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DRY SLIDING WEAR BEHAVIOUR OF GLASS FIBRE REINFORCED EPOXY COMPOSITES FILLED WITH NATURAL FILLERS

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Abstract : Fibre reinforced plastics (FRPs) are emerging as a potential candidate for a wide variety of industrial applications owing to their good combination of physical and mechanical properties. In recent times, FRP parts are widely used as sliding components in different engineering applications. Due to the legitimate theoretical and practical importance, the study of tribological performance of these emerging materials becomes highly decisive. In the present research initiative, two different natural fillers; rice husk and wheat husk were used as fillers in glass-epoxy composite laminates. The frictional and wear characteristics of the developed composites have been studied under different sliding conditions. Results conclude that rice husk is more efficient in improving the tribological performance of glass-epoxy composites than the wheat husk. In addition, scanning electron microscopy (SEM) was carried out to study the morphology of the worn specimens to analyze the wear mechanism.

Keywords : Glass-epoxy laminates, natural fillers, wear, coefficient of friction, SEM.

1. INTRODUCTION

Polymers are the established candidates for sliding elements owing to their excellent corrosion resistance, shock loading, tolerance to misalignments, and low frictional coefûcient. Polymer based composites incorporated with different ûllers or fibres are substantially used for sliding components in various industries. It has been cited in various research initiatives that the specific wear rate and coefficient of friction of polymer composites sliding against metal counter parts can be deliberately reduced by incorporating synthetic fillers [1]. Srivastava and Wahne [2] organized a systematic experimental study and concluded that particulate fillers have the potential of improving the mechanical properties and wear resistance of the glass fibre reinforced epoxy composites. This is because the filler in particle form enrich the bonding strength between the fibre and matrix. The tribological behaviour of glass fibre reinforced epoxy composites filled with SiC and graphite particles as secondary fillers was studied using a pin-on-disc wear test rig under dry sliding conditions [3]. The results show that the inclusion of SiC and graphite as filler materials in glass-epoxy composites increases the wear resistance of the composites.

Basavarajappa et al. [4] presented an experimental investigation on wear behaviour of glass-epoxy and graphite filled glass–epoxy composites. Their results explore that addition of graphite in glass-epoxy composite leads to lower weight loss. This may be due to the formation of a thin film on the surface of counterface which subsequently transfers back to the surface of the specimen. Another research work concluded that incorporation of a small amount of graphite improves the sliding wear and frictional behaviour of the acrylonitrile-butadiene-styrene (ABS) polymer [5]. The authors also concluded that ABS containing 7.5 wt. % graphite powders ascertains the best friction and anti-wear abilities. Kishore et al. [6] presented a study on the effect of the type and content of the ûller in glass-epoxy composite system on the friction and sliding wear characteristics. It was concluded that the tribological response of the glass-epoxy composite system is highly dependent on the ûller type as well as its amount. The results also shows that between the two ûller materials, graphite filled glass-epoxy composites exhibit lower weight loss as compared to the rubber filled glass-epoxy composites. The weight loss drops down further when the graphite powder content is increased in the glass-epoxy composites. In regard to the frictional behaviour of the composites, no common trend was observed in the coefficient of friction values. This may be partly due to the response of the ûllers being different in different sliding conditions. Sabeel Ahmed et al. [7] stated that ceramic fillers such as Al_2O_3 and SiC ominously improve the wear resistance of jute fibre reinforced epoxy composites. The results reveal that jute-epoxy filled with Al_2O_3 have better wear resistance than jute-epoxy filled with SiC.

At this time, a new research trend has been established where polymer based composites are reinforced with lingo-cellulosic materials, such as, wood fillers, jute, sisal, pineapple, wheat straw, almond husk or rice husk [8,9]. These types of lingo-cellulosic materials introduce certain advantages as compared to the inorganic fillers ranging from their renewable nature to low density, non-abrasive properties, reasonable strength and stiffness, biodegradability and low cost [10]. Aigbodion et al. [11] experimentally found that on incorporation of bagasse ash as filler materials, the wear resistance of the recycled low density polyethylene (RLDPE) significantly increased. Though there are many benefits of using natural fillers in polymer composites, but the use of these materials as tribo materials is still in the nascent stage of research. Therefore, the present work is an earnest endeavor to fill this void. In the present research work, the effects of addition of natural fillers in glass-epoxy composite have been carried out in context with weight loss and coefficient of friction.

