Hardness and Surface Scratch Resistance of Basalt/Bagasse fibre Reinforced Poly Lactic Acid Polymer Composites

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Abstract — *The scratch behaviour of the Basalt/Bagasse fiber reinforced Poly (lactic acid) hybrid composite is investigated to understand how the mechanical retaliations of plastics which undergo an induced scratch deformation by a diamond tip under a constant load and linearly increasing normal load."Aesthestics, where visible scratches reduce the products quality". In this work scratch test were performed with constant normal loading and linearly increasing normal load conditions. An attempt has been created to gauge the scratch deformations supported visual, optical observations of failure and fracture mechanisms and morphological surface examinations through Scanning electron microscopy(SEM). Elastic deformation dominates underneath high hundreds within the total deformation. The scratch deformations dependent on the type and physical nature of the wt % of the material added. Scratch sub surface erosion damage in polymers is studied using SEM images. It is observed that the parabolic shear is a the main cause of the plastic flow, while viscoelastic nature on the surface and shear induced fracture on the surface of PBaBg I, III & IV composites are the main damage mechanisms found in the fracture scratch pattern.*

Keywords — *Hardness, Basalt/Bagasse fiber, Scratch Coefficient of friction, poly Lactic acid, Scratch Resistance.*

I. Introduction

Surface damages and Scratch resistance related researches and evaluation has been moving for more than a century. Since, there is a necessity to redefine the scratch resistances in plastics, because of their extended usage in most of the thrust areas like electronic, household, optical and mostly nowadays large scale automotive applications which demands high surface quality. Many works was done by relating scratch hardness to the indentation hardness. During 1950's, Tabor meaningful work on metals in connection with the study of scratch behavior involves in the construction of first scratch testing device [1, 2]. Due to the recognition of the quality of being worthy and importance of surfaces, interconnected boundaries in the past few decades, the study of surfaces and interfaces has noteworthy of awareness from educational research institutes and manufacturing units viewpoint in various applications and purposes like friction reduction microscopy techniques.

Aesthetics and quality product appearance is important parameters in which product developers and consumers aspire for different products. As plastics are comparatively soft and it can be scratched very easily, which in turn leads to stress accumulated susceptible permanent damage. In studying polymer scratch behaviour, aesthetics, structural integrity and durability are three main areas to be addressed. "Aesthetics, where visible scratch reduce the products quality". Poor durability led to damage of the hidden substrate. In case of structural integrity surface quality is a must; especially food packaging films liable to be influenced to scratches can lead to failure, thus spoiling the contents inside the pack. It is a must to conduct proper and suitable testing methodology that will give the better interpretation of polymer scratch behaviour possible. Scratches over the surface reduce the surface integrity and aesthetics of many products. Many types of Scratch deformation processes includes fully elastic, elasto-plastic, ironing, wedge formation, tearing, groove formation, edge crack, and chipping, depends on scratch velocity and indenter tip angle [3]. Most of the applications are concerned with scratch behaviour called visibility. It is because of scattering light due to rough or non uniform features. It includes cracks, molecular orientation induced at the time of scratching and crazes. Mechanical parameters like strength, robustness, and modulus have remarkable influences on the scratch resistance of polymers and composites [4,5]. Since the scratch resistance is reliant on bulk mechanical strength, it is much significant to enhance the function of polymers to have high scratch resistance composites. The genesis of scratch concept over the polymer surface findings was given by Briscoe et al. 1996 [4,6] which provides many data's regarding the material parameters like scratch velocity, modulus and ductility. Wong et al. [7] exhibited the various aspects of devices used to conduct scratch test and different evaluation methods like the single though pendulum test [8,9] pin-on-disc test[10], the pencil test[11], Taber scratcher[12], the Revetest scratch device and the Ford Five- Finger test. The industrial standard scratch test method was formulated by Ford Motors called as FTLM (Ford Lab Test method), a constant load scratch test. Atomic force microscope (AFM) and an acoustic emission device, was developed by CSEM Company to conduct scratch test. [13, 14].

