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Synergistic Effect of Hybrid Micro Fillers on Tensile and Flexural Properties of PA66/PTFE Blend Micro Composites: Effect of Strain Rate

Rudresh B M, Ravikumar B N, Madhu D

Abstract: ***Influence of strain rate on tensile and flexural properties of hybrid micro fillers filled PA66/PTFE based micro composites was studied. The materials systems used for the study were Blend (PA66/PTFE)/ Molybdenum Disulphide(MoS_2) (F1), Blend (PA66/PTFE)/Molybdenum Disulphide/Silicon Carbide(SiC)(F2) and Blend (PA66/PTFE)/ Molybdenum Disulphide/Silicon Carbide /Alumina (Al_2O_3) (F3). The micro fillers such as MoS_2, SiC and Alumina were micro fillers for the development of micro composites. These hybrid composites were developed using melt mix followed by extrusion. The effect of high strain rate (5, 25 and 50 mm/min) on tensile strength and (1.33, 2 and 3 mm/min) on flexural strength are studied as per ASTM method. It was observed from the experimentation results that the increase in strain rate increases the strength of composites both in tension and bending. The stress strain behavior is linear I the beginning later it was nonlinear. The hybridization effect of hybrid fillers helps in shearing the load across the matrix. It was noticed that the yield point of composites is a purely dependent on strain rate. The morphology of failure surfaces was studied through scanning electron microscope photographs (SEM). They revealed that the fillers disintegration and fillers dislocations are the failure mechanisms associated with the micro composites***

Index Terms**:** ***Strain rate, PA66/PTFE, Hybrid fillers, Hybridization, tensile, flexural***

I. INTRODUCTION

Polymer composite materials are the better substitutes for metal based one because of ease of fabrication, self-lubricity, stiffness, specific strength and modulus and better performance. It has been proved from research that the blend performance polymer is superior than homopolymer [1]. Polymer blending is most superior among the methods of polymer modification. Also, the mechanical performance of can be significantly enhanced by the inclusion of fillers and fibers into the base matrix [2]. During the transformation of load through fibers or fillers in to the matrix, the composite will be under pure strain. The rate at which the stress is executing in the system composites is of great importance. The mechanical behavior of composites as a function of strain rate is one of the important field to discuss in order to decide the mechanical performance of polymer composites. Many researchers have studied and reported the strain rate effect on mechanical properties of polymer composites. The strain rate effect on tensile and flexural behavior of thermoplastics is of great importance in today’s polymer materials. The tensile behavior as a function of strain rate 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. It was found that flexural strength and modulus of composites were purely influenced due to enhancement in strain rate. Further, the behavior of polymer composites was promoted as an effect of reinforcement [3] – [7]. Further they reported strain rate effect on flexural behavior of glass mat/polyester composites. They observed that the strength has been with increase in strain rate. Sahin and Yayla [8] studied the influence of experimental parameters on mechanical behavior of polypropylene composites. They showed that the tensile behavior of materials are sensitive to the strain rate of experimentation. The tensile properties increases as an effect of increased strain rate. Investigation on the influence of thermal load and strain rate effect on mechanical properties of polycarbonate/thermoplastic polyurethane blends, polycarbonate and talc filled polypropylene composites have been studied [9, 10]. It was observed that the strain rate influenced the mechanical properties of composites studied. Further, they reported that the effect of temperature is very much significant on the strain arte and mechanical behavior. There is a positive deviation of mechanical behavior due to combined influence of temperature and strain rate. The activation volume and energy have been increased due to the addition of talc.

From the aforesaid literature, it is confirmed that strain effect on mechanical behavior of blend is very rarely reported. In addition, flexural behavior as a function of strain rate is very limited in supply. Further, the effect of pure fillers on the performance of thermoplastics blends has not been reported. PTFE is used as filler for wear resistance in many applications. Polyamide 66 is a high strength polymer for mechanical applications. But the Teflon blend based composites is not reported. Therefore, the blend PA66/PTFE is used a matrix for hybrid composites. Further, the hybrid fillers used for the study are MoS_2, SiC and Alumina. MoS_2 is a very good solid lubricant which governs the ductility of the material, SiC is a ceramic filler for better hardness and thermal stability of composites and alumina is a refractory material. The combination of these hybrid fillers resulted a good micro composite. Therefore, this paper focuses on the different strain effect tensile and flexural properties of micro particulates filled Polyamide 66 and Polytetrafluroetheylene

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Rudresh B M, Mechanical Engineering, Government Engineering College , K R Pet, Karnataka

Ravikumar B N, Mechanical Engineering, Bangalore Institute of Technology, Bangalore, Karnataka.

Madhu D, Mechanical Engineering, Government Engineering College , Ramanagaram, Karnataka

(PA66/PTFE) blend based hybrid micro composites. The synergistic effect of hybrid fillers on the tensile and flexural strength of composites are also studied and reported.

II. MATERIALS AND FABRICATION

The materials and source used in this study are shown in Table 1. Also, the composite materials formulations (wt.%) is reported in Table 2.