2. EXPERIMENTAL DETAILS

2.1 Materials Used and Fabrication of Composite Laminates

The composite laminates were made up of six layers of woven boron free EC-R glass fibre mats of 610 GSM supplied by Owens Corning Fibre Glass, USA. Epoxy resin LY556 and the corresponding hardener HY 951 was supplied by Huntsman Corporation. The resin and hardener were mixed in a ratio of 10:1 by weight and stirred mechanically to get a uniform mixture. Rice husk and wheat husk as filler materials were randomly dispersed during the fabrication of glass-epoxy composite laminates. The weight percentage of filler materials is kept constant to 5 wt. %. All the specimens were fabricated by compression molding where a compression load of 15 tons was applied. The compression ensured that the entrapped air bubbles were completely removed and the excess resin flows out. The mold was left for twenty four hours at room temperature to complete the curing process. Specimens of suitable dimension were cut using a diamond cutter.

2.2 Wear Test Setup and Measurements

The wear performance of the developed composites was carried out on pin-on-disc wear test machine (Ducom TR 20) as per ASTM G99. The pin-on-disc tribo test machine is schematically illustrated in Fig. 1. The specimens of size 30 × 10 × 4 mm^3 were prepared (Fig. 2). The counter body was a disc (140 mm × 8 mm) made of ground hardened steel (EN-31, 64 HRC, surface roughness 0.7 μm Ra). The contact surfaces of all the specimens were polished with an abrasive paper of 800 grit number to ensure proper intimate contact between the specimens and counter disc. Both the rotating disc and specimens were cleaned with acetone before and after each experimental run. The weight loss of each specimen was measured by taking the weight difference of the sample before and after each test. The precision electronic balance (Shimadzu) with a least count of 0.0001g was used to measure the weight of the specimens. As the disc starts rotating, rubbing starts between the specimen and the counter disc. The friction and wear monitor displays the tangential friction force. The value of the friction force was manually recorded in every 10 sec to compute the coefficient of friction. The time duration of force application (test duration) for each experiment can be calculated by dividing sliding distance (m) with sliding speed (m/s).

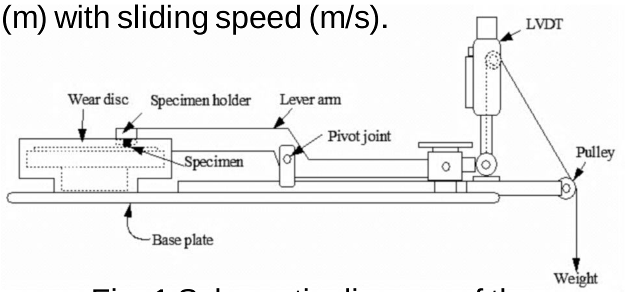

Fig. 1 Schematic diagram of the pin-on-disc tribo test machine

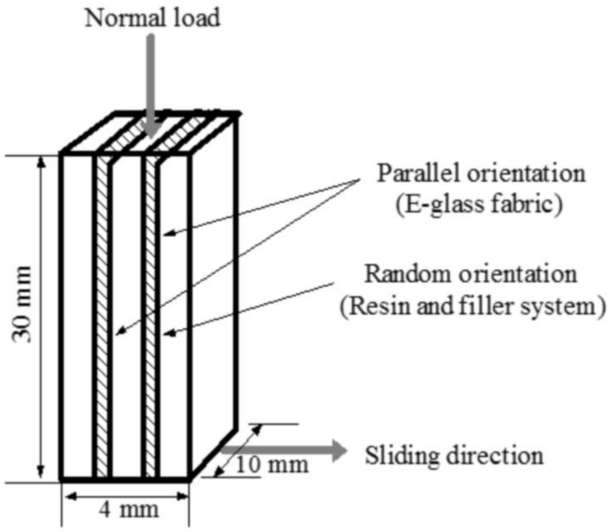

Fig. 2 Schematic illustration of fibre orientation and subjected loads on test spec

3. RESULTS AND DISCUSSION

3.1 Effect of Process Parameters on Weight Loss

The weight loss was measured by applying normal loads of 10, 20 and 30 N under varying sliding distance of 1000, 2000 and 3000 m. The tests were conducted for a constant sliding velocity of 1 m/s. The following equation is used to calculate the sliding distance (S).

$$S = \frac{\pi DNt}{60,000} \quad (1)$$

where, D = Diameter of wear track (mm),

N = Disc speed in RPM, and

T = Test duration (sec)