Progressive load scratch tester gives the load displacement information during scratch and residual scratch profile after scratch. Briscoe et al. [15] analyzed the impact of normal load, sliding speed, cone angle of indenter, and surface smoothness by oiling. Jiang et al. [16] in his study experimented four different types of test modes for the scratched surfaces. A scratch progression map has been developed for ductile polymers where the indenter tip causes plastic flow drawing and settles down with fish-scale pattern. Whereas, brittle polymers reveals scratch visibility periodic cracking. Jiang emphasized for better external appearance, strong mechanical properties are favorable in designing scratch resistance to be considered. Liang et al. [17] during his study on comparison between the tensile properties and scratch performance of (ABS) revealed that the decrease of tensile strength due to increase of rubber content in Acrylonitrile-butadiene-styrene forms surface cracking very earlier and plowing. Different instruments like AFM, SEM and profilometry and were used in quantifying recent studies on scratch resistance in polymers. Several scratch test methods were newly developed and reported by many researchers. In the past few decades, accepted ASTM/ISO scratch test standards which move forward for many more standardized and susceptible of the scratch resistance of polymers [18]. Recent researchers give importance to PLA a best biodegradable material known for its remarkable merits like high transparency, ease of processability, excellent biodegradability and good compatibility [19]. The present work aims to study the scratch behaviors of PLA Polymer hybrid composites with different weight formulations under scratch deformation by a diamond conical tip."In this work scratch test were performed with Constant normal loading and linearly increasing normal load conditions".

II. Experimental

A. Materials

The hybrid composites used for the study are commercially available Poly Lactic acid (PLA) as matrix material with 3052D bio-polymer designed for injection moulding application. PLA were collected from Nature Tec, Chennai, Tamilnadu. Basalt fiber and bagasse fibers is taken as reinforcements. A silane treated Basalt fiber used was obtained from Muktagiri enterprise, Mumbai. Raw Bagasse fiber from Padalam sugar factory. Padalam, Tamilnadu, India.

B. Sample preparation

Pla, Basalt and Bagasse were dried around 80°C for 12 hrs in a vacuum hot oven, prior to melt processing. Then pure PLA with hand mixed reinforcement fibers was co- extruded from twin screw extruder and hot melt extruded pellets were injection molded as per ASTM standards. Table 1.shows the four different weight formulations of PBaBg hybrid composites. Fig. 1.shows the PBaBg hybrid Composites specimen before test

Table 1. Formulation of Basalt/Bagasse PLA Composite

Composites	PLA Wt(%)	Basalt Wt(%)	Bagasse Wt(%)
PLA	100	00	00
PBaBg I	83	10	07
PBaBg II	84	12	04
PBaBg III	85	10	05
PBaBg IV	86	08	06

Figure 1.PBaBg hybrid Composites specimen before test

C. Scratch testing

Figure 2. Scratch Test setup

The scratch test was conducted DUCOM Scratch tester TR-101 shown in Fig. 2. specifications are as follows, Normal Load and Tangential force from min of 0 to max of 200 N. Max stroke length 50mm, max speed 10 mm/sec, pitch 5mm, loading rate 2 and 20N/sec, Diamond indenter Rockwell C, with tip radius R200 micrometer at a temperature of min. 15°C to max 40°C. Two scratch modes were used namely Constant (Fixed) Load scratch test (CLST) and Progressive Loading scratch test (PLST). The samples were tested according to ASTM D 7027-05 standardized test method by executing scratch runs along the path at the constant normal load of 20 N, scratch length 5.0 mm and scratch velocity 0.5 mm/sec at room temperature. Moreover, progressive loading scratch test was from initial load of 0 to 20 N, the loading rate was 2.0 N/sec, scratch velocity 0.5 mm/sec and again with a scratch length of 5.0 mm.

D. Scratch Damage Quantification

Scratch test specimens from Fig. 3. Provides Scratched specimen surface of PBaBg hybrid composites. Figure 3.shows the scratched surface flat. To allow the viscous and elastic recovery nature for the specimens subjected to scratch test, scratch damage investigations were carried out after 24 hrs. The test proceeds by recording Tangential force, Normal loading and the coefficient of friction during the tip make scratch over the specimen surface. thespecimens were examined by Scanning electron microscope to examine the onset formation of macro-cracks. The scratch coefficient of friction, normal load, Tangential force, sliding distance and slope were monitored and documented through data acquisition system.

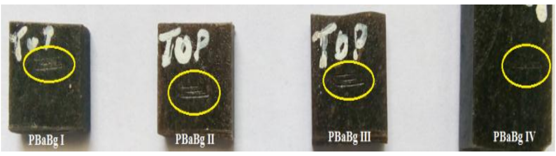


Figure 3.Scratched specimen surface of PBaBg hybrid composites.