TABLE 1. MATERIALS DATA AND SOURCE

Material	Designa-tion	Form	Size (µm)	Density (g/cc)
Polyamide 66	PA66	Granules	----	1.14
Polytetrafluroethylene	PTFE	Particles	12	2.16
Molybdenum disulphide	MoS2	Granules	12-20	5.06
Silicon carbide	SiC	Irregular	5-10	3.21
Aluminium oxide	Al_2O_3	Particles	5 - 10	3.95

TABLE 2. FORMULATIONS OF PA66/PTFE BLEND BASED HYBRID COMPOSITES IN WEIGHT FRACTION PERCENTAGE

Composition	Mat. ID	Wt.%				
		PA 66	PTFE	MoS_2	SiC	Al_2O_3
Blend (PA66/PTFE) /MoS_2	1F	80	20	2.5	---	---
Blend /MoS_2/ SiC	2F	80	20	2.5	2.5	--
Blend/MoS_2/ SiC/Al_2O_3	3F	80	20	2.5	2.5	2.5

A. Preparation of Composites through Melt Mix Method

Polymers such as PA66 and PTFE were dried at about 80 ^{0}C for about 48 hours to remove any hydrolyzing and plasticization effects. This mixture is compounded in the compounder and then supplied to the extruder chamber with the help of twin screw extruder (Barbender twin screw extruder). The fabrication of composites has been studied through melt mix method using twin screw extrusion. Finally, injection molding technique was used for the final specimen preparation as per ASTM Methods. The production of composites was discussed in the previous work [12].

B. Measurement of Tensile and Flexural Behavior using different Strain Rates

The mechanical properties of blend micro composites are studied using ASTM methods under different strain rates. The tensile properties were studied through ASTM D 638 at a strain rate of 5, 25 and 50 mm/min with the help of universal testing machine. ASTM D 638 type 1 specimen is shown (Fig. 1). The tensile strength, percentage elongation, peak load and maximum extension are measured using stress – strain curve. Similarly, the flexural test was conducted using UTM. The ASTM D790 method was used for the test. The strain rate of 1.33, 2 and 2.5 mm/min have been used for the test. Flexural strength, flexural modulus, percentage deflection and also the peak load during the test were recorded by using stress – strain curve in bending. Fig. 1 shows the ASTM standard specimen dimensions used for the test.

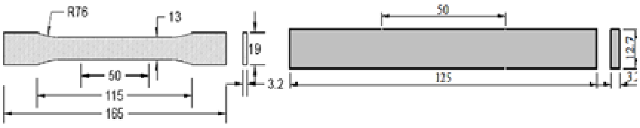


Fig 1. Specimen standards :(a) Tensile test and (b) Flexural Test

C. Morphology of Failure Surfaces

The fractured surfaces of tested specimen were cut without disturbing the failure surface. Then the surface was subjected to gold sputtering for proper conduction of light. The scanned image of the surface through scanned electron microscope (SEM) was recorded as a photograph with different magnification and are analyzed. The voltage used for the study was in the range of 15-20 volts.

III. RESULTS AND DISCUSSION

A. Tensile Behavior of hybrid composites: Strain rate effect

The effect of strain rate on the tensile strength of PA66/PTFE based micro composites is depicted in fig. 2 (a, b and c). The tensile strength as a function of strain rate of MoS_2 filled PA66/PTFE micro composites (F1) is exhibited in fig. 2(a). The tensile strength of F1 micro composites was 63.5 MPa when the strain rate is 5 mm/min. But when the strain rate was 25 mm/min, the tensile strength has been increased to 64.8 MPa which is 2% increase [11]. Further increase in strain rate up to 50 mm/min, improved the tensile strength by 4%. This showed that the tensile strength is purely dependent on strain rate. We believed from Hooke's law that the stress and strain are directly proportional with in elastic limit. Therefore, as the strain increases, the proportionate stress also increases. This can be justified by using the theory of strain energy [9]. As per this theory, the strain energy is a function of work potential and displacement. Higher the work potential, higher will be the strain energy in the material. When the material has been strained using external load, strain energy is stored as a result of strain. The stiffness of the material is one of the factors in judging the reason for increase in tensile strength due to strain rate effect (Table 3).

The variation in tensile strength for different strain rate of PA66/PTFE/MoS_2/ SiC (F2) composites is depicted in fig. 2(b). The effect of SiC inclusion into F1 microcomposites decreases the strength of composites. This is due to brittle nature of materials. Addition of SiC micro filler into MoS_2 filled blend creates agglomeration of fillers and hence voids in the material [10]. This will weaken the compatibility between filler and matrix. The network of composite materials has been broken by the advancement of crack which is the result of void formation. But the strength of composites increases as a result of increase in strain rate. This may be due to synergism of micro fillers. But the combined influence of these fillers (MoS_2, SiC and Alumina) on mechanical properties of blend based composites found to be very much negative on the strength of composites. Further, the loss in ductility of micro composites have been noticed due to inclusion of fillers. Furthermore, effect of strain rate proportionately altered the ductility. Similar observations were made among all the three composites.

The mechanical behavior of micro composites under the influence of synergism is most appreciable. The change in tensile strength among the micro composites studied is seemed to be very less [4]. This showed that the good compatibility of fillers with the matrix blend PA66/PTFE. The loss in ductility of micro composites was moderate because of synergism of micro fillers. The composite PA66/PTFE/MoS_2/ SiC /Al_2O_3 (F3) exhibits least strength due to loss of ductility.

