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Tensile Behaviour of Short Glass Fiber Reinforced PA66/PTFE Blend Composites: Effect of Strain Rate

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Abstract:- The effect of strain rate and short glass fiber loading on tensile and flexural properties of Polyamide 66 and Polytetrafluroethylene (PA66/PTFE) blend based composites was studied. Thermoplastic blend of 80 wt. % PA66 / 20 wt. % PTFE has been used as the matrix. The composite was prepared by reinforcing the matrix with different weight fraction percentage of short glass fibers (5, 10, 20 and 30 wt. %). These material systems were developed using melt mix method using twin screw extrusion technique followed by injection molding. The effect of different strain rates (5, 25 and 50 mm/min) on tensile properties was evaluated as per ASTM D630 respectively. The experimental results revealed that tensile properties of SGF reinforced PA66/PTFE composites vary as a linear function of strain rates. Increase in tensile strength was noticed because of increase in strain rate. This can be attributed to increase in strain energy of a material. The fractured surfaces were studied using Scanning Electron Microscope (SEM) images.

Keywords:- *Strain Rate; Tensile Strength; Flexure; PA66/PTFE; Short Glass Fibers*

I. INTRODUCTION

Polymer composites and their derivatives were seemed to be the better material systems for the development of automotive components because of their self-lubrication, lower strength to weight ratio, light weight and better aesthetic appearance when compared to metal based ones. Polymer composites were witnessed for better stiffness and specific strength. These properties have proved them to be better than other composites. Homopolymer is a single polymer which cannot withstand both tribological and mechanical loading simultaneously. It has been proved from the research bench that polymer blend performance was better compared to single polymer. This polymer blend can be developed using the concept of polymer modification [1]. Polymer blending is one of the economically proved methods in the modification of polymer composites. Polymer modification can be done by reinforcing fillers and fibers, copolymerization and polymer blending [2]. It has been observed that during the load transformation from fibers and or fillers in to the matrix, the entire composite systems are under the condition of pure strain. The rate of stress generation during the transformation is of greater significance during the mechanical performance of composites.

The effect of different strain rates on the mechanical response of composites has proved to be the key factor in defining the tensile response. The different researchers have investigated and explored the effect of cross head speed on the mechanical strength of polymer based composites. Effect of cross head speed on tensile and flexural properties of these polymer composites particularly thermoplastic composites is of great importance in today's polymer materials. The different potential synthetic fibers such glass fibers, carbon fibers and Kevlar fibers of different geometry have defined the strength of polymer composites [3]. The impact of cross head speed on the tensile response of different polymers such as Polyamide 66, Polyamide6 and High density Polyethylene composites reinforced with different geometrical fibers such as glass, graphite and chopped glass strand mats have been systematically explored and reported to the research bench. Rudresh et al [4] explored the impact of different cross head speed on the mechanical behavior of micro particulate filled PA66/PTFE composites under both tensile and flexural mode. They observed that the increase in strain arte could have enhanced the tensile and flexural strength of blend composites. Further, they reported that the deformation of these composites have been proportionately enhanced due to the strain energy induced in the composites system. The study on different loading of fibers ad also the strain rate on different thermoplastic have been reported [5 -7]. They reported that the effect of strain rate enhanced the flexural strength and modulus of composites. The strength of composites has been promoted because of reinforcement effect. Study on the different strain rates on the flexural behavior of glass mat / Polyester composites have been reported [8]. Experiential study showed that increase in strain rate increased the strength of composites. The effects of different testing parameters on mechanical behavior of polypropylene random copolymer have been explored [9].

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They showed that tensile properties of materials systems are fairly rate sensitive. The tensile properties such as yielding, modulus and strain have been increased as an effect of positive strain rate. Investigation on the effect of temperature and strain rate on mechanical behavior of polycarbonate, polycarbonate / thermoplastic polyurethane blends and talc filled polypropylene were studied [10, 11].

The different behavior was noticed from their investigation. As the strength of composite increases due to increase in strain rate, the effect of temperature and strain rate on strength of composites is very much significant. There is a positive deviation of strength of composites due to the combined effect of temperature and strain rate. They also showed that both activation volume and activation energy has been enhanced by the inclusion of talc. Further, addition of increased the strain rate sensitivity and temperature sensitivity of modulus.