E. Micro hardness

Micro hardness tester is used to measure the hardness of fabricated composites. Surface Vickers hardness Hv values were determined according ASTM E384-99 (Standard test method for Micro indentation hardness) on micro hardness HMV tester with a diamond pyramidal indenter. Vickers hardness values have been calculated using the formula Hv = 1.8544 P/ D2 Kg/mm2. Where Hv is the Vickers micro hardness number, P – applied load in Kg, D - indentation mean diagonal length in mm and 1.8544 is the geometrical shape constant of diamond pyramidal indenter. This machine a diamond pyramidal shape impression- whose diagonals length D is measured by using a micrometer eyepiece, the load P was 1kg applied for 10 s in each trial. Averages of a minimum of seven readings were reported.

F. Surface damage investigation

SEM observations were done to check the effects of orientations of the fiber, deformation mechanisms during scratch and trace morphology. A field emission SEM – JOEL 6061 was used to conduct the crystallinity morphology observation sputter-coated with thin layer of gold, at an accelerating voltage of 3.0 KV.

III. Discussion

A. Hardness

The hardness testing repeatability values are illustrated in Table 3. and hardness values for different wt% of PBaBg composites are shown in Table 4 Hardness is the measure of capability of a material to counter-act against plastic deformation under indentation. The hardness values of PBaBg composites are shown in table.

Table 3. Hardness repeatability values of PBaBg Composites

Vickers Micro Hardness (Hv)			
PBaBg I	PBaBg II	PBaBg III	PBaBg IV
339	351	328	367
401	387	399	342
368	413	383	392
389	353	354	400
355	408	350	371
347	390	360	350
370	403	345	386

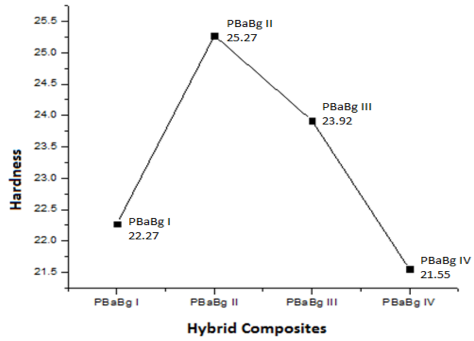


Figure 4. Vickers hardness of PBaBg composites

Table 4. Vickers hardness with Wt % of PBaBg composites

PBaBg I 83/10/07	PBaBg II 84/12/04	PBaBg III 85/10/05	PBaBg IV 86/08/06
22.278	25.27	23.92	21.55

The results revealed that the increased hardness of the composites with addition of higher number of basalt fibers and decreases with the inclusion of bagasse fiber. The hardness of these composites decreased with time. This indicates that during loading, the shape and size of indent increases with time as a result of viscoelastic flow and anelastic relaxation of the polymer. The reduction in hardness is due to the cellulose content present in the bagasse softens the fiber surface due to amalgamation of PBaBg I, III and IV composites. This may happen due to the difference in their chemical structure, Tg, density and hardness. Fig. 4 records a high value of hardness for PBaBg II composites and higher wt% shows the brittle nature of basalt fiber when compared with the remaining composites. This enhances the hardness by the uniform spread over of the load and resists the penetration of the indenter over its surface.

B. Structural characterization-Scratched Surface

The structural characterization of the surface scratch damages of the PBaBg hybrid composites are categorized based on four damage modes in case of polymers namely, Initial invisible zone, visible fish-scale formation zone, parabolic shear zone and material removal zone. The surface scratch damage modes may be different for different composite formulations at different load conditions. For the better understanding of biodegradable polymer composites scratch behaviour, it is the necessary and prime objective to investigate the scratch damage modes. Three tests were executed for reproducibility subjected to CLST and PLST. The scratch coefficient of friction µ (SCOF) is the ratio of tangential load Ft over Normal force Fn [23].

a) Initial invisible zone

The specimens subjected to the progressive load initially experiences very small amount of deformations which are invisible under low loads. These small amounts of deformations are fully recoverable viscoelastic, time dependent deformations. Which are invisible through naked eye. Almost, the four composites shown no initial damage caused by the scratch due to the lower progressive load at the initial phases as seen from the optical and SEM images.

b) Visible fish-scale formation zone

As the normal load increases, the PBaBg composites experiences plastic deformation, forming periodic visible fish-scale crack damage towards the direction. The transition of scratch damage from initial invisible damage zone followed by visible fish-scale formation zone of PBaBg composites. Further increasing the normal load, the damage become fully developed, fish-scale pattern can be seen. This type of damages is mostly observed phenomenon for PLA based polymer composites, where the damage is by the plastic drawing of substrate material below the indenter tip [20, 21, 22, & 23].

