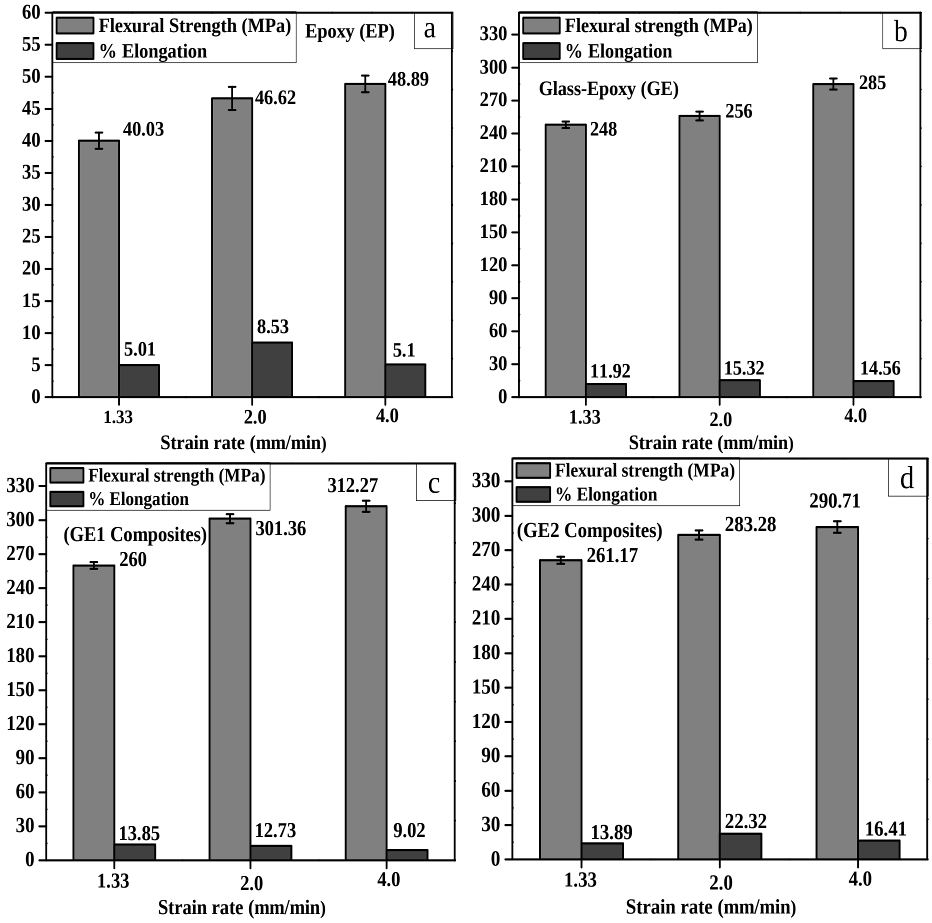

Fig 4. Effect of strain rate on the flexural behavior of epoxy based Nano composites: a) Epoxy, b) Glass –Epoxy composites, c) Glass – epoxy/ 1 wt. % nano graphene and d) Glass –epoxy / 2 wt.% % nano graphene

Fig 4 (a - d) shows the effect of strain rate of epoxy based nano composites on bending strength the flexural behaviour of epoxy based nano composites proportionately varies with strain rate The strength of the composites in bending is much sensitive to the strain rate. The effect of rate of strain on the flexural behavior of the neat epoxy is exhibited in the figure 4(a). It is noticed from the figure that at lower strain arte neat epoxy exhibits a flexural strength of 40.03 N/mm². With increase in rate of strain the flexural strength of the same composites also increases. At higher rate of strain about 4 mm/min, the flexural strength of 48.89 was exhibited by the epoxy composite which is 22.13% increase. This may be because of the pure ductile nature of the composites. In this case the strain energy of the composites studied is effectively good to resist the applied bending load. When the material was strained due bending, the inner surface of the composites was in compression whereas the outer surface was in tension [8]. Due to pure epoxy, the material receives the load and shares the same load to the outer surface. But the advancement of the crack was linear [10, 13]. When the material was strained due to bending, the maximum work was done by the load and it was stored in the form of strain energy [10]. Due to increase in strain energy as an effect of increase in strain rate, the strain is proportional to the bending stress which in turn proportional to the bending strength of composites. Therefore, flexural strength is very much sensitive to the strain rate. But excellent flexural strength was exhibited by Glass- Epoxy composites (Figure 4 (b)). This is because of the ductility of the glass fabric which is present in the composites as reinforcement. Further, the glass fabric resists the applied load by receiving it and storing in the form of strain energy. But at lower strain rate, the flexural strength of 248 N/mm^2 was obtained by glass fabric-epoxy composites which are 519.53% increase than that of neat epoxy. But the flexural strength of these composites responds positively under the influence of different strain rate. At higher strain rate of 4 mm/min, the flexural strength of 285 N/mm^2 was exhibited by glass-epoxy composites. The glass-epoxy interface was strengthened due to uniform wettability of epoxy [10, 13]. At lower strain rate, the impact load becomes severe slowly and travels across the every corner of the matrix.