From the above literature survey, it is clear that the influence of strain rate on mechanical properties is very rarely reported. Further, the effect of cross head speed on the polymer blend was not investigated. In addition, the effect of strain rate on the tensile behavior is very limited in supply. Further, the effect of glass fibers on the mechanical behavior of PA66/PTFE blend composites was limited in supply. The effect of strain rate on the tensile response is very much significant in the field of polymer composites. Therefore, the effect of strain rate on different loading of glass fibers on the performance of PA66/PTFE blend composites has been studied.

II. MATERIALS AND THEIR FABRICATIONS

The details of materials which were used for the production along with the suppliers data has been tabulated in table 1. Also, the formulation of composite materials in weight percentage is shown in table 2. The material formulations in weight percentage including matrix and reinforcement phase with material designation are tabulated in following tables.

Table 1: Data of the Materials used in this Study

Materials	Form	Size (µm)	Trade name	Density (g/cc)
Polyamide	Granules	---	Zytel 101L NC010	1.14
Teflon	Powder	12-14	MP1000	2.2
Short glass fiber	Cylindrical	Length = 5 -6 m Diameter = 10-20	----	2.45

Table 2: Formulations of PA66/PTFE based Micro Composites in Weight Fraction Percentage

Composition	Material ID	Weight percentage		
		PA66	PTFE	SGF
Blend (PA66/PTFE)	G1	80	20	---
Blend (PA66/PTFE) /SGF	G2	80	20	10
Blend (PA66/PTFE) /SGF	G4	80	20	20
Blend (PA66/PTFE) /SGF	G6	80	20	30

A. Preparation of Composites through Melt Mix Method

The base polymers such as Polyamide 66 and Polytetrafluroethyelene (PTFE) which were used for the production of polymer composites are dried using the temperature of about 80^0 C for a period of 48 Hours in te closed oven in order to eliminate any moisture composition and plasticizing effect present due to their inherent characteristics. The mixture is thoroughly mixed in the mixing machine so as to distribute all the fillers uniformly for the homogenization. This process has been carried out using two step processing. In the first step, the heated mixture of PA66/PTFE blend is supplied to the twin screw extrusion chamber ((Barbender twin screw extruder). The heating barrel of this extruder consists of five heating zone for the effective heating of these blend because of different melting points. Different temperatures were maintained across these zones such as: zone I (220 ºC), zone II (235 ºC), zone III (240 ºC), zone IV (265 ºC) and zone V (270 ºC) respectively and the die temperature was maintained at around 240 ºC. The twin screw speed used was 100 RPM with a feed rate of 5 kg / hr. These melted composites were drawn out in the form of cylindrical extrudates and are quenched in cold water. These quenched extrudates rods were send to pelletizing machine to convert cylindrical rod extrudates in to pellets.

In the second step, the heated glass fibers of now quantity is mixed with these blended pellets and once again the processing of extrusion repeats till the glass reinforced extrudates were drawn from the nozzle of the extruder. These composites extrudates were once again quenched in cold water and then supplied to the pelletizing machine to get the pellets. The obtained glass reinforced PA66/PTFE blend composites were dried at a temperature and then subjected to injection molding process using injection molding machine. The barrel of the injection molding consist of two heating chambers which were spanned in the temperature range of zone1 (265 ºC) and zone2 (290ºC) maintaining the temperature at the mold to be 65 ^{0}C.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24MAY2000

B. Measurement of Tensile Behavior using different Strain Rates

The tensile response of these glass reinforced PA66/PTFE blend polymer composites were studied as per ASTM methods under the influence room temperature for different cross head speeds (Strain rates). This tension test was conducted as per ASTM D 638 method under the influence of 5, 25 and 50 mm/min strain rate using universal testing machine. An ASTM D638 type 1 specimen standard was used for conducting tensile test which is shown in the figure 1. The ultimate load, peak elongation, stress and strain have been measured using Stress – Strain curve. The response of these composite systems was carried out using room temperature.