The experimental results reveal that weight loss for all samples increases with increase in applied normal load. The results also show that the weight loss of wheat husk filled glass-epoxy composites is slightly more than the glass-epoxy composites filled with rice husk (Fig. 3). Formation of high amount of debris during sliding is one of the possible reason of poor wear performance of the glass-epoxy composites filled with wheat husk. Whereas such phenomenon for the glass-epoxy composites filled with rice husk is not frequent. In few experimental conditions it was found that the weight loss is more for rice husk filled glass-epoxy composites as compared to wheat husk filled glass-epoxy composites. This may be due to the fact that sometimes fillers create more discontinuities in the specimen mating surface which may decrease the wear resistance. It has also been observed during the experimentation that at applied normal load of 30 N and sliding distance of 3000 m, specimen experienced maximum material loss. This may be due to the generation of high repeated axial thrust at higher applied normal load and sliding distance. The maximum weight loss associated with wheat husk filled glass-epoxy composite observed at sliding velocity of 1 m/s was 3.89 × 10^{-3} g whereas, the maximum weight loss in rice husk filled glass-epoxy composite was observed as 3.37 × 10^{-3} g, which was obtained under the identical working conditions (applied normal load of 30 N and sliding distance of 3000 m). The weight loss increases with the applied normal load for all the specimens because at higher applied normal load the temperature at the junction of the specimen surface and stainless steel counter disc becomes high and when the temperature reaches to the softening point of the polymer, fibre-matrix or filler-matrix debonding starts which in turn results in easy shearing of fibre or fillers due to the repeated axial thrust force. The fibres and fillers into the matrix subsequently support and as well as protect the matrix from being detached during the sliding against counter disc. Another possible reason of detachment of fibre or fillers is the poor bonding strength between the fibre/filler and matrix. Moreover, the weight loss of the composites filled with natural fillers depends upon some basic characteristics such as, shape of the filler, size of the filler, and hardness and thermal conductivity of the ûller materials. It was also observed that the weight loss increased with an increase in the sliding distance at various applied normal loads of 10, 20 and 30 N. This occurred due to the development of high thermo-mechanical stress with an increase in the sliding distance. Further studies can be carried out to improve the wear and frictional performance of these newly developed composites by increasing filler contents i.e. addition of filler materials of different weight percentage.

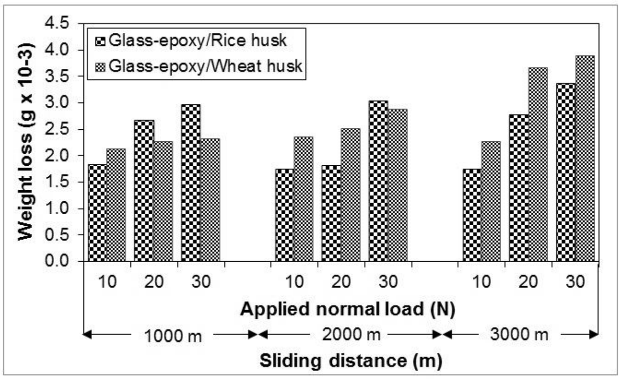

Fig. 3 Variation of weight loss with applied normal load for sliding distance of 1000, 2000 and 3000 m

3.2 Effect of Process Parameters on Coefficient of friction

In tribology, one of the important aspects is to know how friction is generated at atomic level. It is well known that surface asperities of two materials in contact form welded junctions which shear during sliding and cause generation of friction. The proper understanding of the frictional mechanism can solve many industrial problems. Hence, in order to study the frictional behaviour of the developed composites, the average value of coefficient of friction is presented in Fig. 4. As the rubbing starts between specimen and counterface, the friction and wear monitor displays the tangential friction force. The value of friction force was recorded manually in every 10 seconds during the experimentation and the average value was calculated. The following equation is used to calculate the average value of coefficient of friction (μ).

$$\mu = \frac{F}{F_N} \quad (2)$$

where, F = Measured frictional force (N) and

F_N = Applied normal load (N)

A small variation was observed in coefficient of friction values for both the composites with respect to applied normal load and sliding distance. As regards to the coefficient of friction, no common trend was observed for the developed composites. This may be partly due to the response of ûller materials being different in different sliding conditions. The highest value of coefficient of friction for wheat husk filled glass-epoxy composites was computed as 0.62 which was obtained at applied normal load 20 N and sliding distance of 3000 m. Whereas, the maximum value of coefficient of friction for rice husk filled glass-epoxy composites was recorded as 0.58 that was obtained at applied normal load of 10 N and sliding distance of 3000 m. However, the lowest value of coefficient of friction found in glass-epoxy composites filled with rice husk was 0.24 obtained at applied normal load of 10 N and sliding distance 2000 m. The lowest coefficient of friction for wheat husk filled glass-epoxy composites was 0.28 which was obtained at identical sliding condition.

