

# Exploring the Sliding Wear Behavior of PA66/PA6 Blend Nano Composites: Influence of Load and Velocity

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**Abstract**—The effect of nano graphene on the dry slide wear behaviour of Polytetrafluoroethylene (PTFE) and Molybdenum disulphide (MoS<sub>2</sub>) filled PA66/PA6 blend composites is investigated. Blend (PA66/PA6) (80/20 wt.%), Blend (PA66/PA6)/10 wt. % PTFE/5 wt. % MoS<sub>2</sub> and Blend (PA66/PA6)/ 10 wt. % PTFE/5 wt. % MoS<sub>2</sub>/2.5 wt. % TiO<sub>2</sub> /2.5 wt. % Nano Graphene are the materials subjected to investigation. These composites were developed using extrusion melt mix method and followed by injection molding. ASTM G99 method procedural steps have been adopted for the wear test. The sliding wear behavior was studied by varying sliding load (25, 50, 75 and 100 N) and sliding velocity (0.5, 1, 1.5 and 2 m/s). It is observed that the synergistic effect of PTFE and MoS<sub>2</sub> was not promising for the wear resistance of PTFE and MoS<sub>2</sub> filled PA66/PA6 blend composites. But the blend showed the better wear resistance than micro composites. Inclusion of TiO<sub>2</sub> and nano Graphene significantly enhanced the wear resistance of Nano composites. This is because of synergism of PTFE, MoS<sub>2</sub> and Nano Graphene. PTFE and MoS<sub>2</sub> would form the uniform polymer film on the steel disc. Further, Nano Graphene has strengthened the polymer film further improving the sliding wear resistance. The thermal effects on the frictional surface was controlled by the micro filler TiO<sub>2</sub>. The impact of velocity is severe compared to sliding load. The SEM images were used for examining the worn surfaces and the reasons for the tribological failure were evaluated.

**Keywords-** Blend (PA66/PA6); PTFE; dry slide wear; Sliding velocity; MoS<sub>2</sub>

## 1. INTRODUCTION

Polymers composites are multiphase materials used in mechanical industries for light weight and frictionless situations. These composites are preferred because of their ease of fabrication, light weight, self lubrication and superior weight to strength ratio. All most all automobile components require finite element analysis where the stiffness plays the major role. Presently, the polymer composites exhibit good specific stiffness. In connection to this, thermoplastic composites showed excellent stiffness and strength over the metallic ones. The conventional materials have already been replaced with polymer based composites in many applications [1]. Polymers properties can be varied through polymer blending, copolymerization and adding fibers and fillers. Filler filled composites are the promising materials for the wear resistance of thermoplastics [2]. It is well proved that the effect of polymer blending is more superior than homopolymer [3, 4]. Some of the best combination for polymer blend is PA66/PP, PA66/PPS, PA66/POM, PA66/PEEK, PPS/PTFE etc. But the response of these composites must be studied seriously under the influence of different process parameters for their wear and frictional behaviors. Fibers and filler addition is one method to improve wear behavior of polymer composites. On the other hand, some investigations revealed that the sliding wear behavior is effectively improved under the addition of only fillers of micro and nano size. The properties of polymer composites can be improved through stiffness, hardness, and heat distortion temperature significantly [5]. The sliding wear behavior of PTFE composite is presented by Unal et al. [6]. The impact of load and velocity on pure PTFE, PTFE/SGF, bronze and carbon packed PTFE composites was reported. Inclusion of these particles and fibers effectively reduced the volumetric loss of PTFE based composites. Further, the specific wear rate was very much sensitive to sliding velocity than the load. Effect of Molybdenum disulphide (MoS<sub>2</sub>) on dry slide wear behavior of SCF filled Nylon 1010 was reported by Wang et al. [7]. MoS<sub>2</sub> filler is most powerful in lowering the frictional effects of nylon but it increases the wear rate. The inclusion of sub micro titanium dioxide particles (TiO<sub>2</sub>) on frictional and wear properties of SCF reinforced PPS composites was reported [8]. The fiber reinforcement up to 15 vol. % and filler addition up to 7 vol. % was reported. It is showed that the highest percentage of reinforcement has lowered the wear. The