c) Parabolic shear zone

For PBaBg 1, III and IV hybrid composites, visible fish-scale crack damages are seen, no other noticeable scratch damages are seen until increased normal load is reached. At this load, the visible fish-scale damage dominates forming parabolic shear crack for PBaBg I composites. At this point, parabolic shear crack becomes the dominant damage mode, where the parabolic shear cracks facing other side of the scratch direction which features the typical brittle damage. The transition of PBaBg composites from Mar stage to visible stage followed by parabolic shear crack zone, it can be seen that with increasing the normal load, parabolic shear crack damage were more regular and dense. Similar set of parabolic shear cracks are also find in ceramic, glass and metal [24, 25 & 26].

d) Material Removal zone

Normal load with maximum magnitude eventually leads to material removal. In this damage zone, the transition from mar to visible damage followed by parabolic shear finally the indenter tip penetrates over the top of the specimen and partly specific quantity of the material is removed. As far as PBaBg hybrid composites are concerned no such damage was observed. It may occur if the normal load reaches the high value.

C. Progression of scratch damage modes

a) Scratch Behaviour of PBaBg I composites

The evolution map of constant progression process of scratch damage modes for four different hybrid composites is different and is illustrated in Fig. 5. The strong material with ductile nature having good tensile strength, and ductility with low normal scratch load, will exhibit little portion of mar damage. As yield strength and modulus of this material is high, this in turn leads to low penetration depth. This resists the tip indenter to penetrate over the surface resulting less pile up in front of the indenter tip. This shows that the scratch resistance is high, i.e., the scratch coefficient of friction (µs) is less when normal load increased. [27, 28]. These PBaBg composites exhibit very mild strain hardening characteristics. i.e. smaller the coefficient of friction is better will be the scratch resistance.

Mar	Visible fish scale	Parabolic shear zone Crack/Void/Craze	Material removal
Mar	Visible fish scale		Parabolic shear zone
Mar	Visible fish scale	Parabolic shear zone	Material removal
Mar	Visible fish scale	Parabolic shear zone	

Figure 5. Evolution map of Constant and Progression of scratch damage modes.

b) Scratch Behaviour of PBaBg II composites

As observed, from figure the PBaBg composite are brittle nature and low ductility having very high tensile, flexural and impact strength. This brittleness is due the major contribution of PLA (Brittle nature) and basalt fiber which are hard and brittle at high wt% formulations. This combinations show very much of parabolic shear zone areas causing opposite parabolic rupture along the sides in a irregular manner, which is the most extensive damage mode under high scratch normal load. Even at very low normal load small level of scratches may occur. Shear bands are no longer the major mode of deformation as the regular parabolic lines along the stage II are replaced by the irregular type of brittle failure. As the normal load increases, scratch induced damage initiated and ended with visible fish scale damage followed by micro cracks and micro voids. Sometimes material removal may takes place at a very increased level of scratch normal load.

c) Scratch Behaviour of PBaBg III composites

This high ductility composite shows low strength, and at low scratch normal load conditions mar damage initiates then followed by slow formation of visible fish scale damage as the scratch normal load increases for long distance. Further increasing the normal load leads to parabolic fish scale shear damage with high magnitude is developed throughout the remaining distance. The damage was due to displacement material forms 'lips' that overflow to the sides of the groove. This is due to the increase in pile-up of the materials on either side of the scratch groove.

d) Scratch Behavior of PBaBg IV Composites

PBaBg IV hybrid composites experienced similar scratch damage like PBaBg III composite at low Scratch normal loads. In spite of its ductility, high normal is needed to form visible fish scale damage zone followed by parabolic shear damage with high magnitude. PBaBg IV composite exhibit low tensile strength and ductility due to inclusion of bagasse fiber.

IV. Scratch Induced Damage Observations

A. Constant Loading

Scratch induced damages along the scratch length are presented for the tested specimen for Constant loading, several regions of damage modes are projected and SEM images are also displayed. Fig. 6 shows the SEM images of Constant Load Scratch (CLST) test for PBaBg I, PBaBg II, PBaBg III, and PBaBg IV hybrid Composites

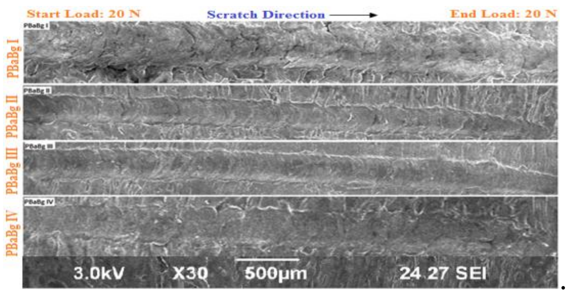


Figure 6. SEM images of Constant Load Scratch (CLST) test for PBaBg I, PBaBg II, PBaBg III, and PBaBg IV hybrid Composites.

