Tensile Behavior of Nano Filled GFRP at Different Strain Rates

Sujesh. G and C. Ganesan

***Abstract*—** Fiber reinforced polymer (FRP) composites plays an important role in many industries; because weight to strength ratio is extremely high when compared to monolithic metals. One of the main limitations of FRP composites are the low mechanical properties due to the presence of polymer associated with it. To solve this problem, material engineers are investigating the use of different nanoparticles mixed in different polymers to improve mechanical properties of the polymer. Here epoxy – silica Nano materials are used as matrix face for Glass Fiber Reinforced Plastics which is manufactured by Vacuum bagging technique, and its improvement in mechanical properties such as tensile strength, tensile modulus are presented. And also in this study, behavior of Nano filled bidirectional fiber reinforced polymer under uniaxial loading is determined at different strain rates such as 5, 50,500 mm/min. The tests were performed using Universal Testing Machine. The result shows slight decrement in ultimate tensile strength and tensile modulus of the material by increasing the strain rates.

Keywords- Glass fiber, Nano composites, Nano filler, strain rate, tensile test

I. Introduction

NORMALLY composite structures are composed of two phases matrix phase and reinforcing phase. In fibre reinforced polymer (FRP), polymer will act as matrix phase and fibre will act as reinforcement. Fibre such as glass, carbon improves strength properties in the direction they are aligned. These FRP will show strength and stiffness which is equal to that of steel. But weight is only ¼ th of steel. But FRP has some sort of disadvantages because of the weak mechanical properties of the polymer. In order to overcome these limitations we should have to improve the strength of the polymer.

One way to improve the strength of polymer is the use of nano material, (i.e.) addition of nano material in polymer improves the strength because the nano material will act as an reinforcing agent. These types of composites are known as nano composites. Nano particle used are on the order of 10^{-9} m in size and comes in various shapes.

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MAHRCLZ and RIEDEL [1] studied about various nano-filler which are most suitable for various polymers. On this study he explains the effect of Barium Sulphate ($BaSO_4$) and Silicon Dioxide (SiO_2) on angle ply GFRP laminates. Result shows considerable increase in mechanical properties such as tensile strength (about 25%) and tensile modulus (about 64%). MAHRHOLZ and STAGLE [2] studied about the quatitation of reinforcement effect of silica nano particle. In this study they explained about amount of silicon content used in polymer for better property. They showed that one can add silica up to 25% wt of the epoxy resin. Depending on the silica content stiffness, strength and toughness of composite will increase and also resin shrinkage and thermal expansion will reduces.

In this research the improvement in mechanical properties of GFRP while adding Silicon Dioxide nano particle is studied and also their tensile behaviors at various strain rates are studied.

DAVIES and MAGEE [3] studied the effect of strain rate ranging from 10^{-3} to 10^{3} s^{-1} on the glass epoxy /polyester composites. They showed that glass polyester composites dependent on strain rate which showed 55% increment in ultimate tensile strength over the strain rate change. OKOLI and SMITH [4] studied the effect of strain rate (.008mm/min – 4m/s) on the tensile, shear and flexural propertied of glass epoxy laminate. They showed that improvement in discussed properties over the increment in strain rate. A study by ARMENAKAS and SCIAMARELLA [5] shows a linear variation of the tensile modulus of unidirectional glass/epoxy composites with various strain rates. Ultimate tensile stress of the composite decrease with the increase in strain rate. Study indicates that there is a change in failure modes as strain rate is increased.

The aim of this research is to investigate improvement of tensile properties of bidirectional glass/epoxy composite by the addition of silicon dioxide nano particle in plane epoxy. The result of tensile testing on nano filled GFRP were compared with the result of tensile testing of plane unfilled GFRP. And also investigates the behavior of nano filled bidirectional glass/epoxy composite at various strain rates. Tensile properties of lamina are extracted from the result of tensile test done on Universal Testing Machine with loading rate changing mechanism. Tests were carried out on various loading rate ranging from 5mm/min to 500mm/min. Specimen with identical geometry are used in all tests. Experimental results show comparatively better tensile properties for nano filled reference. And ultimate tensile stress of nano filled reference observed to be decrease with increase in strain rate.

II. Material, Equipment and Experimental Procedure

A. Material and preparation of test specimen

Bidirectional woven glass fiber reinforced epoxy was studied in this paper. The laminate composed of 5 layers of reinforcement with epoxy resin Araldite LY556 giving a laminate approximately 3.5mm thickness. Fiber volume fraction on the composite was 50%.

