Impact of Grit Geometry on the Abrasion Wear Behavior of Glass – Basalt Hybrid Thermoplastic Composites

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***Abstract*—**The abrasion wear behavior of Glass - Basalt hybrid composites in two body wear mode under the impact of varying abrasive particle size has been investigated. The blend (PA66/PTFE)(80/20 wt.%), Blend/10 wt.% short glass fiber(SGF), Blend/ 10 wt.% short basalt fiber (SBF) and Blend/ 10 wt.% SGF and 10 wt.% SBF (GB) were the material systems used for investigation. The melt mix method and injection molding were the processes used for the production of these hybrid composites. The abrasion wear test due to interaction of two bodies was conducted through ASTM G99 method. The experimentation response showed that synergistic effect between fibers and matrix played the significant role in enhancing the abrasion wear resistance. The volumetric loss of hybrid composites has been impaired due to increase in the rank of grit size. Further, it is proved that the wear behavior of composites is independent of grit size at higher order of grit. Fiber debonding, microcutting, microploughing and matrix deformation were noticed during the morphological study through SEM image

Keywords- Blend (PA66/PTFE); Hybrid; two body; abrasion effect; basalt fiber

1. Introduction

The severity of abrasion in thermoplastics is one major drawback which limits the scope of thermoplastics in the field of materials engineering. The effect of abrasion in multipass condition during abrasion is one of the major threat to thermoplastics which may lose their importance in mechanical industries. The effect of geometry of abrasive grains and sliding distance are some of the severe parameters which affect the abrasion behavior of thermoplastic composites. Almost 60% of the total failure of thermoplastics is due to abrasion wear [1]. There may be two or three body abrasion effects in applications during the materials performance. The failure of components have been observed in rolling action of mills, bearing applications, clutch plates, friction of tyres and many more. Polymers properties can be varied using their blending, copolymerization and adding fibers and fillers. Fiber 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]. Some of the best combination for polymer blend is PA66/PP, PA66/PPS, PA66/POM, PA66/PEEK, PPS/PTFE etc. The main abrasives used for the testing consists of SiC, Emery, Sand grains, graphite grains and many more because of their severe abrasion effect. There may be a single pass and multipass travel to study the abrasion wear behavior. Multipass condition is the most favorable condition to examine the abrasion resistant of polymers. Further, it was proved that the effect of hybridization improved the mechanical behavior of hybrid polymer composites [4]. Some of the short fibers like glass (SGF), carbon (SCF), basalt fibers (SBF) and Kevlar (SKF) and many more promised to be the best fibers for structural applications. Recent development in research bench has focused their attention towards the tribology of hybrid fibrous composites. SGFs and SCFs are commonly used fibers in the structural applications due to their best combination of modulus, stiffness and strength. Further, the basalt fibers proved that they are also equally competitive with the aforesaid fibers [5]. Many investigations in the field of abrasion behavior of fiber filled composites are presented and the results obtained were discussed critically. The abrasion wear properties of PA66/SGF composites in two body wear mode (2-BAW) was investigated by Kumar et al [6]. They studied the influence of fiber reinforcement up to 30 wt. % in steps of 10 wt. % for varying load of 10 to 30 N. They reported that the volumetric loss and wear rate have been declined because of the reinforcement of glass fibers. The performance evaluation of 2-BAW behavior of SGF and particulate filled Polymethylemethacrolyte (PMMA) composites was made by Kuruvinashetty et al. [7]. They reported the impact of 10 wt. % SGF on wear performance of hybrid composites. They reported that the wear resistance has been enhanced by reinforcing SGF in to the blend PMMA/PTFE. Further, the effect of grit size is the dominant parameter for the wear volume loss. The wear rate has been decreased with increase in glass fiber reinforcement. They reported that volumetric loss has been declined due to increased grit size. The abrasion effect of SGF filled and SCF filled PTFE composites have been investigated by Sahin [8]. They reported the effect based on taguchi approach. The wear volume decreases with the addition of short fibers in to PTFE. Further, SCF and SGF were proved to be the best reinforcement members for the abrasion wear resistance. The reinforcement effect of SGF and SCF with PA6 and PEEK composites was studied by Zsidai and Katai [9]. They studied the effect of load separately on 30 wt. % SGF and 30 wt. % SCF for both the composites. They found that the abrasion resistance experienced by SCF filled composites was better than SGF filled ones. Further they showed that the effect of load is most severe on the abrasion behavior of PA6 composites. The frictional constant of composites decreases with the effect of fiber addition. Investigation on mechanical and 2-BAW properties of fillers filled Polyamide 66/Polypropylene composites was investigated by Ravi Kumar et al [10]. They reported that nano clay filler was unfavorable to abrasion behavior of Polyamide 66/Polypropylene composites. The combined effect of SCF and nano clay improved the abrasive wear resistance. The wear behavior of PA66/PP was strongly influenced by distance, abrading pressure and abrasive grit size. The 2-BAW performance of fibers and fillers filled polymers was studied by Bijwe et al. [11]. The influence of synergism between fillers and fibers on 2-BAW was reported. They reported the effect of carbon filler, graphite, Polytetrafluroethyelne and Molybdenum disulphide filler on short glass fiber reinforced Polyetherimide (PEI), Polyimide (PI), Nylon 6 and PTFE composites. The results showed that in most of the cases the specific wear rate declined with rise in load. But bronze filled PTFE exhibited the good wear resistance compared to all other SGF reinforced composites. They showed that the inclusion of fibers greatly impaired the ductility which controls the abrasive wear behavior. The 2-BAW behavior of PA6 and its composites was studied by Mimaroglu et al. [12]. Different fillers such as 25 wt. % glass beads, 20 wt. % talc and 30 wt. % wollastonite fillers were used as reinforcement phase. It was proved from the abrasive wear volume graph that the lowest wear rate was obtained by glass bead filler. The hybrid effect of SCF and solid lubricant PTFE on abrasive wear behavior of PA66 composites was studied by Tewari et al. [13]. The composites were prepared by varying the composition of both SCF and PTFE in PA66. The SCF varied from 0 to 40% whereas PTFE from 0 to 15%. The combined effect of SCF and PTFE has worsened the abrasive wear behavior. The impact of pressure and sliding velocity on two body abrasion behavior aramid fiber filled PA1010 composites was investigated [14]. The addition of aramid fiber promoted the wear resistance and decreased the frictional coefficient. The wear resistance of composites has been seemed to be best for 15 wt. % aramid fiber reinforcement. The impact of grit geometry and distance on abrasion wear behavior of thermoplastic composites has been investigated [15, 16, 17]. They reported that the wear loss is higher at lower rank of grit size whereas less wear volume loss at higher rank of grit size. The influence of grit geometry on 2-BAW of SGF reinforced PA66/PP blend composites was studied by lingesh et al. [17]. It was noticed that wear volume loss due to abrasion has been resisted because of fiber reinforcement. Further, they concluded that the volumetric loss increases as the size of abrasives increases.