Fig. 7 shows a graphical representation of Constant Load Scratch Test (CLST) a) Scratch Length vs. Normal Load b)Scratch Length vs. Coefficient of friction. Under CLST of 20 N, The damages seen in every sample are from slight to severe namely Mar (Initial invisible zone), visible progressive fish-scale formation zone, parabolic shear zone and material removal zone. There were transitions like Stick-slip behaviour and no tear induced puncture damages.

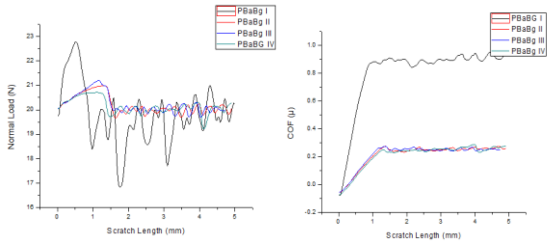


Figure 7.CLST a) Scratch Length vs. Normal Load b) Scratch Length vs. Coefficient of friction.

Different portion of interests are projected and SEM micrographs of these spots are displayed from Fig. 8. a), b), c), & d). The scratched region shows the characteristic wave-like deformation, in PBaBg I hybrid composites throughout the scratched distance. Similar progression in severity of surface damage is witnessed and these wave like templates are likely be the outcome of shear bands formed near the ploughed groove path [29]. The coefficient of friction increases abruptly during the initial stage in case of PBaBg I composites. This type of increase in SCOF has been reported already [30]. Force of friction gradually rises with an increase in perpendicular load for all the specimens. Firstly a clear transition takes place from visible fish scale damage to parabolic shear-induced plastic drawing. Later part showed removed material rough surfaces. Thus, the evidence projects that the inclusion of bagasse fiber affects the damage mode during scratch which leads to ductile formation. The transition in damage feature of PBaBg I hybrid composites where the increased weight percentage presence of bagasse makes irregular brittle type chatter failure.

During the scratch test at a steady speed and steady dead weight test, the scratch tip experiences a liability of skipping or jumping, based on the type of polymer type and testing conditions applied [31]. Fig. 8 b) & Fig. 8 c) shows the constant scratch load SEM image of PBaBg II and III hybrid composites subjected to CLST. It is seen that a segmented type of pattern appeared (Parabolic shear), resulting in the possibility of a stick-slip phenomenon. The entire scratch portion showed transitions damage, where the entire width of the plough path widens linearly for PBaBg II composites. Whereas, the groove increases more rapidly for PBaBg III hybrid composites. A regular fish scale pattern was seen followed by parabolic shear because of increased wt% of basalt and minimum wt % of Bagasse the material exhibits viscoelastic behaviour. In the case of PBaBg III composites the transition damage, the regular parabolic fish scale pattern is seen in the initial stages later replaced by parabolic shear type damage mode.

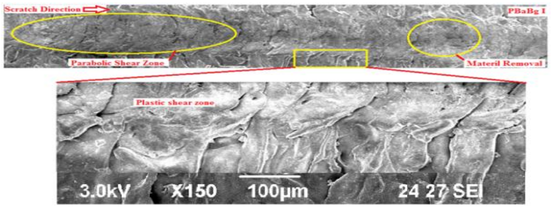


Figure 8. a) CLST Damages observed on PBaBg I hybrid composites.

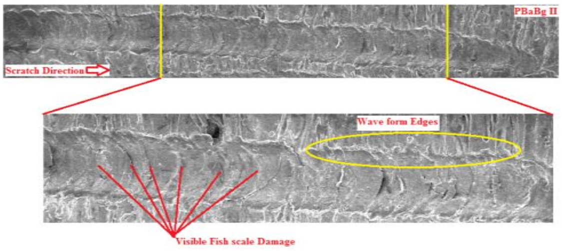


Figure 8. b) CLST Damages observed on PBaBg II hybrid composites.