synergistic effect of nano graphene on mechanical and thermal properties of PA6/SGF composites was investigated [9]. Nano graphene addition enhanced the mechanical behavior. The strength of the composites studied has been promoted by the inclusion of 1 wt. % nano graphene. Furthermore, increase in weight percentage of nanographene has worsened the mechanical strength. The impact of process parameters on tribological response of SGF reinforced PA66/PTFE blend was studied by Rudresh et al [10]. They reported the synergism of PTFE and glass fibers enhanced the friction properties. This may be due to the presence of PTFE which controlled the wear rate of glass fibers reducing the stress concentration. The impact of sliding pressure on sliding wear properties of PA66/PTFE composites was investigated by Rudresh et al [11]. They studied the effect of micro sized PTFE particles varying from 5 wt. % up to 30 wt. %. Results showed that the further increase in weight percentage of PTFE effectively enhanced the tribological resistance of composites. The impact of addition of nanographene on the tribological behavior of polyvinyl chloride was reported [12]. The study suggested that Nano graphene filler is the best antifriction agent. This is because of the effective wear resistance property of Nano graphene. The sliding wear properties of PA66/ UHMWPE Blends was reported by Wang et al [13]. They stated that the rate of volumetric loss has been apparently declined due to the addition of UHMWPE filler. Further, they proved that positive response of wear resistance is due to good mechanical properties of the blends. The sliding wear response of Polyamide 6 and UHMWPE blends (PA6/UHMWPE) was reported by Liu and Ren [14, 15]. They investigated the response under the influence of surface roughness, sliding load and varying sliding velocity. They submitted that the volumetric loss is very sensitive to sliding load and surface roughness but the effect of distance and velocity was moderate. The dry sliding wear behavior of PA6/HDPE blends with and without compatibilizer has been presented by Palabiyak and Bahadur [16]. They showed that the sliding wear behavior depends on load and composition. Addition of HDPE filler worsens the rate of wear volume loss. Friction and wear mechanism of PA66/HDPE blends was reported [17]. They showed that wear behavior was controlled from PA66 to HDPE as the content of HDPE increases in blend. The tribological behavior of PEEK/PTFE /Potassium Titanium whiskers composites was reported by Xie et al. [18]. They stated that polymer substrate on steel disc could enhance the wear resistance. Chen et al [19] studied tribological response of PA66/PPS/PTFE composites. They showed that the inclusion of PTFE into PA66/PPS blend results in decrease in mechanical properties. The wear performance of the blend was superior by the inclusion of PTFE. Du - Xin et al. [20] showed the impact of solid lubricant like PTFE on tribological behavior of fillers filled Polyamide 6. They observed that the addition of PTFE as an internal lubricant enhanced the frictional performance. But the inclusion of PTFE has impaired the mechanical properties of Polyamide 6.

In the journey of the above literature, the effect of addition of nano filler on the homopolymer is available in plenty. The synergism of fillers on frictional behavior of polymer composites was very rarely presented. But, combined impact of micro and Nano fillers on wear properties of polymer blend composites was not discussed. The present day industries welcoming the applications based on the nanographene. In this connection, the synergism between fillers (PTFE, MoS<sub>2</sub>, TiO<sub>2</sub>) and Nano filler (Nanographene) on wear properties of (PA66/PA6) blend is reported. Therefore, this article deals with the impact of velocity and sliding pressure on wear mechanisms of PA66/PA6 blend Nano composites.

## 2. MATERIALS, PROCESSING AND TESTING

### A. Materials, Processing of Composites and Testing

The material's data used for the production process is shown (Table 1). The data represents the supplier's data. The materials system used for the study and their designations with composition is recorded in the table 2.

TABLE I. MATERIALS DATA USED FOR THE PRODUCTION OF COMPOSITES

Materials	Designation	Form	Size (µm)	Trade name	Manufacturer	Density (gr/cc)
Polyamide 66	PA66	Granules	---	Zytel 101L NC010	Dupont co.Ltd.	1.14
Polyamide 6	PA6	Powder	12-14	Zytel 101L NC010	Dupont co.Ltd	1.12
Polytetrafluoroethylene	PTFE	Powder	10 to 30	Teflon	Dupont co.Ltd	2.2
Molybdenum	MoS <sub>2</sub>		20 to 30	---	Aldrich, Bangalore	3.8

disulphide		Particles				
Titanium Dioxide	TiO <sub>2</sub>	Particles	20 to 30	----	Aldrich, Bangalore	1.92
Nanographene		Nanoparticles	5		United Nanotech	0.17