The research work related to fiber filled composites on the abrasion behavior in two body mode has been reviewed. It is observed from the review that the blend concept was rarely discussed. Further, the abrasive wear behavior of fibrous composites reflects the mixed response. Abrasion wear behavior on hybrid fibrous thermoplastic composites is not reported effectively. Thermal effects are some of the major effects involved in the wear process. Basalt fiber is thermal resistant in nature. Impact of this basalt fiber on the abrasion wear behavior is not reported. In view of the above, blend (PA66/PTFE) was used as matrix material in the development of hybrid composites. The combination of glass fiber and basalt fiber has been effectively used for the hybridization of fibers in composites. Further, the abrasion effect under the action of different grain size is very rarely reported. Therefore, this article deals with the study of abrasion wear behavior of hybrid fiber filled thermoplastic composites in two body wear mode by varying the grit geometry. The morphology of the tested composites was subjected to SEM studies and the reason for the variation of abrasion behavior is discussed related to thermoplastics and short fibers.

2. Ease of Use

A. Materials, Processing of Composites and Testing

The material's data used for the production process is shown in Table1. The data represents the supplier's data. The materials system used for the study and their designations with formulations (wt. %) is tabulated (table 2). The processing and development of composites has been carried out using melt mix method followed by injection molding [31]. The materials used for the production process were exposed to the atmosphere before subjecting them to processing. The procedural steps of ASTM G99 method has been adopted for the experimentation of 2-BAW test. The wear loss was recorded using weight loss method. The volumetric loss and wear rate (Ks) are determined by experimentally determined density [31].