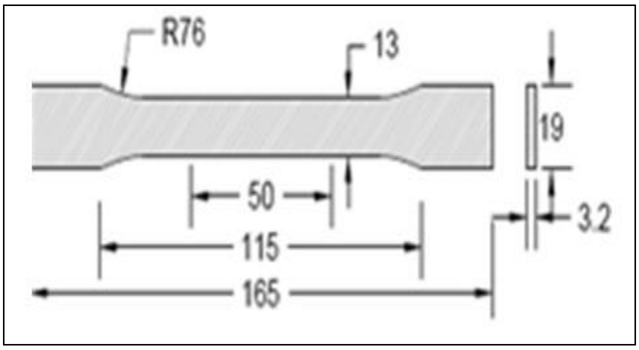


Fig 1: Specimen Standards for Tension Test: ASTM D 638 (Tension test)

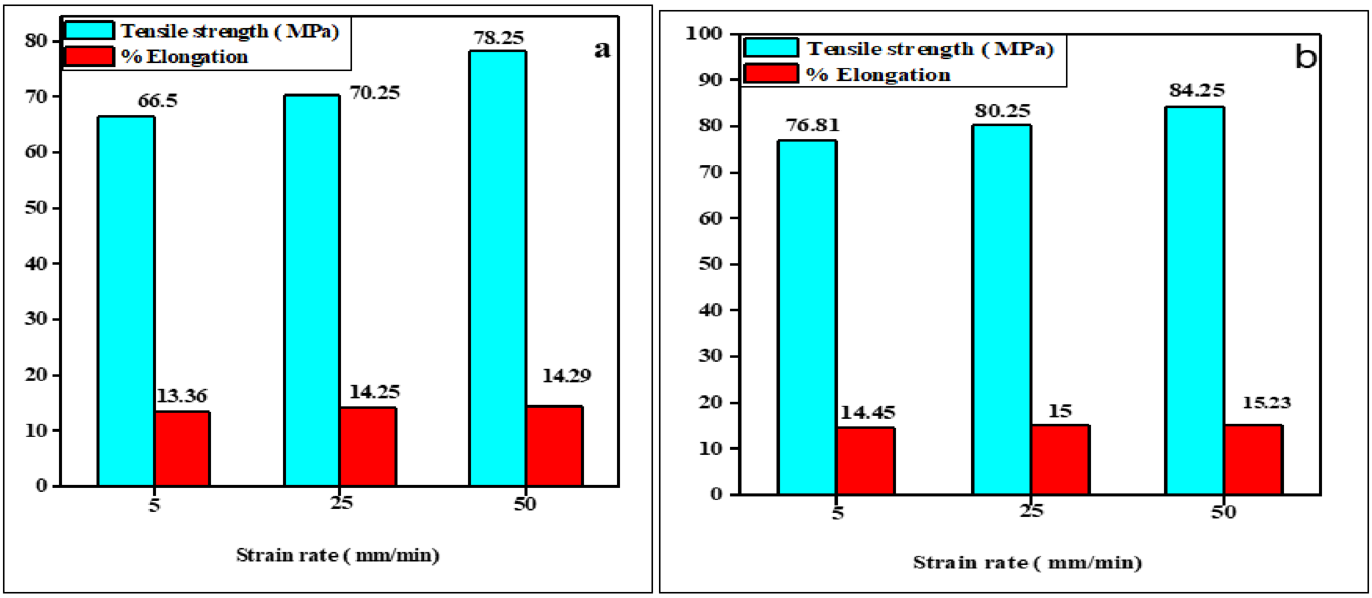
The different cross head speeds were used in order to maintain the strain rates for the study. Three specimens were tested for the experimentation. The specimens were tested in the interval of 30 minutes in order to relive the strain in the systems. The gauge length, load specifications and also the strain rate values were tested in advance and then the actual experimentation has been carried out.

C. Morphology of Failure Surfaces

The tensile fractured specimen was removed from the assembly and the portion where the severe fracture has been noticed was cut without touching the fractured surface. Using the concept of gold sputtering for proper conduction of light, these surfaces were subjected to scanning using Scanning Electron microscope and the scanned images of different magnification were collected for the investigation. The voltage used for the study was in the range of 15-20 volts.