TABLE II. MATERIALS SYSTEM FORMULATIONS FOR THE STUDY

Composition	Designation	PA66	PA6	PTFE	MoS <sub>2</sub>	TiO <sub>2</sub>	Nano graphene
Blend (PA66/PA6)	U1	80	20	---	---	---	---
Blend (PA66/PA6)/PTFE/MoS <sub>2</sub> (Micro composites)	U2	80	20	10	5	---	---
Blend(PA66/PA6)/PTFE/MOS <sub>2</sub> /TiO <sub>2</sub> /Nano graphene (Nano Composites)	U3	80	20	10	5	2.5	2.5

**B. Materials, Processing of Composites and Testing**

The materials used for the process (Table 1 and Table 2) were dried at a temperature 48 °C for about 24 hours to free up them from moisture and plasticizing effects. The production process consists of two steps. The materials PA66 and PA6 were mixed thoroughly using mixer and subjected to melting process through the extruder chamber. The temperature controlled in the zones of heating chamber in the extruder were 220, 230, 245, 260 and 267 °C respectively. The melt mix of composites has been extruded in the cylindrical form through quenching followed by pelletization [10, 11]. In the second step, the obtained blend pellets were again mixed thoroughly with all micro fillers and Nano fillers. The mixture is then passed through heating chambers in the extruder and is extruded in the form of cylindrical wire. These pellets were once again heated in the chamber and then subjected to injection molding process. The injection molding machine produces the specimens as per ASTM [12]. All the inspected specimens were subjected to testing and defective ones was rejected.

**C. Sliding wear testing of Hybrid composites (ASTM G99)**

The wear testing machine supplied by Ducom, Bangalore was used to conduct the sliding wear experiment as per ASTM G99 method (Fig.1). The samples for the test were prepared using cutting machine and are cut into proper dimensions prescribed by ASTM. The generally used dimensions are 6 mm x 6 mm x 3.2 mm. The prepared specimens were rubbed against smooth abrasives of 600 Grit SiC abrasive paper in order to prepare the uniform sliding surface against the steel disc. The samples to be tested were attached to steel pins of 8 mm diameter and length 27 mm. The weight of the specimen is measured before subjecting them to sliding process along with the pin. The counter surface has been cleaned with the help of soft material using acetone before sliding process to ensure no polymer substrate of previous stroke was present.

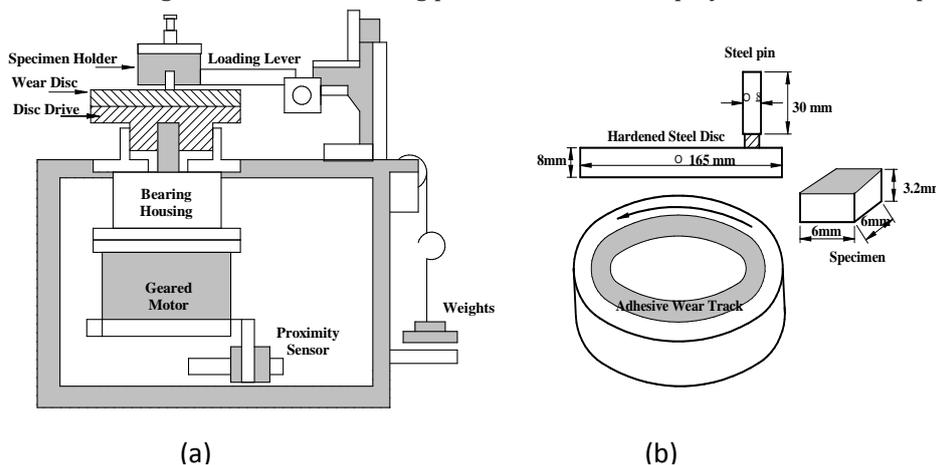


Fig. 1. Sliding wear system for ASTM G99: a) Experimental set up and b) specimen details

The details of the experimentation and the process parameters used for the test as per ASTM G99 are depicted in Table 3. The experimentally determined density ( $\rho$ ) is used to determine the volume loss of composites. The volumetric loss and specific wear rate (Ks) is calculated. The volume loss =  $\delta V = W/\rho$  mm<sup>3</sup>. The Ks =  $[\delta v / (F \cdot D)]$  mm<sup>3</sup>/N - m, where F, applied load in N and D, sliding distance. The experimental details used for the test is shown in the table 3.