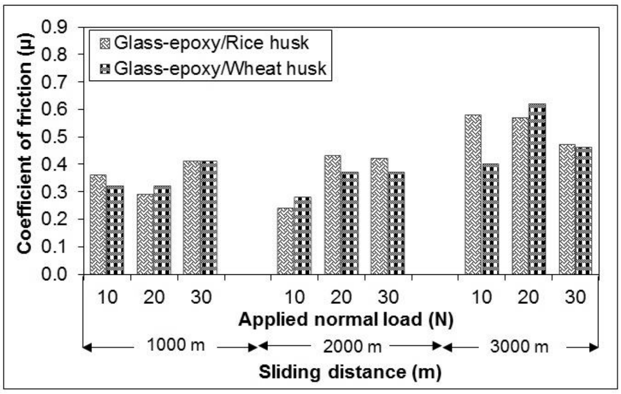

Fig. 4 Variation of coefficient of friction with applied normal loads for sliding distance of 1000, 2000 and 3000 m

3.3 Analysis of Worn Surface Morphology

The surface morphology of the worn surfaces of all the specimens was examined by scanning electron microscope (LEO 435VP). The electrical conductivity of all the specimens was enhanced by coating of thin gold film (10 nm). The thin film of gold was coated using a sputter coater (BALTEC SCD 005) before photomicrographs were taken. The SEM image of the worn samples at various combinations of applied normal loads is presented in Fig. 5 and Fig. 6. Fig. 5a to Fig. 5c represents the morphology of the worn surfaces for glass-epoxy composites filled with rice husk at three different loading conditions. An increase in the applied normal load and sliding distance causes an increase in the specimen surface temperature and mechanical stresses developed. The combined effect of the mechanical and thermal stress results in subsequent damage of the specimen sliding surface. Fibre fracture, matrix breakage, ploughing in the resinous region, debris formation and fibre pull out were the common damage forms detected in the SEM images. Sometimes, the detachment of filler from the resinous region appeared as micro-pits in the SEM images. The surface pattern for wheat