The specimen was prepared from glass fiber in the form of roving and epoxy resin. Araldite LY556, Hardener HX951 in the ratio 10:1 by weight was used as matrix material. The reinforcement material used was E glass fiber. Specimens were fabricated by vacuum bagging technique developed in laboratory. In vacuum bagging technique first we want to fabricate the laminate by hand layup technique. A layer of mix was applied on the mold and a layer of roving. The fiber was impregnated with the help of a rover. After that again mix applies on that, like this 5 layers of fiber are impregnated one over other. After this, uncured specimen was placed in a vacuum bag setup. Vacuum bag lamination is a clamping method that used atmospheric pressure to hold the resin coated component of a lamination in place until the adhesive cures. The uncured laminate is sealed within an air tight envelope. On top of envelope a vacuum was connected which evacuated the air inside the envelope which create a pressure difference between outside and inside of envelope creates required clamping pressure. This clamping pressure holds the laminate plies together until it cures. The laminate was allowed to cure at this clamping pressure about two hours. After that 24 hours curing in normal atmospheric pressure was allowed.

For Nano filled specimen, Nano filler should be mixed with plane epoxy. This is done by using electrical string machine. Here nano scaled spherical spherical dioxide were stirred directly into the resin. It will take 6 hour to dissolve in completely on resin. Here spherical silicon dioxide (SiO_2) is used as nano filler and it covers 5% weight of resin.

The cured specimen is cut as per ASTM D3039 standard. Water jet cutting technique is used for cutting the specimen. Specimen size was 250mm X 25mm X 3.5mm. figure 1 shows the typical test sample for the tensile test.

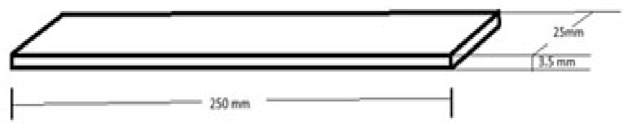

Fig. 1 Test Sample Dimension

B. Testing machine

Testing machine used here for tensile test is universal testing machine (UTM). FIE make UTN 40 model UTM machine is used here. This machine has a capability for changing the loading rate. We can change the loading rate from 5mm /min to 500mm/min. The maximum capacity of this machine is 50 tones. For this study, tensile test were performed at 3 different loading rates such as 5mm/min, 50mm/min and 500mm/min.

III. Results and Discussions

A. Effect of Silicon Dioxide(Sio_2) Nano filler on GFRP

On tensile testing while applying uni-axial tensile load nano-filled reference shows better tensile properties compared to unfilled reference. Addition of 5% spherical silicon dioxide (SiO_2) nano particle in plane epoxy (LY 556) increases the stiffness of the GFRP laminate about 68%. Result shows that addition of nano particle increases the mechanical property such as tensile strength, tensile modulus and F_{max} without considerable weight increment. Theoretically this increment in mechanical property while adding nano particle is due to the improved interfacial surface area and smaller inter particle distances. In filled GFRP the filler material will act as an additional reinforcing component. This extra reinforcement increases the above considered mechanical properties. Basically composite material especially FRP are brittle in nature. Filler content also increases the brittleness but not considerably.

Comparison of tensile properties .

TABLE 1 COMPARISON OF ULTIMATE TENSILE STRENGTH

UNFILLED REFERENCE		**NANO FILLED REFERENCE**	
SAMPLE	**Ult TENSILE STRENGTH (MPa)**	**SAMPLE**	**Ult TENSILE STRENGTH (MPa)**
SAMPLE 1	232.22	SAMPLE 1	246.18
SAMPLE 2	232.56	SAMPLE 2	247.89
SAMPLE 3	233.76	SAMPLE 3	246.12
AVERAGE	**233.84**	**AVERAGE**	**246.73**

In table 1, the ultimate tensile strength of GFRP with unfilled reference and Nano filled reference has been given. The Average increment in ultimate tensile strength by using nano filled reference is about is 20%.

TABLE 2 COMPARISON OF TENSILE MODULUS

UNFILLED REFERENCE		NANO FILLED REFERENCE	
SAMPLE	**TENSILE MODULUS IN GPa**	**SAMPLE**	**TENSILE MODULUS IN GPa**
SAMPLE 1	5.23	SAMPLE 1	7.25
SAMPLE 2	5.36	SAMPLE 2	7.39
SAMPLE 3	5.41	SAMPLE 3	5.42
AVERAGE	**5.33**	**AVERAGE**	**7.35**

In table 2, the tensile modulus of GFRP with unfilled reference and Nano filled reference has been given. The Average increment in stiffness by using nano filled reference is about is 38.5%.

Ultimate tensile load(F_{max})

TABLE 3 COMPARISON OF F_{max}

UNFILLED REFERENCE		NANO FILLED REFERENCE	
SAMPLE	**F_{max} (KN)**	**Sample**	**F_{max} (KN)**
SAMPLE 1	19.6	SAMPLE1	23.86
SAMPLE 2	20.12	SAMPLE 2	24.43
SAMPLE 3	19.78	SAMPLE 3	25.12
AVERAGE	**19.83**	**AVERAGE**	**24.47**

Increment in Fmax is 22.25%
It is easy to visualize the % increment in bar diagram

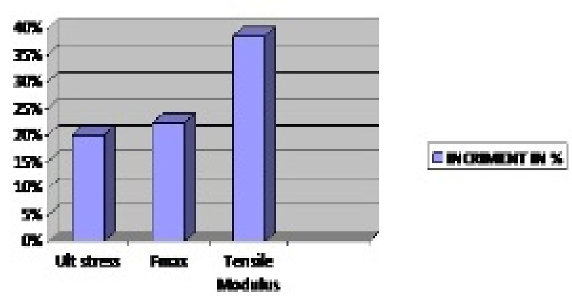

Fig. 2 Tensile values for silicon dioxide nanocomposites in comparison to the unfilled epoxy resin on a relative scale.