III. RESULTS AND DISCUSSION

A. Effect of Strain Rate on the Tensile Properties of SGF Reinforced PA66/PTFE Blend Composites



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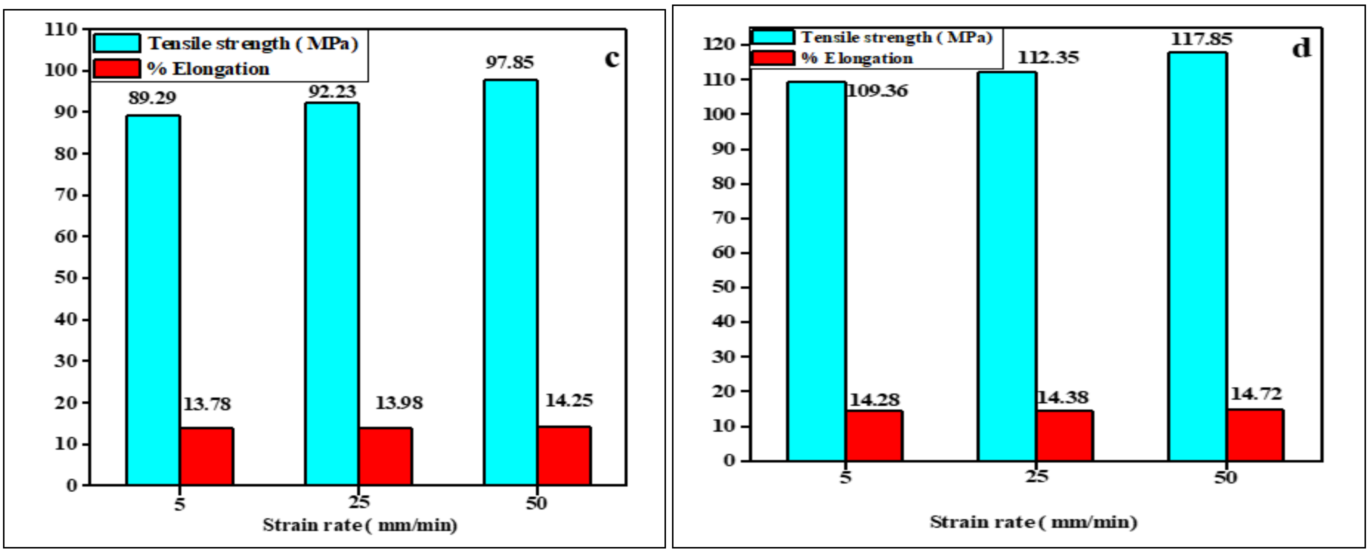

Fig 2: Effect of Strain Rate on Tensile Strength and % Elongation of SGF Reinforced PA66/PTFE Composites: a) G1 Composites b) G2 Composites and c) G4 Composites and d) G6 Composites

The impact of different strain rates on the tensile response of short glass fibers (SGF) reinforced PA66/PTFE blend composites is presented in the figure 2 (a - d). It is observed from the investigation that increase in loading of SGF in to the blend has significant effect on tensile response of blend composites. Figure 2 (a) presents the impact of strain rate and the effect of fiber reinforcement on 5 wt. % SGF reinforced PA66/PTFE blend composites (G1). It is observed that the tensile strength of 5 wt. % SGF in the blend was 66.5 N/mm^2 under the strain rate of 5 mm/min. But the tensile response of G1 composites has been positively improved due to increase in strain state of the composites. The tensile strength of 70.25 N/mm^2 has been exhibited by G1 composites due to the effect of increased to strain rate to 25 mm/ min. This showed that the 6% increase in tensile strength. Further, the effect of cross speed has been increased to 50 mm/min, the composite system has been reflected with 17.66% increase in tensile strength over 5 mm / min strain rate. This clearly the indication that the tensile response of G1 composites is a linear function of strain rate. The Hook's law states that the stress is a linear function of strain under the elastic limit. But even though the peak point and break point for the polymer composites are one and the same, the stress – strain law has been justified under the action of different strain rates and also the corresponding stresses. It is well documented from the strain energy. Here the work potential and extension (Deformation) are functions of strain energy. Higher the strain rate, maximum will be the resistance offered by the material due to stored strain energy (Table 3). When the composite system was strained under the influence of external load, the higher strain energy has been experienced by the systems due to the effect of higher strained state. The increased stiffness enhances the material to receive more load in turn more strain energy resulting in enhancing the tensile response of the systems. The effect of glass fiber reinforcement has enhanced the strength bearing capacity of blend composites. This may be due to good slenderness ratio of glass fibers. This indicates that reinforcing SGF into 80 wt. % PA66-20 wt. % PTFE blend has showed the excellent tensile strength. Further, the excellent adhesion between fiber surface and the matrix has helped the composites system to acquire good strength. The interfacial bond between the fiber surface and the matrix has been improved due to the effective interaction of glass fibers. The surface area of glass fibers interacting with the matrix improved the strength of composites. This may be due to increase in specific strength of glass filled composites. The silane treated glass fibers could develop the good bonding between the outer surfaces of glass and the resin matrix.