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
Teflon	PTFE	Powder	12-14	MP1000	Dupont co.Ltd	2.9
Short Glass Fiber	SGF	Cylindrical	Length = 2 -3 mm	----	Fine organics , Mumbai	2.5
Short Basalt Fiber	SBF	Cylindrical	Length = 2 -3 mm	----	-----	2.45

TABLE II. MATERIALS SYSTEM FORMULATIONS FOR THE STUDY

Materials system formulations for the study					
Particulars	*Mat. ID*	*PA66*	*PTFE*	*SGF*	*SBF*
Blend(PA66/PTFE)	Blend(PA66/PTFE)	80	20	---	----
Blend(PA66/PTFE)/Short glass fibers	Blend/SGF	80	20	10	---
Blend(PA66/PTFE)/Short basalt fibers	Blend/SBF	80	20	---	10
Blend(PA66/PTFE)/SGF/SBF	Blend/SGF/SBF	80	20	10	10

TABLE III. THE EXPERIMENTAL PARAMETERS USED FOR THE STUDY

Experimental Parameters			
Distance	100 m	Velocity	1 m/s
Load	10 N	Grit size	180, 320, 400 and 600 grit SiC abrasive

3. RESULTS AND DISCUSSION

The impact of abrasive grit size on the abrasive wear behavior of GB hybrid fibrous composites is studied under two body wear mode through a abrading velocity of 1 m/s. The load considered for the investigation was 10 N. The investigation revealed that volumetric loss depends on grit geometry. Further, the abrasion wear behavior was influenced by the composition of composites tested. A unique observation made during the abrasion test is that there is a transformation of abrasion process to adhesion process when the rank of grit size increases.

TABLE IV. FACTORS AFFECTING THE TWO BODY ABRASION BEHAVIOR OF GB HYBRID COMPOSITES

Particulars	**GB hybrid composites**			
	Blend (PA66/PTFE)	*Blend /SGF*	*Blend /SBF*	*GB hybrid*
Tensile strength (σ)	66.5	76.81	60	88.5
% elongation (ε)	16	14.45	12	14
Factor (σε)	10.64	11.09	7.2	12.39
Hardness (H)	69	72	60	75

B. Two body Abrasion Effect on Volumetric loss and Wea rate : Impact of Grit Size

The impact of grit size on the volumetric loss and wear rate of GB fibrous composites is presented in figure 1 (a - b). The SiC abrasive grit size selected for the study with an average particle size 180 grit (average particle size of 71 μm), 320 grit (46.2 μm), 400 grit (32.5 μm) and 600 grit (26.5 μm). Figure 1 shows that the volumetric loss of fiber filled composites is purely dependent on grit size and multipass distance. Also, the volumetric loss during abrasion is dependent on the composition of composites tested for evaluation. The volumetric loss of GB fibrous composites and the effect of abrasive grit size are presented in figure 1 (a). It is observed that increase in grit size tends to increase the wear volume loss. The blend exhibited the highest wear volume loss among the composites studied. It was noticed that the wear rate of composites is high at lower grit rank than at higher rank. The volumetric loss due to abrasion was greatly influenced by abrasive SiC particles.

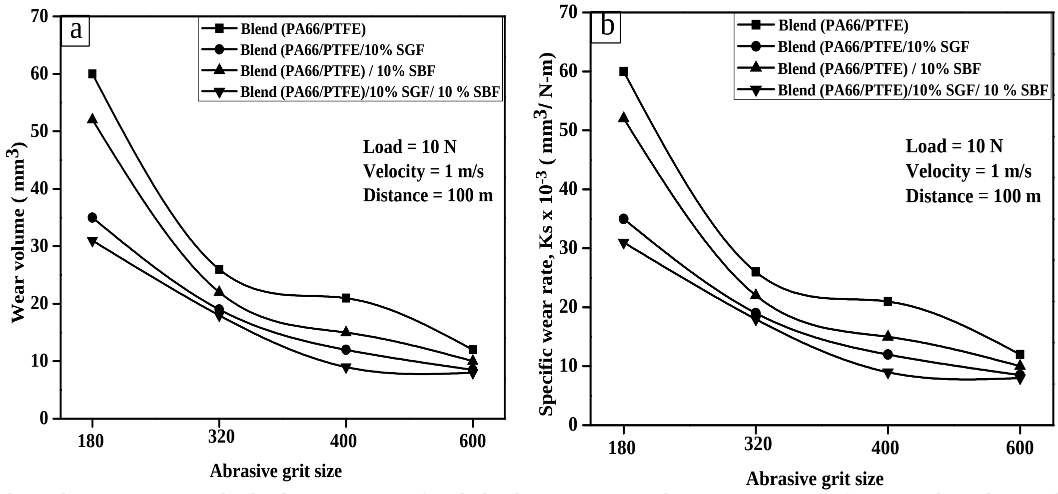

Figure 1. Tribological response in two body abrasion wear of GB hybrid composites with varying grit size: a) Wear volume loss and b) Specific wear rate