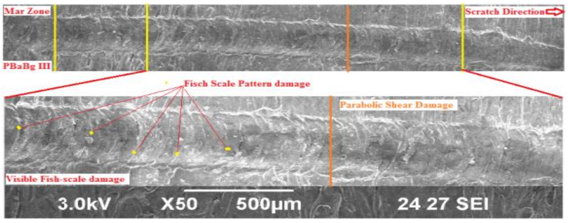


Figure 8. c) CLST Damages observed on PBaBg III hybrid composites.

This damage occurs very severely and the deformed material formed lips that overflow to the sides of the Plough groove path. This indicates an increase of built-up in the scratch groove in PBaBg II & III Composites. Fig. 8 d).Shows the SEM image of PBaBg IV composites which is similar to PBaBg I composites. It is observed that scratch with constant load starts with fish visible fish scale damage followed by a large amount of parabolic shear damage and end with material removal debris. This may be because of the reduced bagasse and increased basalt fiber turns to brittle on the later stages of CSLT. Among the four specimens, PBaBg II and PBaBg III hybrid composites showed a similar pattern without any drastic damage over the scratched surface for the applied constant load

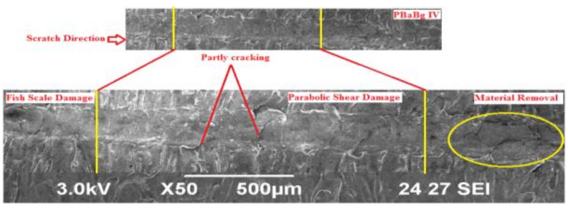


Figure 8. d) CLST Damages observed on PBaBg IV hybrid composites.

B. Progressive Loading

Fig. 9 illustrates the graphical representation of PLST i) Scratch Length vs. Normal load ii) Scratch Length Vs. Coefficient of friction

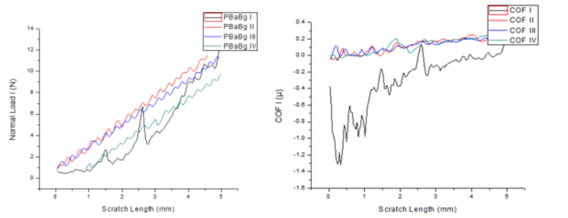


Figure 9. PLST i) Scratch Length vs. Normal load ii) Scratch Length Vs. Coefficient of friction

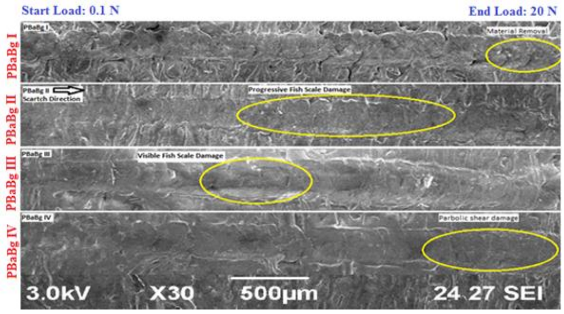


Figure 10. a) SEM images of Progressive Load Scratch (PLST) test for PBaBg I, PBaBg II, PBaBg III, and PBaBg IV hybrid Composites.

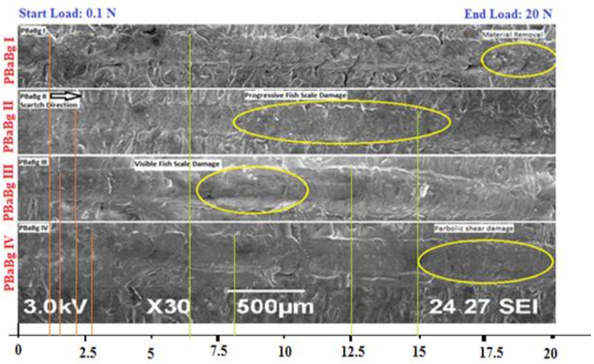


Figure 10. b) SEM images PLST test loading distance of onset groove formation and on set of ploughing for hybrid Composites.

Table 5. Loading distance of onset groove formation and on set of ploughing

OnsetGroove formation (N)	Onset Ploughing (N)
1.2	6.7
2.2	14.9
1.8	12.5
2.9	8.2

In progressive load scratch test both mar-scratch and the stress whitening transitions can be observed. Fig. 10 a) shows the SEM images of Progressive Load Scratch (PLST) test for PBaBg I, PBaBg II, PBaBg III, and PBaBg IV hybrid Composites. Table 5.