The effect of strain rate on the tensile strength and percentage elongation of 10wt.% SGF reinforced 80wt.% PA66- 20wt.% PTFE (G2) blend based composites are shown in the figure 2 (b) As an effect of SGF reinforcement, the tensile strength increases from G1 composites to G2 composite at a strain rate of 5 mm/min which is 15.5 % increase. Similarly, as an effect of increase in strain rate to 25 mm/min, the tensile strength of G2 composite is increased to 80.25 MPa. This showed that the effect of strain rate influences the tensile strength of the filed composites. The high modulus SGF undergoes good ductility exhibiting the effective strain and hence the strain energy of the composites. The strain energy of a composite is a function of strain rate, hence the strength of the composite increases as an effect of increase in strain rate. Similarly the percentage elongation at the break also increases as an effect of strain rate. But due to an effect of SGF reinforcement, the ductility of the composites decreases. The adhesion between the matrix blend and the glass fibers had established the good network interfacial bond, there by the strength of the composites can be effectively retained by the composites.

The effect of strain rate on the tensile strength and percentage elongation of 20 wt.% SGF reinforced 80wt.% PA66- 20wt.% PTFE (G4) blend based composites are shown in the figure 2 (c). The tensile strength of G4 composites at 5 mm/min is 89.29 MPa. When the strain rate is raised to 25 mm/min, the tensile strength is 92.23 MPa

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which is 4% increase. Further increase in strain rate to 50 mm/min increases the tensile strength by almost 10%. But the effect of strain and its linearity on the tensile strength decreases as an effect of higher loading of SGF into the blend. This is purely due to the fact that higher loading of SGF into the blend decreases the ductility and the material becomes brittle. The effect of strain rate on the tensile strength and percentage elongation of 30wt.% SGF reinforced 80 wt.% PA66- 20 wt.% PTFE (G6) blend based composites are shown in the figure 2(d). It is clear from the figure that the effect of strain rate on the strength of composites slightly decreases due to the brittle nature of composites. At higher SGF loading, the strength of composites is not a function of strain rate. At strain rate of 5 mm/min, the strength of the composite is 109.36 MPa. Further increase in strain rate of the system, the strength of the composites increases to 112.35 MPa [14, 15]. The increase in tensile strength of composites is due to SGF loading into the composites. At the same time, the strain energy of the composites slightly decreases when compared to the lower loading of the SGF filled composites. Hence, it is not possible to expect the strength of composites at higher loading of SGF as effect of strain rate. The ductility of the composites has given the same preference as that of strength of the composites. In all G1, G2, G4 and G6 composites, the elongation at break increases as an effect of strain rate. But mean time, decreases due to an effect of loading SGF into the blend. At higher loading of SGF, at a strain rate of 5 mm/min, the percentage elongation was 14.28. As an effect of strain increment by 500%, the elongation was increased to 14.38. Also, for higher strain rate, it is 14.72. This shows that the effect of strain rate due to SGF loading always influences the strength of the composites and also the ductility of the composites [12, 13]. Among the studied composites, 80 wt. % PA66- 20 wt. % PTFE/ 30 wt. % SGF (G6) composites exhibited better tensile strength properties.

Table 3: Strain Rate and its Effect on Strain Energy of PA66/PTFE/ SGF Composites

	Strain rate (mm/min)	**Ultimate Stress (σ)**	**Max. Strain (ε)**	**Volume (mm^3)**	**Strain Energy (N-mm) (1/2* σ* ε*v)**
G1	5	66.5	0.136	4673.6	20761.07
	25	70.2	0.142	4673.6	23392.83
	50	78.2	0.142	4673.6	26129.92
G2	5	76.8	0.144	4673.6	25936.25
	25	80.2	0.150	4673.6	28129.23
	50	84.2	0.152	4673.6	30102.25
G4	5	89.2	0.137	4673.6	28752.37
	25	92.2	0.139	4673.6	30130.12
	50	97.8	0.142	4673.6	32583.46
G6	5	109.3	0.142	4673.6	36492.89
	25	112.3	0.143	4673.6	37753.18
	50	117.8	0.147	4673.6	40537.68