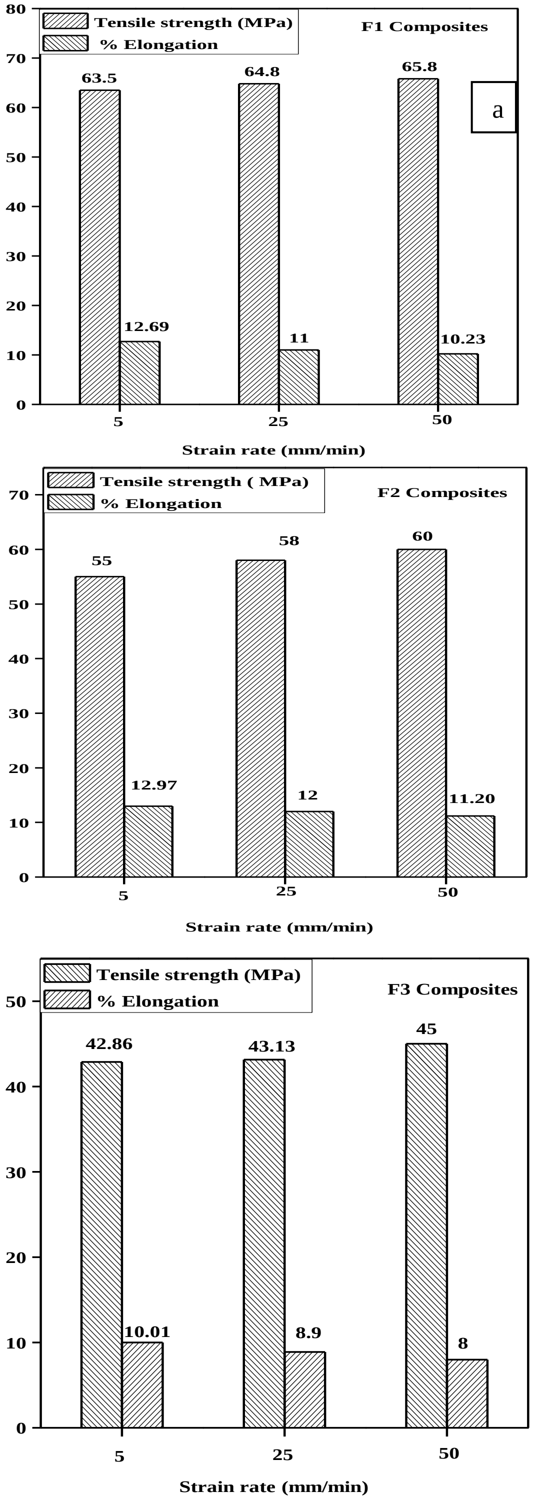


Fig. 2. Variation of tensile strength and % Elongation of PA66/PTFE based micro compositesa s afcuntion of strain rate: a) F1 Composites b) F2 Composites and c) F3 Composites

The strength of these composites is moderate when compared to blend. Among the composites studied, strain rate effect is found to be effectively exhibited by all the three composites. The best strength has been exhibited by PA66/PTFE/MoS_2 (F1) composites. The obtained results matches with the work of others [3,4, 5].

TABLE 3. STRAIN RATE AND ITS EFFECT ON STRAIN ENERGY OF PA66/PTFE MICRO COMPOSITES (TENSION)

Composite	Strain rate (mm/ min)	Ultimate stress (σ)	Max. Strain (ε)	Volume (mm^3)	Strain energy (N-mm) (1/2* σ* ε*v)
F1	5	44	0.2	4673.6	20563.84
	25	47.24	0.2	4673.6	22078.09
	50	51.42	0.26	4673.6	31241.15
F2	5	44.29	0.216	4673.6	22355.32
	25	44.53	0.234	4673.6	24349.5
	50	47.49	0.225	4673.6	24969.29
F3	5	41.83	0.091	4673.6	8895.099
	25	43.79	0.09	4673.6	9209.562
	50	44.29	0.09	4673.6	9314.718

The effect of strain rate on load- deflection (l-d) curve of PA66/PTFE micro composites is exhibited in the fig.3 (a, b and c). The effect of strain rate on l-d curve of F1 composites is shown in the figure 3(a). The l-d curve of F1 composites is linear up to collapsing point. Later, it becomes nonlinear following the declining trend. The higher ductility is exhibited by F1 composites due to the presence of MoS_2 filler. Due to this property, the flatness of curve is seen even after the break point. The shift in curve from 5 mm/min to 50 mm/min is mainly due to the extreme strain of composites. This can be explained by maximum strain theory of composites [9]. The composite material fails when the strain in the composite exceeds or equal to the ultimate strain of composites. Similar observations are made with F2 composites. In this case, presence of hybrid fillers made the material brittle. This has introduced the voids in matrix which promotes the development of cracks [11]. Hence, strength of composites decreases. All the three strain rate effects affect the l-d curve linearly up to the peak point. All the strain rate curves followed the same trend and the ductile nature of composite flattens the curve after the break point. Similar observations are made with F3 composites. In this case, a different behavior of composites has been noticed as an effect of strain rate. Further, all the strain rates curves followed the same trend up to the peak point. But the sudden collapse of the curve took place after the collapsing point. Among all the composites, F1 composites exhibited good l-d curve. In addition, the strain rate of 50 mm/min had the maximum load carrying capacity among all the studied composites.