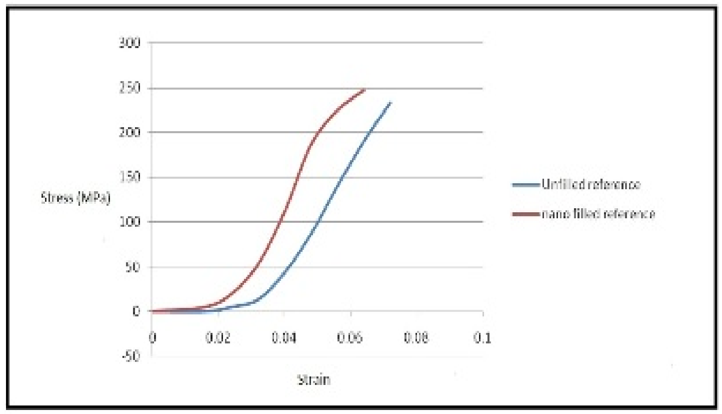

Fig. 3 stress-strain diagram of nano filled and unfilled GFRP composites

The essential enlargement of the tensile modulus (38.5%) of nano filled reference and its great linearity compared to the unfilled reference leads to a 15% higher damage free range. Therefore, the performance of the modified GFRP composite and the field of potential applications are essentially improved. Obviously nanoscaled silicon dioxide is interesting and promising reinforcing filler for fibre composites.

B. Effect of strain rate on tensile properties of Nano-Filled GFRP.

Tensile test were conducted on three different loading rates 5mm/min, 50mm/min, 500mm/min on nano filled coupon. This loading rates applied nominal strain rates of $.00035S^{-1}$, $.0035S^{-1}$ and $.035S^{-1}$ on the specimen. These strain rates are calculated by dividing loading rate of machine by the gauge length of the coupon.

1) Stress-Strain Relation:

The stress strain curve of the tested coupon under different strain rate is presented in figure: 4. From Stress-Strain curves it is clear that mechanical properties of the specimen depends on the loading rate. For tensile test performed at high loading rates, it has been observed that damage earlier in terms of strain level. As we increases the loading rate the curve shows slight non-linearity.

2) Tensile mechanical propertie:

Extracted data after testing summarized in the Table 4 which gives tensile strength and tensile modulus. To determine the stiffness (slope of stress- strain curve) linear portion of curve was fitted with a linear curve.

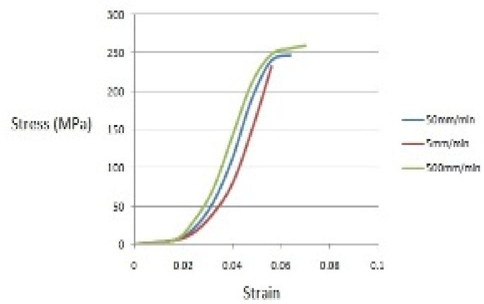

Fig. 4 stress-strain diagram at various strain rate

TABLE 4 TENSILE PROPERTIES AT VARIOUS STRAIN RATES.

Property	**Tensile Strength(MPa)**			**Tensile Modulus(GPa)**		
Loading Rate (mm/min)	**5**	**50**	**500**	**5**	**50**	**500**
SAMPLE 1	259.12	247.63	232.12	8.01	7.41	6.14
SAMPLE 2	261.28	246.30	231.98	8.25	7.28	6.21
SAMPLE 3	260.35	247.14	233.01	8.35	7.30	6.16
AVERAGE	**260.25**	**247.02**	**232.2**	**8.20**	**7.33**	**6.17**

Experimental results show gradual decrease in tensile properties such as tensile modulus and tensile strength as we increase the strain rate. This decrement is due to the increased brittleness of the GFRP material exhibited by the addition of nano filler.

IV. CONCLUSION

Nano scaled silicon dioxide is good reinforcing component for GFRP because addition of it shows essential increase in stiffness (38.5%) and damage free range. So it is proven that nano filler can compensate the weak mechanical properties of GFRP exhibited by the polymer. But its tensile behavior at higher strain rate is not satisfactory as compared that in low strain rate. Stiffness of the material decreases about 34% as we increases the loading rate from 5mm/min to 500mm/min. So nano scaled silicon dioxide filled GFRP is a good alternate for monolithic metal in mechanical industry especially in aerospace applications, but its usage will be limited for low rate of loading applications.

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