B. Effect of Strain Rate on the Load v/s Deflection Curve of SGF Reinforced PA66/PTFE Blend

Figure 3 (a - d) presents the impact of strain rate on the deformation of SGF filled PA66/PTFE composites. The load – extension curve for G1 composites and the effects of different strain rates on the same is shown in the figure 3 (a). It is observed that the response curve is linear up to the breaking point. Nonlinear response was exhibited by the G1 composites after the break point. The load carrying capacity of the material systems has been enhanced due to increases in strain rate. The ductility of G1 composites has been enhanced due to presence of lesser percentage of glass fibers. Due to this property, the response curve was little flattening even after ultimate point. The eccentricity between the curves of G1 composites between 5 and 50 mm/min strain rates was due to severe cross head speed. This is due to the maximum strain in the composites. This has been attributed to the maximum strain theory [15]. The material systems fail when the strain executed by the composites is more or less equal to ultimate strain. G2 composites have exhibited the same response as that of G1 composites. Here 10 wt. % of SGF in composites has declined the ductility due to transformation of phase from ductile to brittle. Due to this there is a slight decrease in load carrying capacity. Further loading of short glass fibers in to PA66/PTFE composites made the systems still harder and brittle (G4). But increases in strain rate has slightly increased the strength and hence the load bearing capacity of composites.

Even though the strength of the composites was promoting due to the effect of heavy loading of SGF, meantime, the ductility of composites decreases. The effect of strain rate on the load deflection curve of 30 wt. % SGF loaded PA66/PTFE blend composites is shown in the figure 3(d). This showed that the effect of SGF loading increased the strength of the composites.

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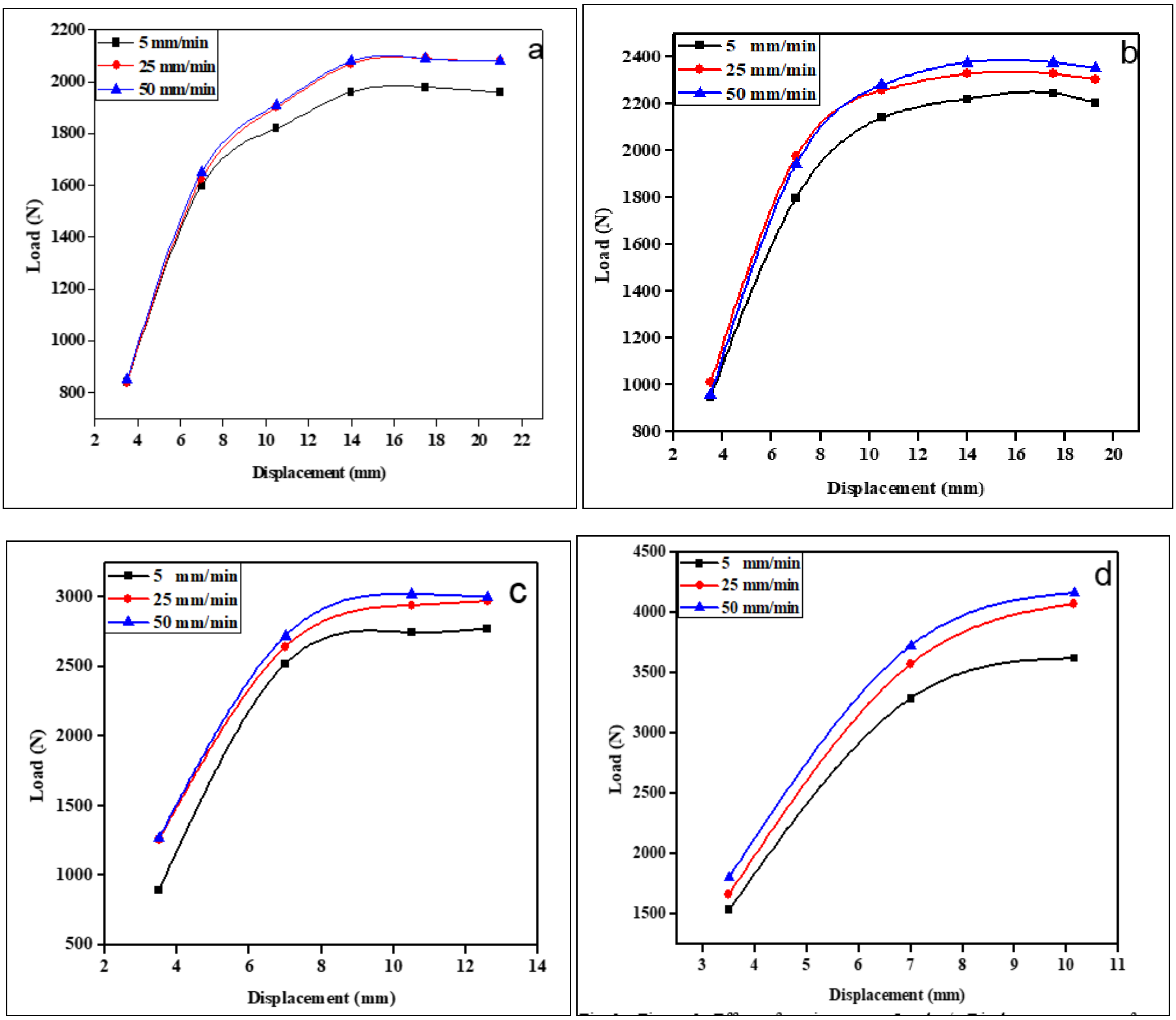