TABLE III. THE EXPERIMENTAL PARAMETERS USED FOR THE STUDY

Load (N)	Velocity (m/s)	Distance (m)
75, 100, 125 , 150	0.5, 1, 1.5 and 2	1000

### 3. RESULTS AND DISCUSSION

The sliding wear behavior of PTFE, MoS<sub>2</sub>, TiO<sub>2</sub> and Nanographene filled Polyamide 66 and Polyamide 6 Blend composites was studied using varying sliding load and sliding velocity as per ASTM G99 Method. The sliding load of 25, 50, 75 and 100 N and sliding velocity of 0.5, 1, 1.5 and 2 m/s were selected for the study. The effect of these process parameters were discussed critically and the effect of PTFE, MoS<sub>2</sub>, TiO<sub>2</sub> and Nanographene filler on these thermoplastic blend was discussed effectively to rate the material. It is proved from the experimented values that the tribological response of composites depends on both velocity and load. But the volumetric loss is very sensitive to velocity rather than sliding load.

#### D. Effect of Sliding Load on Wear volume and Specific wear rate (Ks)

The effect of varying sliding load and synergistic effect of micro and nano fillers on the tribological response in dry sliding process of Nano composites was studied (figure 2 (a - b)). The tribological response was studied through weight loss through volume and specific wear rate (Ks). Figure shows that volumetric loss and Ks depends on load and composition of Nano composites. The impact of raise in sliding pressure increases the wear volume. The volumetric loss of the blend (PA66/PA6) at lower sliding load was 0.16 mm<sup>3</sup>. Increased sliding pressure promotes the wear volume loss. Further, the wear loss of the blend at higher sliding load of 100 N was 0.27 mm<sup>3</sup> which is 68.75% increase. At lower sliding load, the deformation of the matrix was less due to poor interfacial friction at the sliding surface [11, 18]. In this condition, very less amount of material has been dragged on to the surface. The wear behavior was controlled by the thermal regime of Polyamide 66 [16, 20]. When the load increases, the severe deformation of the matrix increases causing high wear volume loss. The plastic deformation of the matrix blend at this condition is severe resulting melting of blend composites. At higher load, the thermal regime of the blend PA66/PA6 was not sufficient to prevent from the interfacial temperature effects due to high pressure at the interfacial surfaces [12].

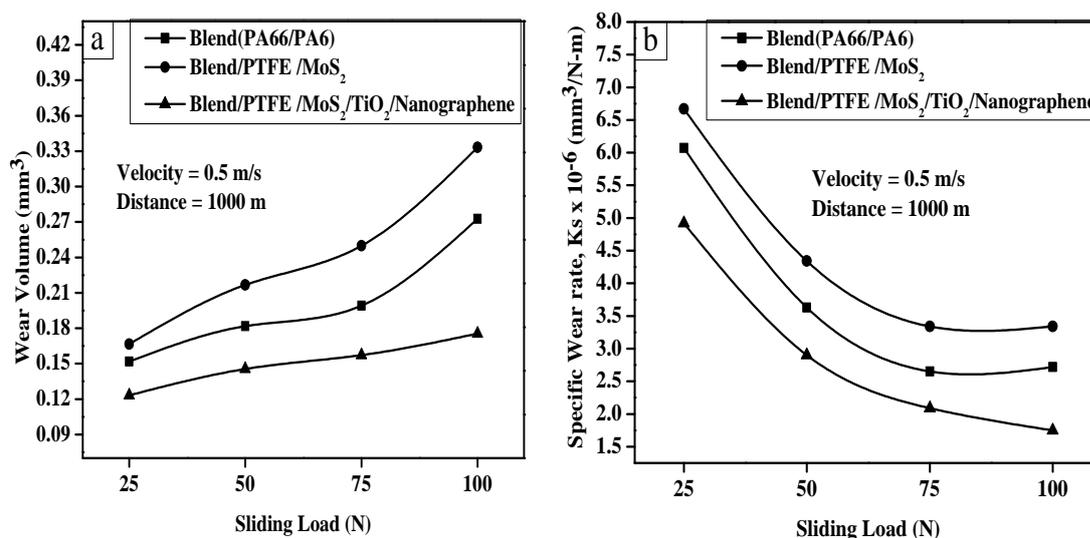


Figure 2. Effect of sliding load on the tribological response of Nano composites: a) Wear volume loss and b) Specific wear rate

But the combined effect of PTFE and Molybdenum disulphide has negative response on the wear behavior of particulate filled composites. But the individual contribution of PTFE in improving the wear behavior was excellent. But the synergistic effect with MoS<sub>2</sub> is totally failed to resist the wear volume loss against the applied sliding pressure. The wear volume loss of

micro composites at lower pressure was  $0.17 \text{ mm}^3$ . But the effect of increase in pressure increases the wear volume loss to  $0.36 \text{ mm}^3$  which is highest loss among the composites studied.