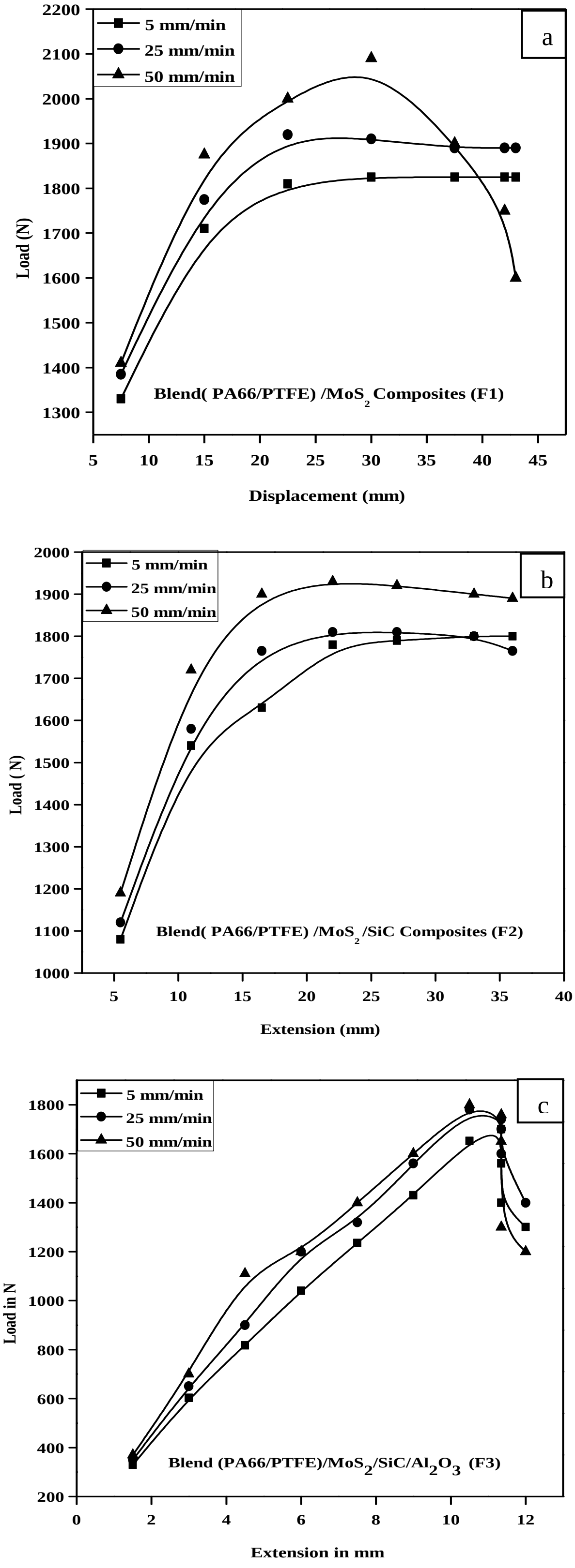


Fig 3. Strain rate effect on stress - strain curve of PA66/PTFE based micro composites: a) F1 composites b) F2 composites and c) F3 composites

The stress –strain behavior of PA66/PTFE micro composites under the influence of different strain rates is depicted in fig. 4(a, b and c). The strain rate impact on s-s curve of F1 composites is shown in the fig. 4(a). The collapsing of composites occurred at a peak point. Initially all the curves followed the same linear trend but later followed the nonlinear trend. This concept of stress –strain can be explained by maximum stress theory of composites [7, 11, 14].