Figure 1 shows the tribological response of fibrous composites under the impact of different grit size. It depicts that increase in rank of grit size significantly increases the wear volume loss. The influence of grit geometry on 2-BAW of PA66/PTFE blend is exhibited in figure 1 (a). The volumetric loss of blend for 180 grit is 60.6 mm^3. The higher rank of grit size decreases the volumetric loss. 12.52 mm^3 of wear volume loss was experienced by blend for 600 Grit SiC paper which is 79.33% decrease. This is due to the large sized coarse abrasive particles of 180 grit abrasive paper and small fine grain size of 600 grit abrasive papers respectively. The abrasive wear volume loss of fibrous composites followed the same trend but slightly below the wear values of neat blend. The wear volume of 34.6 to 8.5 mm^3, 51.25 to 10.23 mm^3 and 31.26 to 8 mm^3 was obtained by SGF filled, SBF filled and GB Hybrid for 180 and 600 grit SiC abrasive paper respectively. For higher grit size of particles (180 grit), 42.9%, 15.4% and 48% decrease in wear volume loss was experienced against the blend by SGF filled, SBF filled and GB hybrid composites respectively. As the rank of grit size was increased, the wear loss of composites decreases and stabilized to a constant value. The abrasive wear performance of the blend against 180 grit was poor because of large sized abrasive particles ploughed severely low modulus matrix removing more volume of material [6, 10]. High wear volume loss of material was due to severe cutting and ploughing action of these coarse grits abrasives particles against the soft polymer. The actual contact area between abrasive grains and asperities decreases due to large size of abrasive particles on the polymer surface [16, 18]. Therefore, the contact stresses at these junctions were high for the applied normal load which leads to advancement of crack removing more volume of material. As the rank of grit increases, wear volume loss of material decreases slightly. This is attributed to smaller fine grain size of abrasive grits. The volumetric loss due to abrasion of composites strongly depends on the geometry of abrasive particles. The performance of SGF filled composites against abrasion in two body wear mode is better than blend. This is because of reinforcement effect of high modulus SGF in to the blend. When SGF filled composites abraded against 180 grit abrasive paper, high wear volume loss was noticed due to the penetration of hard abrasive particles into the soft polymer matrix. The deformed matrix has been dragged by these abrasive grits exposing hard SGF to abrading surface. By this time, the abrading efficiency of grains reduces to lower value and sufficient amount of fracture energy was not available to fracture SGF filled composites. Therefore, high abrasive wear resistance. As the rank of grit increases, the wear volume loss of composites decreases and reaches a steady value. This is due to the successive decrease in abrasive size. The transition from abrasion to adhesion process results in low wear volume loss [10]. The fine sized abrasive particles (600 grit) fail to abrade the material with fine cutting resulting low volumetric loss. The poor abrasive wear resistance of SBF filled composites than SGF filled ones is due to inferior mechanical properties of composites which could control the abrasive wear behavior. The abrasion wear factor ‘σε’ is low for SBF filled composites. But the substantial abrasion resistance is due to hardness of composites. At larger abrasive size, the wear volume loss of blend and SBF reinforced composites was higher than SGF filled composites and followed the same trend at increasing order of grit. The effect of abrasion due to varying geometry of grit on SBF reinforced composites followed the same trend. But the appreciable wear resistance has been retained by SBF filled composites. The fact about this can be attributed to basalt fibers that can retain their strength even at high temperature. Therefore, the fracture energy of SBF filled composites was better than blend. This leads to have better wear performance than neat blend.