At higher pressure, due to heavy plastic deformation, PTFE was dragged from the polymer on to the steel surface to create a neat uniform transfer film [18, 19]. This PTFE along with the blend PA66/PA6 has formed the high strength polymer substrate on the counter steel disc. But the addition of  $\text{MoS}_2$  in to the thermoplastic polymer film will not react compatibly with the blend instead there was a formation of sulphur compounds on the transfer film. This may tend to lose the strength of the polymer film [7]. Further, the structural integrity of the polymer film has been destructed by the transfer of  $\text{MoS}_2$ . This may cause the failure of polymer film due to development of rough texture on the existing substrate. This may cause high wear volume loss. But synergism of micro fillers and Nano graphene significantly enhanced the wear resistance of Nano composites. At lower sliding pressure, less deformation of the matrix occurs resulting least wear volume loss. But at this stage minimum volumetric loss was exhibited by Nano composites compared to others. But the volumetric loss has been promoted due to heavy deformation. The wear volume loss of around  $0.18 \text{ mm}^3$  has been noticed at higher applied pressure of 100 N. This is 33% and 50% reduction in volumetric loss compared to micro composites and blend respectively at higher pressure. This declined wear volume loss is purely attributed to the highly lubricate nanographene. Addition of  $\text{TiO}_2$  in to the composites controlled the thermal effects at the interface there by avoiding the early reaching of the softening point of the polymer [8]. Further, wear volume loss was controlled because of the inclusion of nano graphene which may control the stress concentration across the structural network of polymer composites. Further, nano graphene enriched the strength of polymer film by controlling the shear force by its layer structure [8, 9]. This reduces the wear volume loss. Figure 2 (b) exhibits the 'Ks' of composites studied. It is well documented that 'Ks' have been declined by increase in sliding pressure. This may be due to addition of  $\text{TiO}_2$  which may control the thermal effects and declined the heavy loss of material due to frictional effects. The wear rate varies from  $6.3 \times 10^{-6}$  to  $3 \times 10^{-6} \text{ mm}^3/\text{N-m}$ ,  $6.7 \times 10^{-6}$  to  $3.8 \times 10^{-6} \text{ mm}^3/\text{N-m}$  and  $5 \times 10^{-6}$  to  $1.6 \times 10^{-6} \text{ mm}^3/\text{N-m}$  for blend, micro composites and nano composites respectively.

The SEM photographs of surfaces subjected to abrasion of blend, micro composites and Nano composites under the influence of higher load is presented (figure 3(a – c)). SEM picture exhibits the smooth surface (Fig. 3(a)). Light deformation of the matrix is seen. This is due to blend (PA66/PA6). Extruded fibrils are not seen on the surface. But SEM image (Fig.3b), large deformed wear tracks are seen. Surface exhibits the rough texture indicating severe wear volume loss. Agglomeration of micro fillers is also seen. But the layer structure is shown by Nano composites because of nanographene (Fig.3c). Further, the material surface looks like ductile surface. The SEM image exhibits the smooth and small deformed surface indicating no agglomeration of fillers. But the abraded surface of nano composites seemed to be worn resistive. This indicates that the volumetric loss is less for these composites.