Shows the loading distance of onset groove formation and on set of ploughing. The transition in damage can thus be observed. Fig. 10 b) shows the SEM images of PLST, where loading distance of onset groove formation and on set of ploughing for hybrid Composites are revealed. Another advantage of using the progressive load is the prevention of chattering of the scratch tip during the scratch test. The PBaBg I composite reveals more surface scratch than the remaining composites. This is mainly because the materials modulus and yield strength are less than those of remaining polymer [32]. Fig. 11 depicts the graphical representation of Normal Load Vs onset groove formation and on set of ploughing of PBaBg hybrid Composites. Fig. 12 shows the graph of PSLT - Scratch distance vs. Normal load a) PBaBg I composites b) PBaBg II composites c) PBaBg III composites d) PBaBg IV composites

In all the specimens, there were no damages registered at lower loads, but when there was gradual increase in progressive load, force of friction increases simultaneously leading to different damage modes. Fig. 12 (a).Illustrates the transitions of PBaBg I hybrid Composites, from no load as the load increased the scratch progresses from 0.05 N. The fluctuation amplitude of scratch coefficient of friction increases gradually, which initiated the mar zone, later with gradually increased load forms visible fish scale zone followed by parabolic shear zone throughout the scratch length.

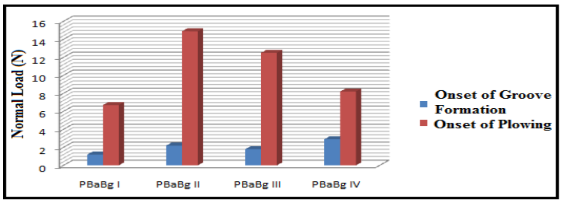
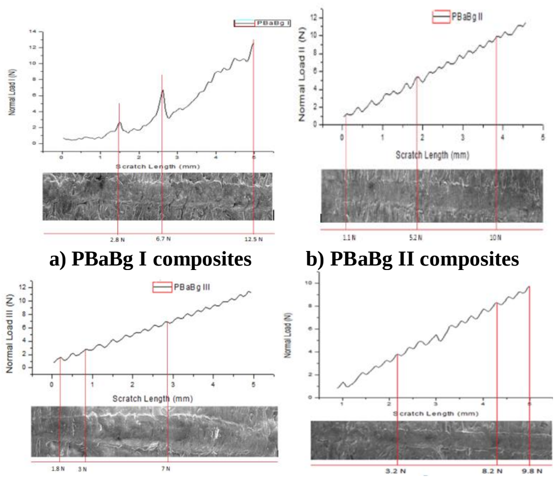


Figure 11. Normal Load Vs onset groove formation and on set of ploughing



a) PBaBg I composites **b) PBaBg II composites**

c) PBaBg III composites **d) PBaBg IV composites**

Figure 12. PSLT - Scratch distance vs. Normal load

The intermediate loads exhibits some fish scale zone due to visco-elastic behaviour of the composite. Therefore, Mar zone followed by visible fish scale damage is marked between 2.8 N and 6.7 N. whereas, beyond the load 6.7 N, the onset fish scale damage marked in the form of solid wave form on the surface indicates the occurrence of parabolic shear damage. This occurred, when the tip moves linearly along the surface length, a high tensile stress was concentrated near the scratch tip and the spot experiences ploughing and waves along the edges of the scratch. This stress at the tip induces material build-up upon the surface of the composites. This build-up purely depends on the scratch coefficient of friction (SCOF) which evaluates scratch behaviour. SCOF is termed as the ratio of tangential and normal forces throughout the scratch process [33]. The coefficient of friction on the graphs show peaks and valleys continuously because of the increased content of Bagasse fibers which usually will behave in ductile manner. Parameters like Scratch Coefficient of friction µ, elastic recovery depth de , residual depth dr, contact depth hc increased with increasing normal load Fn [34] . When there is an increase in normal load there was an increase in SCOF which is mostly because to ploughing effect with increase in dislocation density attributed by plastic deformation [35]. Different positions of interests are explored and SEM images of these spots are shown from Fig. 13 a), b), c) & d). At maximum loads all the specimens exhibited some form of damages. The SCOF of PBaBg I composites are less when compared to PBaBg II, III and IV because the maximum wt % of bagasse forms the visco-elastic nature between the matrix and reinforcements. Fig. 6.13 a) shows the PLST Damages observed on PBaBg I hybrid composites. At maximum loads all the specimens exhibited some form of damages. The normal load acting along the scratch length gradually increased towards larger values and it reached maximum in material removal zone of PBaBg I Composites. It showed groove formation at regions corresponding to parabolic shear and material removal zone. PBaBg II composite presented in Fig. 13 b) shows that width of the ploughing area remains unchanged throughout the scratch length of the composites. However, only smooth groove is left on the surface nearly no visible cracks are initiated around parabolic shear damage zone. At low normal loads the magnitude adhesion mean shear stress is high because of the inclusion of basalt fiber and decreased with increase of normal loads.