The improved abrasion wear behavior of GB hybrid composites under the effect of varying grit size was due to exceptional mechanical properties, high hardness and effective adhesion between fiber surface and matrix. The factor 'σε' is high for GB hybrid composites which controlled the abrasion wear of composites [31]. At higher abrasive size, deformation of large abrasive particles by hard fibers resulted low wear volume loss. The deformation energy of GB hybrid composites was more which is most required for the abrasion wear resistance [31]. The abrasive particles were ruptured under the influence of fiber rubbing load which deactivates the abrasive surface. As the rank of grit increases, the wear volume loss decreases as there was a state of wear transition from abrasion to adhesion by forming a suitable polymer transfer film on the surface of abrasive paper [27, 28]. Due to clogging process, the wear volume loss of composites is less. Therefore, hybrid fibrous composites are most promising composites for abrasive wear resistance. The investigated results are matching with the findings of others research work [1, 11, 21, 25, 26]. The impact of grit geometry on 'Ks' of GB fibrous composites is presented in figure 1 (b). Figure shows 'Ks' of composites decreases as rank of grit size increases. The 'Ks' of neat blend at 180 grit is 60.6 x 10^{-3} mm^3/ N-m. The decrease in abrasive grain size decreased the wear rate of blend. The blend exhibited the wear rate of 12.5 x 10^{-3} mm^3/ N-m at 600 grit abrasive grit which is 80 % decrease over 180 grit abrasives. Similar observations are made with fiber filled composites. The wear rate varied from 34.6 x 10^{-3} to 8.5 x 10^{-3} mm^3/ N-m, 51.25 x 10^{-3} to 10.2 x 10^{-3} mm^3/ N-m and 31.26 x 10^{-3} to 8 x 10^{-3} mm^3/ N-m for SGF filled, SBF filled and GB hybrid composites respectively between the range of grit size. The higher wear rate is due to abrasive cutting and ploughing action of grits. The decrease in material removal rate is due to poor particulate size [18, 20, 29]. As the grit number increases, the fine and medium grade abrasives rub the surface. But at 400 and 600 grit abrasives, almost equal volume of wear loss is exhibited by the composites studied. This is due to finer abrasive grain size. Also, at this condition, the wear rate of composites studied becomes independent of grit size. The SBF filled composites showed the highest wear rate among fiber filled composites due to its least Ratner –Lancaster factor [16]. Among the composites studied, GB hybrid composites exhibited the highest abrasive wear resistance.

Figure 2 (a - h) shows SEM images of worn surfaces of GB fibrous composites abrading against 180 and 600 grit abrasive paper under the influence of normal load (10 N) for 100 m abrading distance. The morphology of abraded surfaces revealed that micro cutting mechanism was dominant at higher abrasive size followed by ploughing action of grits. Figure 2 (a) depicts the SEM images of the abraded surface of blend PA66/PTFE rubbing against 180 grit abrasive paper. The heavy matrix damage is noticed because of the penetration of large sized abrasive particles on soft polymer surface followed by abrasive cutting and ploughing actions. The abrasive wear tracks are deep and wide due to heavy penetration. But the abraded surface of the same blend rubbing against 600 grit SiC abrasive paper reflects thin and fine grooves. This is because of smaller size of abrasives (Figure 2(b)). The smooth worn surface of same blend indicates the wear mode transition from abrasion to adhesion (600 grit SiC). The SEM images of abraded surfaces of SGF filled composites under the action of abrasive grit size are shown in figure 4(c and d). The surface reflects that the SGF filled composites were over abraded due to large abrasive particles. In this case, low modulus matrix deformed initially followed by fiber micro cracking [18]. The abrasive grits damaged the fiber – matrix interface. The fiber filled composites failure initiated with micro cutting followed by fiber fracture. The hard SGF filled composites resisted further loss of material. There are some traces of fiber pull out due to abrading of fiber – matrix interface (Figure 2(c)). But the surface abraded against 600 grit SiC abrasive paper seemed to be very smooth with very thin damage to fibers and matrix. A thin polymer layer is seen on the surface rubbed against 600 grit SiC abrasive paper with fine penetration of abrasive particles (Figure 2(d)).