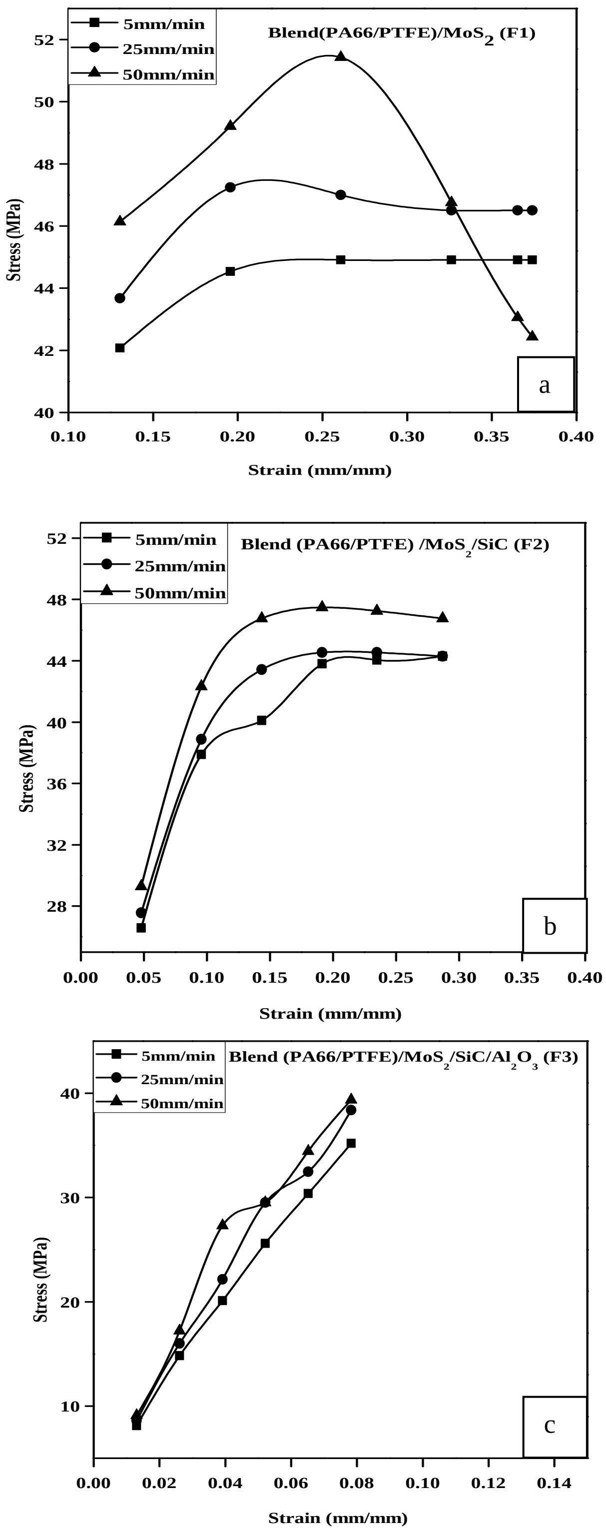


Fig 4. Strain rate effect on stress - strain curve (Tension) of PA66/PTFE based micro composites: a) F1 composites b) F2 composites and c) F3 composites

According to this theory, the failure of composites occurs when the maximum stress in composites exceeds or equal to the ultimate stress. But the effect of filler addition into blend deteriorates the strength as an effect of loss in ductility. Therefore, F2 composites (Fig. (4b)) exhibits the less strength than F1 composites. The formation of micro voids as an effect of inclusion of micro fillers weakened the structure of composites. Further addition of these fillers deteriorates the mechanical strength. In this case (Fig. 4(c)), it has been found that the maximum loss in ductility occurs.

Due to this, the peak point of all the three composites lies at the same deformation. The strain rate always enhances the stress bearing capacity of composites by the loss of elasticity of composites.

B. Effect of Strain Rate on Flexural Behavior of Micro Composites

The impact of strain rate on the flexural properties of the micro composites is presented in fig. 5(a, b and c). The flexural strength of composites decreases slightly as an effect of fillers addition. Addition of MoS_2 into blend deteriorates the flexural strength (F1). This is because of the influence of addition of MoS_2 into the blend which is in ductile nature of. The geometrical compatibility of fillers with the blend resin has been found to be slightly poor which may not transfer the load properly through the fillers in the resin. This leads to loss in strength [10, 12]. Further, addition of SiC into F1 composites further decreases the strength of the composites (F2). The flexural strength is a function of nature of filler, geometrical shape, compatibility and uniform distribution of particles in the matrix [11, 15]. Effect of filler addition in to the blend matrix may create voids which may support the advancement of crack development. Furthermore, the influence of micro fillers addition in to blend (F3) further experiences the loss of flexural strength .This is purely due to less elastic ability as the fillers added decreases the ductility. Filler addition tends the material to become brittle. This may results in loss of strength. Further, effect of MoS_2, SiC and Al_2O_3 on flexural strength witnessed the synergistic effect of hybrid fillers. When comparing the strength of F1, F2 and F3 composites, it is found that not much variation in the flexural strength of composites was noticed. Almost not more than 10% variation of strength has been noticed among the micro composites. This shows clearly that the flexural strength has been influenced due to synergism of potential fillers [8]. Therefore, the synergistic effect of fillers is most significant. The composite blend (PA66/PTFE)/MoS_2 (F1) exhibit the good flexural strength properties among the composites studied. The obtained results are in line with the work of others [3,4, 5, 16, 17]

The strain rate effect (5 mm/min) on flexural properties of F1 composites is presented in fig.5(a). The flexural strength at this strain rate was 103.3 MPa. But the strength of composites was increased by 6% as an effect of increase in strain rate by 400%. Further increase in strain rate up to 50 mm/min resulted a flexural strength of 11% increase. It has been observed from the figure that for F1 composites, the variation of strength versus strain rate was moderate. Similar observations were made with the other micro composites (F2 and F3). Conventionally, addition of potential fillers decreased the flexural strength. The strain rate effect varied due to synergistic effect of micro fillers [3, 4]. But the strength of composites varies in small scale as an effect of strain rate.