Fig 3: Effect of Strain Rate on Load v/s Displacement Curve of PA66/PTFE /SGF Composites: a) G1 Composites b) G2 Composites, c) G4 Composites and d) G6 Composites

The load carrying capacity of composites is enhanced by the increase in SGF content [15] . Initially, at low strain rate, the curve followed the linear trend up to the peak point. Later, after crossing the elastic limit of the material. The material starts releasing the strain energy, thereby reducing the load carrying capacity of the composites. From the graph, it is clear that the effect of strain rate was very sensitive to the SGF loading. In this case, even though the load carrying capacity of the composite is very high, but the material is very brittle in nature. Even the hardness of the composites is high when compared to all the studied composites. Due to high hardness, the failure of the material is at very low value when compared to other types of composites. Among the studied composites, among the studied composites, 80 wt. % PA66- 20 wt. % PTFE/ 30 wt. % SGF (G6) composites exhibited better load carrying capacity with high brittle behavior.

It is observed from the graph that the strain rate has appreciable effect on the tensile behavior of the blend based composites. It is observed for all the material systems, the extension has been established as a function of the applied load. But when the limiting value of each material system has been reached, there is no question of extension instead complete breaking of the material takes place. Therefore, it is evaluated that for G1, G2, G4 and G6 composites, the breaking point and the ultimate point are one and the same.

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C. Effect of Strain Rate on the Fracture Surface of SGF Reinforced PA66/PTFE Composites (SEM Analysis: Failure Studies) (Tensile Fracture)