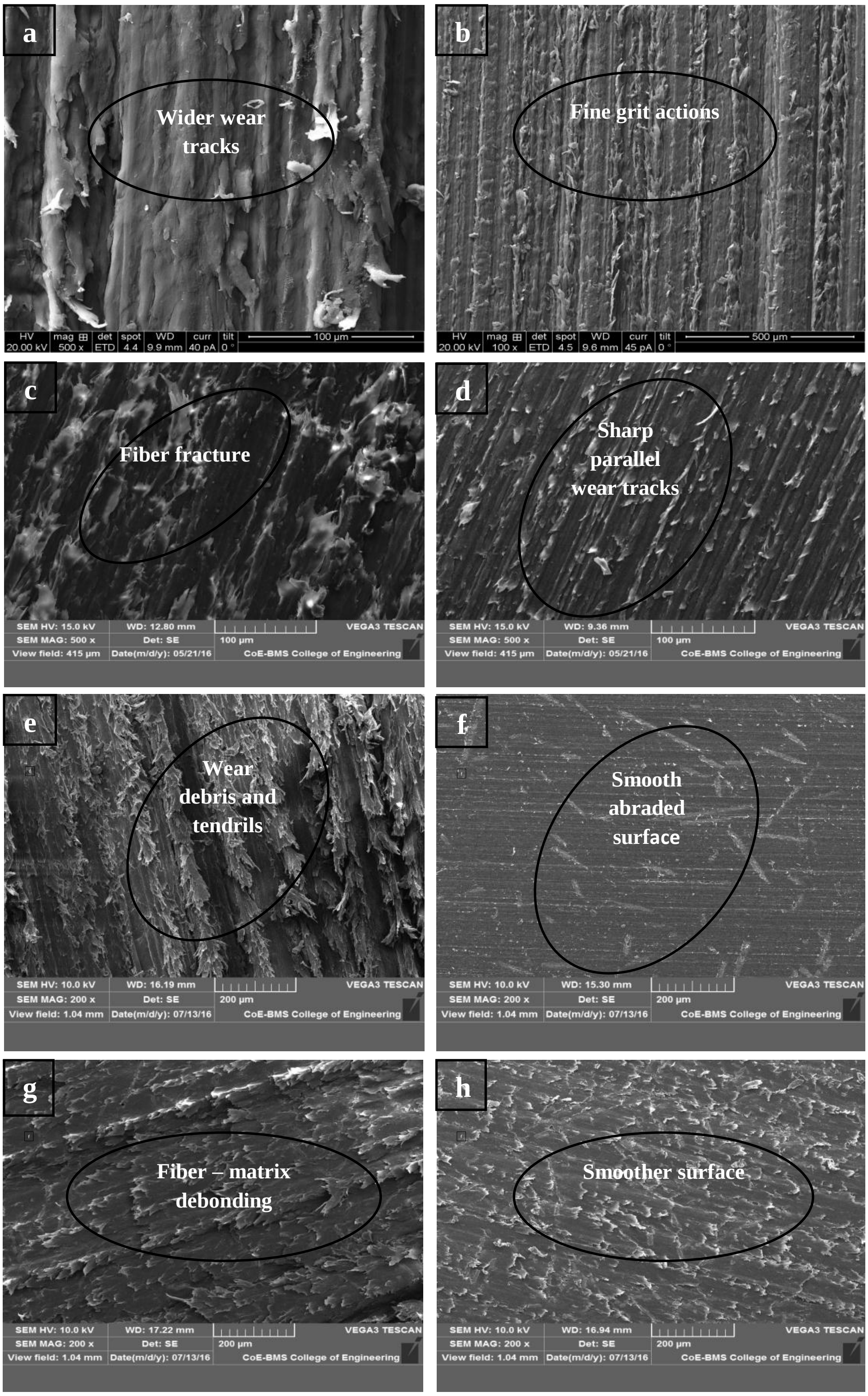

Figure 2. SEM images of the worn surfaces of 2-BAW behavior of GB hybrid composites for varying grit size : a) Blend (PA66/PTFE) (180 grit), b) Blend (PA66/PTFE)(600 grit), c) Blend (PA66/PTFE)/SGF(180 grit), d) Blend (PA66/PTFE)/SGF (600 grit), e) Blend (PA66/PTFE)/SBF (180 grit), f) Blend (PA66/PTFE)/SBF (600 grit), g) GB hybrid composites (180 grit) and h) GB hybrid composites (600 grit)

4. Conclusions

The impact of varying grit size on the abrasion wear behavior of GB hybrid composites was studied. The investigations lead to conclude the following:

1. The abrasion wear behavior of Glass – Basalt (GB) hybrid composites is more sensitive to abrasive geometry
2. The Glass-Basalt combination for hybridization has been proved to be the best for two body abrasion behavior of hybrid composites
3. The blend (PA66/PTFE) proved to be best matrix for hybridization
4. The volumetric loss of hybrid composites due to abrasion is a function of abrasive grit size and is independent of grit size at higher ranking of grit
5. The abrasion wear behavior of SGF filled composites was superior than SBF filled composites
6. The clogging of wear debris is the major cause to prevent the volumetric loss of hybrid composites
7. The morphology concludes that the fiber debonding, microcutting, microploughing and fatigue are some of the mechanisms which altered the abrasion behavior of composites
8. Among the composites studied, GB hybrid composites proved to be the best composites for two body abrasion effect under the effect of grit size

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