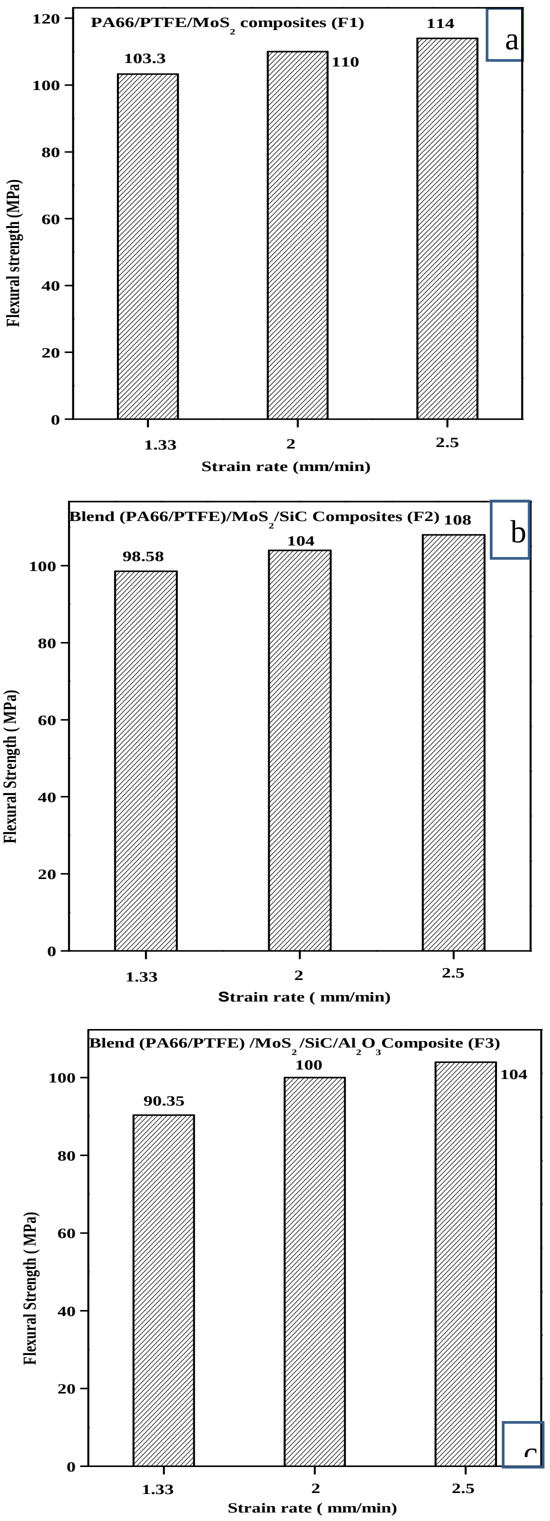


Fig 5. Strain rate effect on the flexural strength of PA66/PTFE based micro composites: a) F1 Composites b) F2 Composites and c) F3 Composites

The enhancement in flexural strength was because of increase in strain energy of composites (Table 4). As an effect of strain energy, the strength of composites increases (Table 4). Among the composites studied, Blend (PA66/PTFE)/MoS_2 (F1) composites exhibits the best flexural strength.

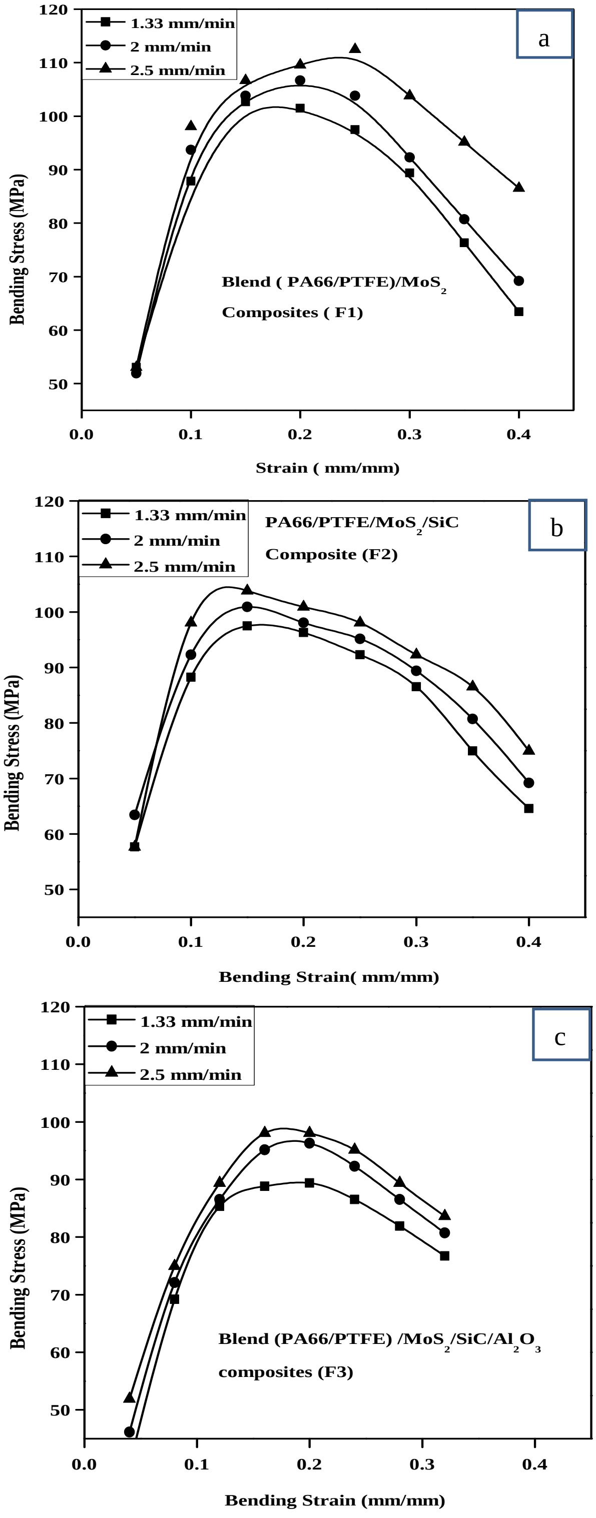


Fig. 6. Stress - strain behavior (Flexure) of PA66/PTFE based micro composites: a) F1 composites b) F2 composites and c) F3 composites