TABLE IV. STRAIN RATE AND ITS EFFECT ON STRAIN ENERGY OF NANO COMPOSITES IN BENDING

Particulars	***Strain rate (mm/min)***	***Ultimate stress (σ)***	***Max.Strain (ε)***	***Volume (mm³)***	***Strain energy (N - mm) (1/2 * σ * ε * v)***
Epoxy	1.33	40.01	0.005	4064	406.50
	2	46.62	0.0085	4064	805.22
	4	48.89	0.005	4064	496.72
Epoxy + Glass fabric	1.33	248	0.1142	4064	57549.49
	2	256	0.1532	4064	79693.41
	4	285	0.1456	4064	84319.87
Epoxy + Glass fabric + 1 wt.% Nanographene	1.33	260	0.1385	4064	73172.32
	2	301.36	0.1273	4064	77953.88
	4	312.27	0.009	4064	57107.79
Epoxy + Glass fabric + 2 wt.% Nanographene	1.33	261.17	0.1389	4064	73713.87
	2	283.28	0.2232	4064	128479.49
	4	290.71	0.1641	4064	96937.60

This may weaken the strength of the glass-epoxy interface [12]. Therefore, less flexural strength. But at higher strain rate, the advancement of the crack was rapid and may travels linearly resulting sudden failure of the material. This may escape the voids in the material [13]. This leads to increase the strength of the composites. But the presence of 1 wt. % nanographene in glass fabric–epoxy material system effectively improved the flexural strength of glass fabric-epoxy nano composite. This is because of strengthening of glass-epoxy network by nanographene particles. The synergistic effect of glass fabric and nanographene particles effectively enhanced the flexural strength of the composites. But the flexural strength of these composites is very much sensitive to the rate of strain. The flexural strength of 260 N/mm2 and 312 N/mm2 was obtained respectively at lower and higher strain rates. The glass epoxy system responds negatively on the flexural strength due to higher addition of nano graphene. But the higher loading of nanographene filler affects the flexural strength due to agglomeration. Further, the non-resin region in the composites introduces voids which may cause the composite system to lose its strength. Further, the strain energy was more at all the strain rates but the strength has been declined. This is purely due to brittle nature of composites which may exhibit the non-linearity in crack path. Further, the glass fabric – epoxy interface was much further weakened due to higher loading of Nano filler. The strain rate of 2 mm/min propelled the compo- site system to exhibit the good strength and also good strain energy (Table 4). Among the composites studied the glass-epoxy system with 1 wt. % of graphene in nano size exhibits better strength.

4. Conclusions

The following conclusion were drawn after studying the strain rate effect on the behavior of glass reinforced – epoxy nano composite systems under tensile and bending loads:

- The behavior of the glass epoxy based nano composites under mechanical loading were very much sensitive to the strain rate
- The behavior of glass-epoxy based nano composites under mechanical loading is a function of strain rate which varies linearly with strain rate
- The strength of glass- epoxy composite system under tensile load was increased as an effect of glass fabric reinforcement
- The flexural behavior of the glass-epoxy composites was excellent due to good glass-epoxy interaction which may due to good wettability of epoxy
- With 1wt % of nanographene the glass-epoxy composites shows better mechanical behavior compared to that of Glass epoxy composites with 2 wt.%
- The increase in mechanical behavior was due to increase in strain energy of the composites

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