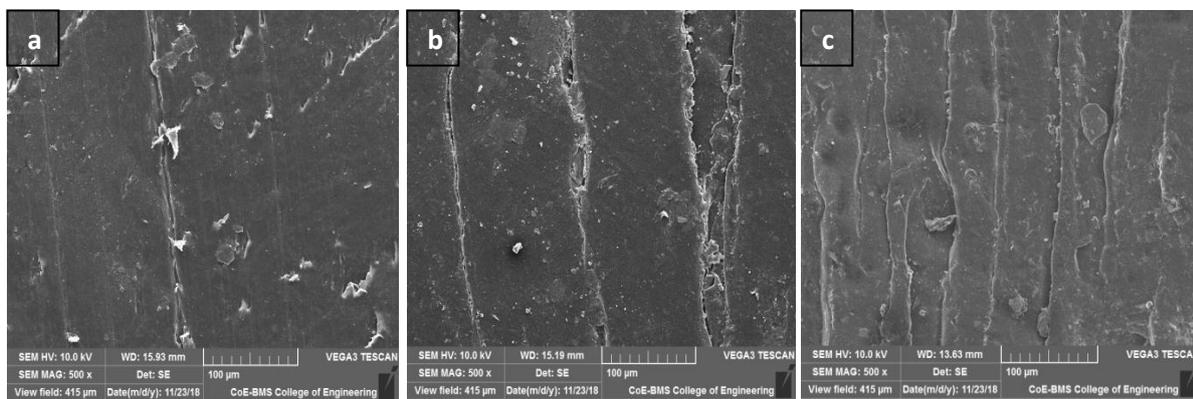


Figure3. SEM photographs of failure surfaces of PA66/PA6 Blend nano composites under higher sliding load (100N) load: a) Blend (PA66/PA6), b) Blend/PTFE/ $\text{MoS}_2$  and c) Blend/PTFE/ $\text{MoS}_2$ / $\text{TiO}_2$ /Nanographene

E. Effect of Sliding Velocity on the Wear volume and specific wear rate (Ks)

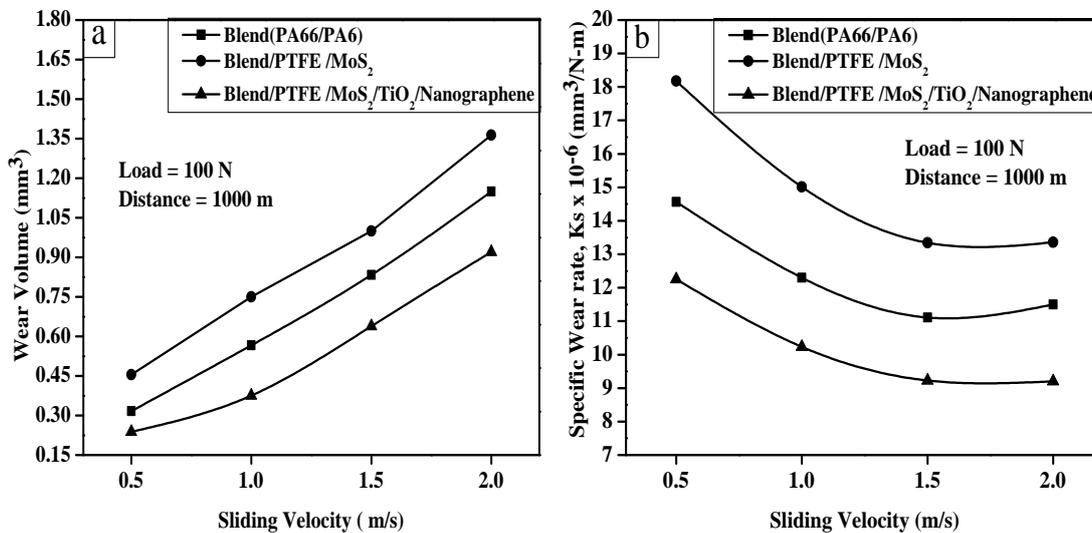


Figure 4. Impact of sliding velocity on wear response of Nano composites: a) Wear volume loss and b) Specific wear rate

Figure 4 (a and b) shows the effect of sliding velocity on the wear volume loss and 'Ks' of PA66/PA6 Nano composites. It is documented through graph that the volumetric loss purely depends on speed and contents of composites. But the tribological response of these composites studied under dry condition is very sensitive to the velocity rather than load. The similar response as that of load is observed. The volumetric loss is less at lower sliding velocity because of the less fractional effects at the interface [21]. But the volumetric loss increases with increase in frictional force at the interface due to higher velocity. The blend exhibited the wear volume loss of 0.27 mm<sup>3</sup> at lower sliding velocity. But the wear volume loss of 1.8 mm<sup>3</sup> has been exhibited by blend at higher speed which is 560% increase. But the micro composites responded with 0.4 mm<sup>3</sup> to 1.4 mm<sup>3</sup> and Nano composites with 0.2 to 0.9 mm<sup>3</sup>. This indicates that the response of the composites against the sliding velocity is more sensitive than the load. Further, the effect of addition of nanographene and TiO<sub>2</sub> superiorly promoted the wear resistance of Nano composites. Micro composites are more susceptible to wear under the action of sliding velocity. The increased wear volume loss of micro composites is due to high frictional effects at the interface which caused the polymer to reach its softening point early [8]. Further, the counter effect by the transfer film on steel disc is not enough to resist the shear force at the interface. Therefore high wear volume loss. But the neat blend (PA66/PA6) has well defined polymer film on the counter steel disc. But the interfacial temperature at the friction surface had broken the neat formed film. But addition of Titanium di-oxide has strengthened the polymer film and avoiding the interfacial temperature across the substrate [8, 11].