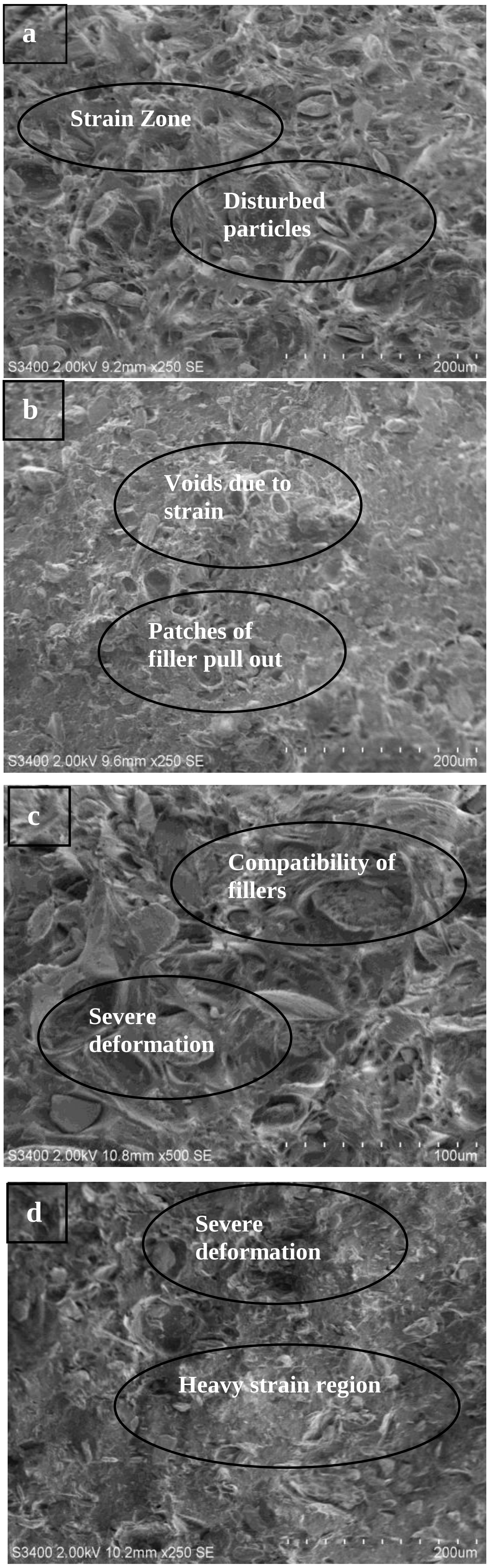
The flexural stress - strain behavior is depicted in fig. 6 (a, b and c). The s-s curve (Flexure) of F1 composites is presented in fig.6(a). It is observed from the figure that the impact of strain rate modeled the s-s curve to follow the linearity up to peak point. After the peak load, curve followed the nonlinear mode. The load carrying capacity of micro composites was slightly enhanced with increase in strain rate. The shift in position of curve F2 and F3 from F1 is due to the effect of strain energy. The strain energy of composites is a function of stress and strain of composites. Among the composites studied, the ultimate strain of composites which is exhibited by all micro composites is around 0.2. Further, slight decrease in ultimate point was noticed due to fillers addition into the blend. Obviously, F2 and F3 composites exhibit lesser strain than F1 composites. Similar observations have been noticed among F2 and F3 composites. Among the composites studied, Blend (PA66/PTFE)/MoS_2 (F1) composite exhibited the highest load carrying capacity [15, 16].

The flexural modulus of composites has been found to decrease due to addition of micro fillers. The modulus of composites slightly increased with increase in strain rate. The flexural modulus of F1 composites at 1.33 mm/min is 5680 MPa. When the strain rate is increased to 2 mm/min, there is a slight increase in flexural modulus (0.5%). Similar observations are made with other strain rates also. This is purely attributed to the synergistic effect of micro fillers present in composites. The combined effect of micro fillers shared the load and transferred effectively to the matrix. Similarly, for all the composites studied (F2 and F3), strength and modulus are very sensitive to the strain rate.

TABLE 4. STRAIN RATE AND ITS EFFECT ON STRAIN ENERGY OF PA66/PTFE MICRO COMPOSITES (FLEXURE)

Composite	Strain rate (mm/ min)	Ult. stress (σ)	Max. Strain (ε)	Vol. (mm^3) (v)	Flexural Modulus (MPa)	Strain energy (N-mm) (1/2* σ* ε*v)
F1	1.33	102.65	0.15	4064	6580	31287.72
	2	106.69	0.2	4064	6612	43358.82
	2.5	112.45	0.25	4064	6715	57124.6
F2	1.33	97.46	0.15	4064	5250	29705.81
	2	100.92	0.15	4064	5352	30760.42
	2.5	103.8	0.15	4064	5372	31638.24
F3	1.33	89.39	0.2	4064	4210	36328.1
	2	96.31	0.2	4064	4320	39140.38
	2.5	98.04	0.2	4064	4421	39843.46

