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# EXPERIMENTAL STUDY ON ABRASIVE WEAR BEHAVIOUR OF FLEXIBLE GREEN COMPOSITE INTENDED TO BE USED AS PROTECTIVE CLADDING FOR STRUCTURES

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***Abstract:*** In the present study, the influence of material and process parameters on the two body abrasive wear behavior of Jute-Rubber flexible composite is investigated using Taguchi's design of experiments (DOE). Three different stacking sequences of composite namely jute-rubber-jute (JRJ), jute-rubber-rubber-jute (JRRJ) and jute-rubber-jute-rubber-jute (JRJRJ) are considered and their wear behavior is evaluated using two body abrasion test with multi-pass condition for abrading distances of 0.4 m to 1.2 m in increments of 0.4 m and varied load of 9.81 N, 12.26 N and 14.71 N. Abrasive volume loss and specific wear rate as function of abrading distance are determined. The results from Taguchi's design of experiments show that for two body dry sliding wear situation, an abrading distance significantly affects the specific wear rate compared to load and composite configuration. However, volume loss is more and appreciable when jute fabric is exposed to abrasive medium rather than when the rubber is exposed. Surface morphology study is carried out using a scanning electron microscope to get an insight of wear mechanism of constituents of the flexible composite. Stretching of asperities results in wear of the rubber, whereas fiber breakage causes wear of the jute. Rubber being the dominating constituent of flexible composite results in providing better wear resistant properties and thus can act as a potential candidate for sacrificial structures to protect primary structures subjected to wear.

***Keywords:*** abrasion, wear, two body, flexible composites, sacrificial structure, Taguchi, DOE, cladding

## 1. INTRODUCTION

To overcome the problem involved in wear of structural components, the need for newer materials is growing day by day. Fiber reinforced polymer-based composites find the top priority in the rapidly growing class of material due to the enormous advantage they provide and are being used in a variety of engineering applications. Tribological properties are important for polymer-based composites which enforced many researchers to concentrate on studying and improving the friction and wear behavior of such composites.

The relative motion between the surface and the other surface which is in contact with it results in loss of material causing damage to the surface. This is termed as wear. Different types of wear such as adhesion, abrasion, erosion, fatigue, and fretting are observed in practice, out of which the most important is abrasive wear (*ASM Handbook*, 1992). Abrasive wear is caused by the hard lumps which move against the solid surface and forced against it (Hutchings, 1992). In the event of two body wear, hard projections caused wear on just one surface. Flexible polymeric based composites are finding their application in material handling, material transportation systems and claddings with various polymer displaying diverse tribological properties. It is worth noting that neat polymers are seldom used for applications involving wear (P.K. Mallik, 2008). Study of abrasive wear in material handling systems, material transportation systems and claddings are gaining importance (Friedrich, Lu and Hager, 1995). Bidirectional fabrics have emerged as a solution for fulfilling the demand for newer materials having better performance and processing (Vishwanath, Verrnab and Raoc, 1993). Enhancing the hardness and stiffness of the material to get improved wear resistance of polymeric materials is a conventional approach (Chang, 1982; El-Sayed *et al.*, 1995). The tribological properties of the composites are influenced to a greater extent by the matrix material used. Nature has provided us with plenty of materials that can address the various issue. For example, the hardness incorporated in nails and teeth helps us in grinding, digging and tearing purpose. The feet which has soft pads helps in reducing the wear and tear during transportation. On these grounds, it

becomes interesting to explore the use of elastomer for tribo applications. Elastomers have a narrow range of operating temperature within which they can be used as wear resistant materials. The ranges of some of the elastomers are provided in Table 1, (Sare, Mardel and Hill, 2001).
Similarly, metals too have the limitation of erodent hardness below which they can be useful as wear resistant materials. Figure 1 gives the reason why nature prefers flexible rather than stiff materials for wear resistance.
Replacement of steel with rubber or coating the steel with rubber will reduce the wear rate (Sare, Mardel and Hill, 2001). The natural rubber apart from offering wear resistance also offers advantage such as tear and impact resistance (Xie *et al.,* 2015).