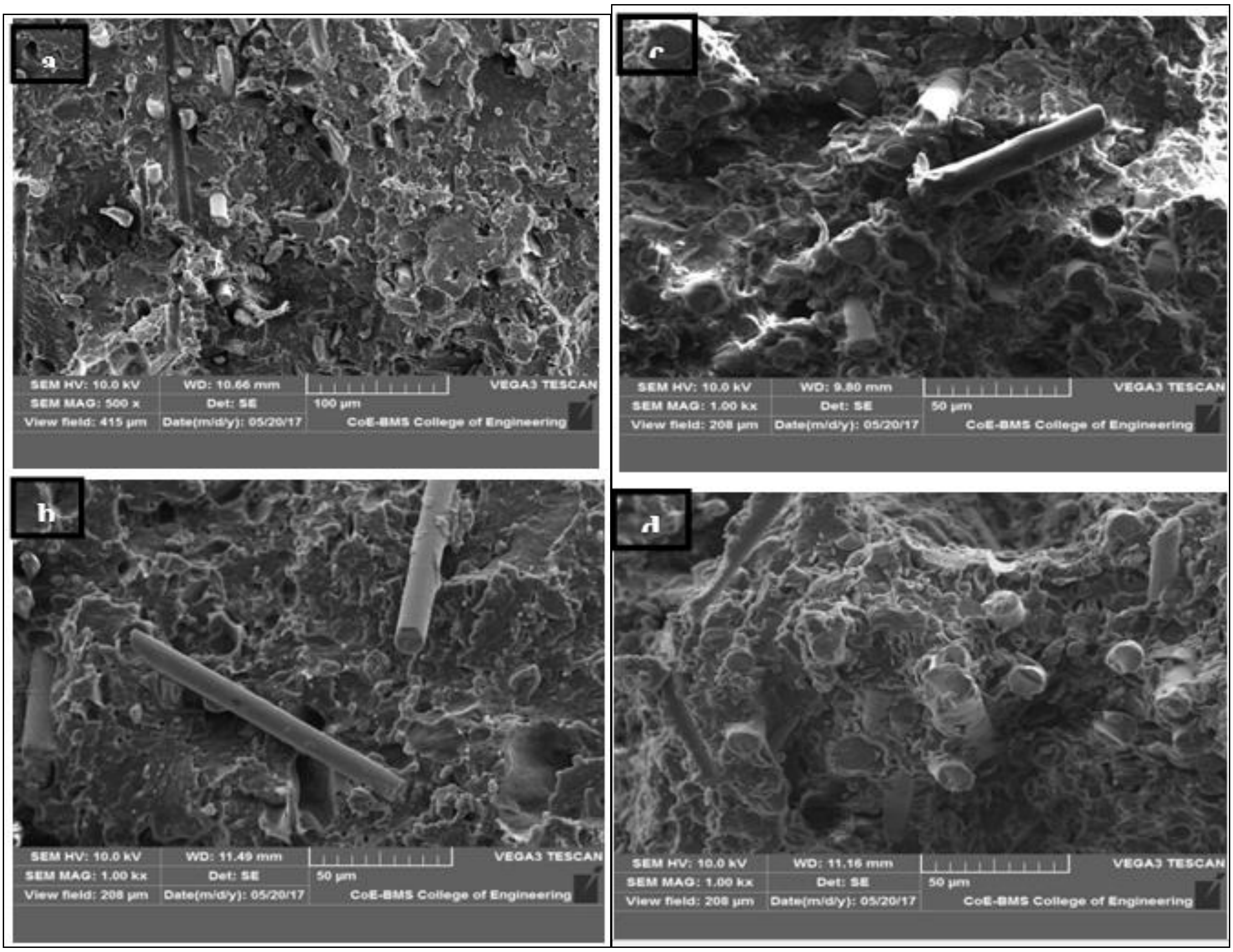

Fig 4: SEM photographs of Fractured Surfaces due to an Effect of Strain Rate (Tensile Properties) of SGF Reinforced PA66/PTFE Composites: a) G1 Composites (5 mm/min and b) G1 Composites (50 mm/min) , c) G6 Composites (5 mm/min) and d) G6 Composites (50 mm/min)

The fractured surfaces of tensile fracture of G1 and G6 composites at a strain rate of 5mm/min and 50 mm/min are shown in the SEM picture in the figure 5 (a, b c and d). The SEM image of tensile fracture of G1 composites at lower and higher strain rates are shown in the figure 5 (a and b). It is clear from the figure; the strain of the composites is purely shared by the matrix only. The plastic deformation of matrix is shown in the figure. Also, less percentage of SGF in the blend does not have the capacity to resist the applied load. Therefore, then credit of tensile strength and also the strain purely goes to matrix. But at higher strain rate, pull out of the fiber was also seen in the figure. Plastic deformation along with the fibre pull out is the mechanism observed during the tensile fracture of G1 composites. The SEM image of tensile fracture of G6 composites at lower and higher strain rates are shown in the figure 4.5 (c and d). It is clear from the figure, that at higher loading of fiber, the load is equally shared by the matrix and the fiber. The SEM image shows the matrix and fiber interfacial adhesion which causes the composites to possess good strength. At higher strain rate, the combined effect of both fiber and the matrix has played the role. Fiber fracture and matrix deformation was seen in the SEM image of higher strain rate.

IV. CONCLUSION

The following facts were drawn during the study on the effect of strain rate on tensile properties of short glass fiber reinforced PA66/PTFE composites. It is proved from the research work that higher loading of short glass fibers could effectively reinforce the composites systems in defining the strength. The effect of different strain rates on the tensile strength of SGF filled PA66/PTFE blend composites is appreciable. The results indicate that the tensile strength of composites studied is a function of strain rates. Higher loading of SGF is not sensitive to the effect of strain rate. The inclusion of SGF has played the major role in enhancing the mechanical characterization of PA66/PTFE/SGF composites. Higher loading of glass fiber

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could significantly improve the mechanical characterization of PA66/PTFE/SGF composites. The ductility of composites was increased to certain extent as an effect of increased strain rate. This improvement in strength is mainly due to increase in strain energy of composites. The morphological study suggested that fiber fracture, fiber pull put and matrix dislocation were some of the important failure mechanisms observed during the study

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