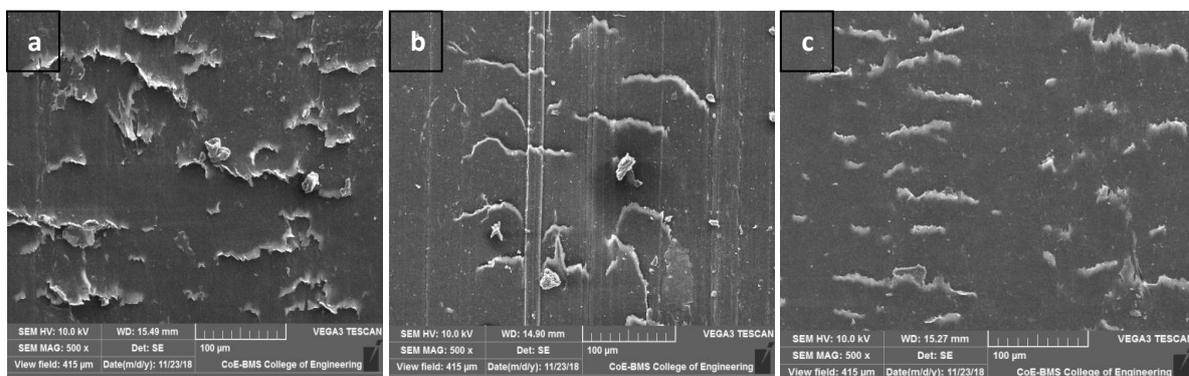


Figure 5. SEM images of the worn surfaces of PA66/PA6 Blend nano composites under higher sliding velocity (2 m/s) load: a) Blend (PA66/PA6), b) Blend/PTFE/MoS<sub>2</sub> and c) Blend/PTFE/MoS<sub>2</sub>/TiO<sub>2</sub>/Nanographene

Addition of nanographene reduced the deformable ability of Nano composites due to improved strength of adhesivity among the fillers in composites [9, 12]. This may reduce the shear force at the friction surface reducing the wear volume loss of the materials. Among the composites studied, Nano composites excelled as the best materials for the wear applications. The SEM pictures of surfaces under the action of higher sliding velocity are shown in the figure 5(a - c). The blend surface clearly indicates that the frictional surface has been subjected heavy melting. The disposed melt due to melting wear is noticed. Further, the surface of micro composites exhibits the melted surface with less melting. This is due to addition of micro fillers (Fig. 5(b)). But the worn surface of the Nano composites is clearly exhibited by SEM image (Fig. 5(c)). But the less melting wear has been resulted from the surface. Further, the surface exhibits the smooth frictional surface due to less friction.

#### 4. CONCLUSIONS

The study on the effect of process parameters on the wear properties of PA66/PA6 Nano composites led to following conclusion:

1. The tribological response of the composites studied is function of sliding pressure and velocity
2. The sliding wear behavior of the composites studied were very sensitive to sliding velocity than sliding load
3. The synergistic effect of PTFE and MoS<sub>2</sub> has negative effect on the wear behavior of Blend (PA66/PA6)/PTFE/MoS<sub>2</sub> micro composites
4. The addition of Nanographene has effectively enhanced the wear resistance of the Blend /PTFE/MoS<sub>2</sub>/TiO<sub>2</sub>/Nanographene nano composites
5. The inclusion of TiO<sub>2</sub> filler has controlled the thermal effects during the friction at the interface
6. The Blend (PA66/PA6) has exhibited the better wear resistance than micro composites
7. The SEM images showed that the matrix melting, plastic deformation and matrix deformation were the major cause for the failure of composites studied
8. Blend /PTFE/MoS<sub>2</sub>/TiO<sub>2</sub>/Nanographene nano composites proved to be the effective ones for the sliding wear applications

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