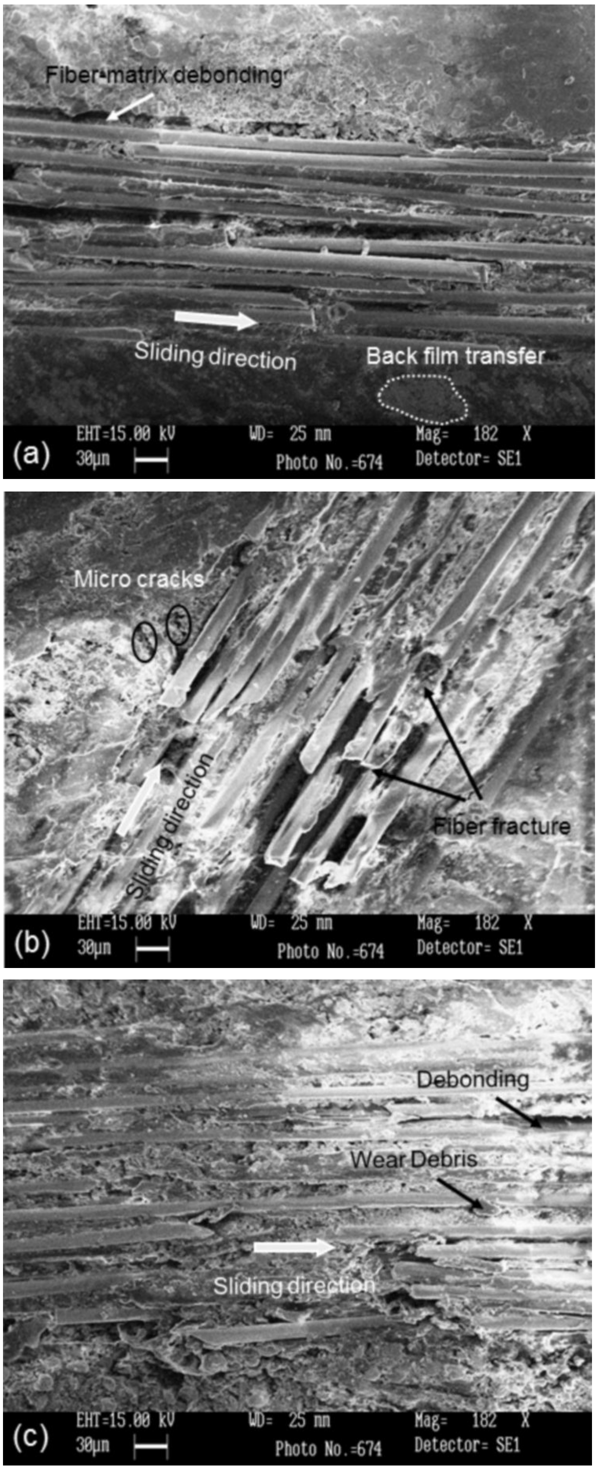

Fig. 5 SEM image of the worn specimen of rice husk filled glass-epoxy composites for a sliding distance of 3000 m at sliding velocity of 1 m/s and applied normal load of (a) 10 N; (b) 20 N and (3) 30 N

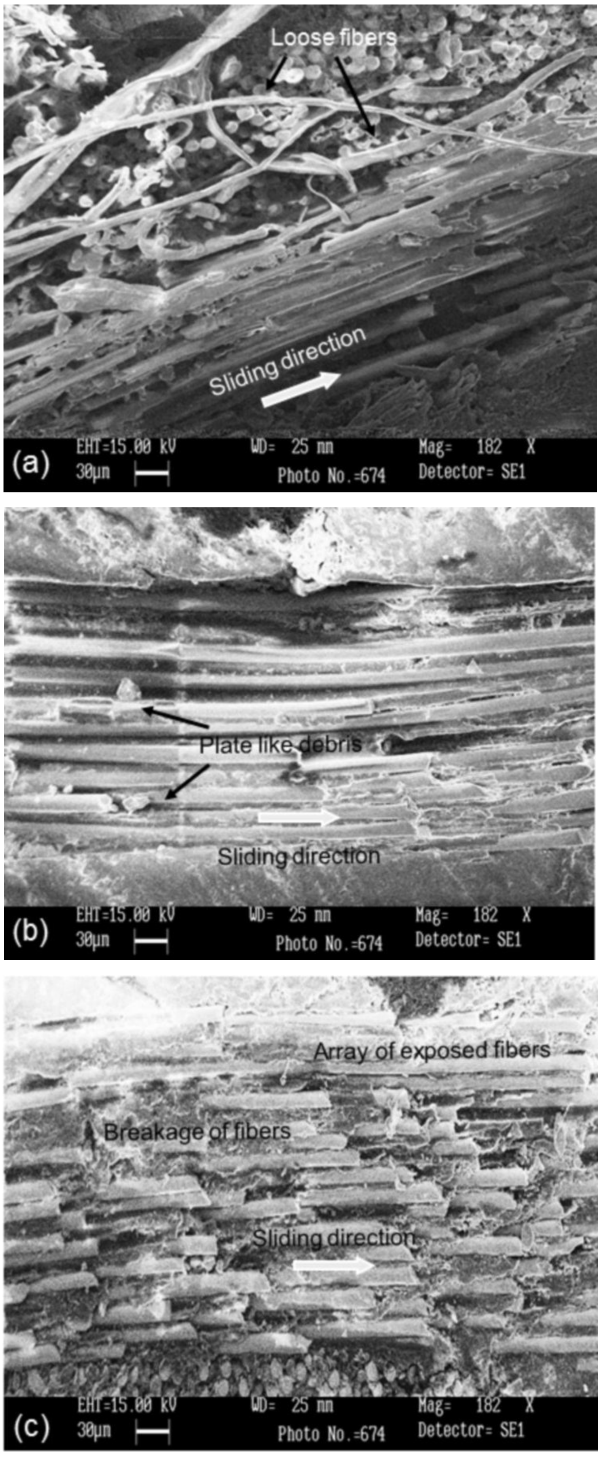

Fig. 6 SEM image of the worn specimen of wheat husk filled glass-epoxy composites for a sliding distance of 3000 m at sliding velocity of 1 m/s and applied normal load of (a) 10 N; (b) 20 N and (3) 30

husk filled glass-epoxy composites is shown in Fig. 6a to Fig.6c, where the wear was more severe as compared to the rice husk filled glass-epoxy composites. For wheat husk filled glass-epoxy composites, large volume of wear debris appeared in the SEM image. Most of the debris were plate like as shown in Fig. 6b. But, in case of glass-epoxy composites filled with rice husk, a relatively low amount with smaller size wear debris were found on the worn specimen which confirms the low weight loss of composites. The high amount of wear debris and fibre fracture of glass-epoxy composites filled with wheat husk was observed at applied normal load of 30 N and sliding distance of 3000 m. A predominant mild wear has observed in rice husk filled composites which includes back film transfer, micro cracks and patches of thin polymer film formed over the fibres due to the plastic deformation of polymer which shields the composite surface and contribute to higher wear resistance.