Due to predominant elastic deformation the adhesion coefficient decreases and reaches constant value under increasing normal load in the total deformation. Therefore, the mitigated formation of cracks in PBaBg II composites clearly shows the scratch performance, significantly the resistance to the development of cracking.

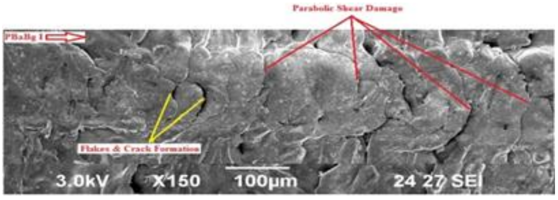


Fig. 13 a) PLST Damages observed on PBaBg I hybrid composites.

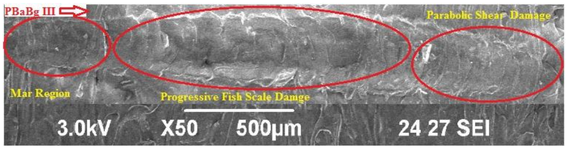


Fig. 13 c) SEM image of PLST damages onPBaBg III hybrid composites.

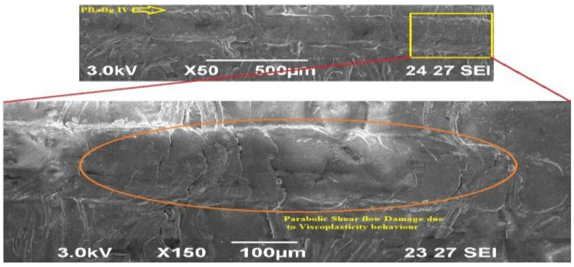


Fig. 13 d) SEM images of PLST on PBaBg IV hybrid composites.

Mechanical Modelling of Scratch behaviour of polymeric coatings on hard and soft substrates, reported that the cracks developed perpendicular to the scratch direction are the built-up parallel scratch like component [36].

Visible fish scale and parabolic shear cracks absorbed around the groove on the surface of PBaBg III & IV composites. It is also noticed that the difference in SCOF between different specimens reduces at higher loads. Fig. 13 c) SEM images showed very little wave-like deformation, which is likely to be the result of shear bands resulted along the surface of the scratch groove [38]. Fig. 13 c) & 13 d) shows SEM images of PBaBg III & IV composites which presents a segmented type of damage pattern appears in stage III, a stick- slip phenomenon that results in pile-up wear debris and dimples formed around few places, this may be because of the presence of soft fibrils of bagasse fibers. It should be noted that the scratch hardness values are an indicator of the resistance of a material against permanent surface deformation. Comparatively, PBaBg II composite showed hard surface when differentiated to the other three hybrid composites due to the increased wt% presence of Basalt fiber which are known for their strength and hardness.

V. Conclusions

In the early stages of advancement, execution of the constant and progressive load scratch test for evaluating robustness of PBaBg hybrid Composites exhibits high impact initial outcomes. It was observed that the hardness of PBaBg II composites maintains constant and reported high values at the range of loads used in this experiments. Different materials shows different hardness that can be correlated to its mechanical properties. In case of higher contact inclinations, higher perforation depths are achieved. Sliding velocity in the presence of normal load affects the force of friction to a considerable level. The pressure in the normal side remains same as in the lateral direction. The shear stress less than normal stress induces the plastic deformation in case of CLST. The values of SCOF increased due to increase in contact angle and scratch normal load. Under increased normal loads of PLST, elastic deformation dominates in total scratch induced deformation. Elastic deformation dominated the total sliding length as the normal load reaches the higher value. Friction coefficient varies with respect to the observations of the SEM micrographs reveals that the increase in the contact angle shows the larger scratch width of the samples. The reduced scratch width along the surface shows the reduced sensitivity to scratch hardness and deformation. SEM photographs revealed that the surface deformation mechanisms that were influenced by the dissimilarity of contact angle.

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