IV. ANALYSIS OF FILAURE SURFACES



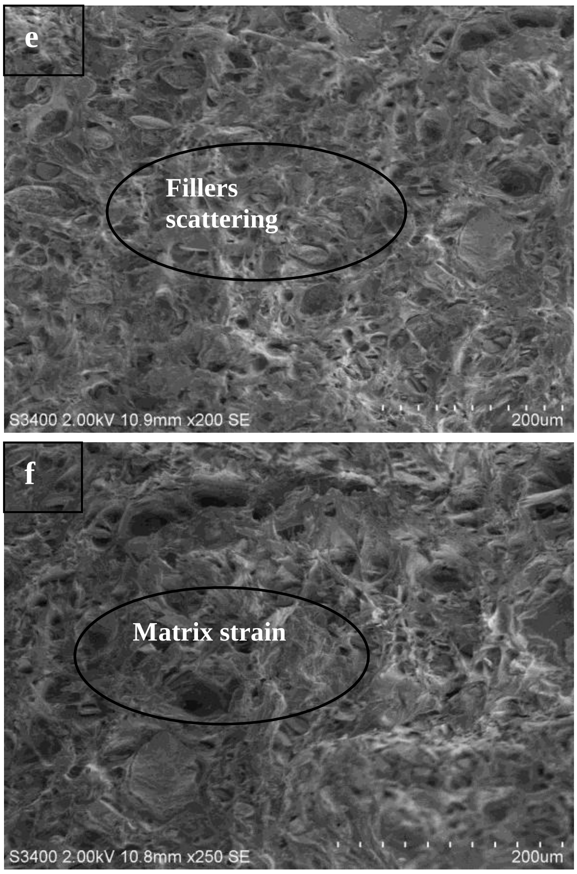


Fig. 7. SEM Micrographs of failure surfaces as an effect of strain rate on tensile strength of PA66/PTFE based micro composites: a) F1 composites : 5 mm/min b) F1 composites: 50 mm/min and c) F2 composites: 5 mm/min and d) F2 composites : 50 mm/min, e) F3 composites: 5 mm/min and d) F3 composites : 50 mm/min

The SEM images of the failure surfaces of F1, F2 and F3 composites at 5 mm/min and 50 mm/min strain rate during tension is presented in fig. 7 (a, b , c and d). Fig. 7 (a) depicts SEM images of the fractured surface under the action of strain rate of 5 mm/min of F1 composites on the tensile strength. It is clear from the figure that all particles disturbed from the original orientation due to the effect of strain. Also, severe plastic deformation is found in the figure. However, due to the presence of MoS_2 particles, the material seemed to retain the ductility of composites [13, 17]. Heavier strain rate effect on the tensile strength of same composite is depicted in fig.7(b). Here the voids due to heavier strain rates were noticed. Also the figure shows the filler pull out impression due to the effect of heavier strain rate. Hence the deformation of composites compared to lesser strain rate is less due to the heavier strain energy. Hence, higher strength of composites.

The SEM micrographs of failure surfaces during tension of micro composites F2 for different strain rates is shown in fig. 7 (c and d). Fig. 7 (c) shows the SEM images of the fractured surfaces under the action of strain rate (5 mm/min) of composites F2. The nature of the material seemed to be very brittle due to the SiC addition into F1 composites. Severe deformation of matrix has been noticed than micro fillers [12]. But the presence of voids in the material seemed to be very less.

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Hence the synergistic effect of fillers. Similar observations are noticed due to the effect of higher strain rate 50 mm/min on the failure mechanisms of F2 composites. From the figure, it is very clear that the effect of strain scattered the particles in different orientations [14]. Due to this, heavy strain regions are exhibited in the figure. Hence, high strain and strain energy. This may improve the strength of composites.

The SEM images of the failure surfaces of F3 composites under the action of different strain rate are shown in the fig. 7 (e and f). The strain rate on F3 composites is moderate due to lesser strain energy. The matrix found to be deformed less due to lower strain rate. But the effect of high strain rate strained both matrix and fillers. The matrix deformation along with scattered fillers is seen on the surface (Fig. 7(f)). But the surface exhibits the moderate deformation.

V. CONCLUSION

The effect of strain rate on the tensile strength and flexural strength of PA66/PTFE based micro composites has been studied along with the synergistic effect of hybrid micro fillers. Obviously, the strength of composites was decreased due to inclusion of micro fillers. The loss of ductility was noticed due to the addition of potential fillers. But the variation of strength among micro composites is very moderate. The effect of strain rate effectively increased the strength of composites both in tension and also in flexural mode. Both tensile and flexural strength of composites was increased due to positive effect of strain rate. This may be due to increase in strain energy of composites. The load carrying capacity of micro composites has been improved due to the strain rate effect. It was found that the strain rate effect increased the flexural modulus of composites. The strength and modulus of composites are very sensitive to the strain effect. The failure surfaces were analyzed through SEM micrographs. Filler pull out, filler compatibility and shape of filler were some of the factors influenced the strength of micro composites. Among the micro composites studied, Blend (PA66/PTFE)/MoS_2 (F1) exhibited better strength

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AUTHORS PROFILE

Rudresh B M: Rudresh B M is working as Associate professor in the department of mechanical engineering, Government Engineering College , K R Pet – 571426, Karnataka state India. Author has obtained Ph.D. degree from Visvesvaraya Technological University, Belagavi in Materials science and Engineering. Author has published his work in more than 40 international journals of repute. Presently working on the ANN concept applied to polymer composites. His field of interest includes FEM, ANN, Fuzzy Logic and CAD/CAM. Author has more than 20 years of teaching experience and guiding three students for Ph.D. degree.