4. CONCLUSIONS

Generally, the addition of fillers leads to cost and weight reduction in the resulting composites. In the present study the dry sliding wear tests were performed on glass-epoxy composites filled with rice husk and wheat husk. The following conclusions can be drawn from the results and discussion.

- The maximum weight loss for rice husk filled glass-epoxy composites was found as 3.37×10^{-3} g, whereas, the maximum weight loss for wheat husk filled glass-epoxy composites was obtained as 3.89×10^{-3} g. The results suggest that rice husk should be used instead of wheat husk to improve the wear performance of glass-epoxy composites.
- The weight loss of the developed composites increases with an increase in applied normal load and sliding distance at constant sliding velocity of 1 m/s.
- No common trend was observed in the coefficient of friction values. This may be partly due to the response of the ûller materials being different in different situations.
- SEM images display more fibre breakage, debris formation and fibre-matrix debonding in glass-epoxy composites filled with wheat husk as compared to the glass-epoxy composites filled with rice husk under the similar working conditions.

REFERENCES

[1] Suresha, B., Chandramohan, G., Samapthkumaran, P., Seetharamu, S. and Vynatheya, S., Friction and Wear Characteristics of Carbon-Epoxy and Glass-Epoxy Woven Roving Fiber Composites, Journal of Reinforced Plastics and Composites, Vol. 25, pp.771-782, 2006.

[2] Srivastava, V.K. and Wahne, S., Wear and Friction Behaviour of Soft Particles Filled Random Direction Short GFRP Composites, Materials Science and Engineering: A, Vol. 458, pp.25-33, 2007.

[3] Basavarajappa, S., Arun, K.V. and Davim, J.P., Effect of Filler Materials on Dry Sliding Wear Behaviour of Polymer Matrix Composites - A Taguchi Approach, Journal of Minerals and Materials Characterization and Engineering, Vol. 8, pp.379-391, 2009.

[4] Basavarajappa, S., Ellangovan, S. and Arun, K.V., Studies on Dry Sliding Wear Behaviour of Graphite Filled Glass-Epoxy

Composites, Materials and Design, Vol. 30, pp.2670-2675, 2009.

[5] Ben Difallah, B., Kharrat, M., Dammak, M. and Monteil, G., Mechanical and Tribological Response of ABS Polymer Matrix Filled with Graphite Powder, Materials and Design, Vol. 34, pp.782-787, 2012.

[6] Kishore, Sampathkumaran, P., Seetharamu, S., Thomas, P. and Janardhana, M., A Study on the Effect of the Type and Content of Filler in Epoxy-Glass Composite System on the Friction and Slide Wear Characteristics, Wear, Vol. 259, pp.634-641, 2005.

[7] Ahmed, K.S., Khalid, S.S., Mallinatha, V. and Amith Kumar, S.J., Dry Sliding Wear Behaviour of SiC/Al_2O_3 Filled Jute/Epoxy Composites, Materials and Design, Vol. 36, pp.306-315, 2012.

[8] Pande, H., Non-Wood Fibres and Global Fibre Supply, Unasylva, Vol. 49, pp.44-50, 1998.

[9] Pan, X.J., Sano, Y. and Ito, T., Atmospheric Acetic Acid Pulping of Rice Straw II: Behaviour of Ash and Silica in Rice Straw during Atmospheric Acetic Acid Pulping and Bleaching, Holzforschung, Vol. 53, pp.49-55, 1999.

[10] Bledzki, A.K. and Gassan, J., Composites Reinforced with Cellulose based Fibres, Progress in Polymer Science, Vol. 24, pp.221-274, 1999.

[11] Aigbodion, V.S., Hassan, S.B. and Agunsoye, J.O., Effect of Bagasse Ash Reinforcement on Dry Sliding Wear Behaviour of Polymer Matrix Composites, Materials and Design, Vol. 33, pp.322-327, 2012.