Table 1. Temperature window and abrasion resistance of various elastomers(Sare, Mardel and Hill, 2001)

| Elastomer (Nomenclature) | Operating temperature ($^0$C) | Glass transition temperature ($^0$C) | Abrasion resistance |
|---|---|---|---|
| Polyurethane (PUR) | Up to 75 | -40 to -20 and 50 to 80 | Excellent |
| Styrene butadiene rubber (SBR) | Up to 110 | -60 to -50 | Excellent |
| Natural rubber (NR) | -50 to105 | -52 | Good/Excellent |
| Nitrile butadiene rubber (NBR) | -50 to120 | -55 to -20 | Excellent |
| Chloroprene (CR) | -45 to120 | -45 | Fair |
| Ethylene Propylene Diene Monomer (EPDM) | -50 to 125 | -50 to -40 | Fair |

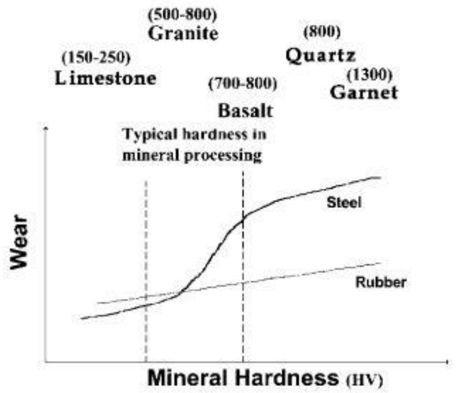



Fig. 1. Variation of wear rate for steel and rubber for different erodents (Sare, Mardel and Hill, 2001)

Different types of wear mechanisms have been proposed by various researchers pertaining to rubber (Schallamach, 1952, 1963; Grosch, KA, and Schallamach, 1965; D.H. Champ, E. Southern, 1974; Briggs, GAD; Briscoe, 1976; Pulford, 1983; Grosch, 1990). When rubber is abraded unidirectionally, the characteristic surface pattern consisting of a series of periodic parallel ridges lying perpendicular to the sliding direction, looking like a wind-wrought pattern on the sand, often referred to as abrasion pattern is formed. The ridges forming on the surface of the rubber when it is abraded is indicative of wear mechanism. Ridges were generated by coalescence of particles, sequentially through the formation of ribs, rings, and ruffles (Bhowmick, 1982). The wear pattern was also discussed by (E. Southern, 1979). In spite of the obvious possibility of utilization of wear resistant application, studies on tribological properties of jute reinforced natural rubber flexible composite have not received due attention. Most of the work being carried out on wear till date concentrates on metallic materials and limited work has been focused on elastomer with no work being found on the tribological behavior of flexible composites comprising of natural rubber and natural fiber. In order to protect the primary structure like the bumper of the automobile from wear during its service, it is essential to interpose a sacrificial secondary structure. Hence, the present study aims at investigating the tribological behavior of the flexible composite comprising of woven jute mat as reinforcement and natural rubber as a matrix material with the intention of characterizing them for their two-body abrasive wear behavior and intended to be used as a sacrificial structure in protecting the primary structures.

## 2. EXPERIMENTAL WORK

### 2.1 Specimen

The proposed composites used in the present study comprises of plain woven jute fabric as reinforcement and the naturally available rubber along with elastomer based gum acts as the matrix. The jute and the rubber sheets are supplied by the local suppliers and the bonding gum is supplied by Manjunath Rubbers, Baikampady, Mangaluru, India. The composites are manufactured by a compression molding technique. The details of the composites used in the present study are presented in Table 2.
Concerned to the processing of the composite, an open mold plates of required dimension are prepared and is placed with Teflon sheet on its top layers. High vacuum silicone releasing agent is smeared on the surface of the mold to facilitate easy removal of the

laminate after curing. The jute and rubber sheet grade rubber sheet is cut to the desired dimension and placed according to the desired configuration of the composite to be prepared. In between each layer, the bonding gum is placed. The entire arrangement is subjected to temperature and pressure in the compression molding machine for a certain time, after which it is allowed to cure for 24 hours. The laminates after curing are carefully withdrawn from the mold. The specimen needed for two body test with a diameter of 16 mm are cut from the laminate prepared using a hollow drill. The properties of plain woven jute fabric are provided in Table 3 and that of natural rubber in Table 4.

Table 2. Composites used in the present study

| Material (Designation) | Jute (wt. %) | Rubber Sheet (wt. %) | Rubber based bonding gum (wt. %) | Density (Kg/m$^3$) |
|---|---|---|---|---|
| Jute-Rubber-Jute (JRJ) | 12 | 56 | 32 | 1159.64 |
| Jute-Rubber-Rubber-Jute (JRRJ) | 7 | 64.5 | 28.5 | 1121.57 |
| Jute-Rubber-Jute-Rubber-Jute (JRJRJ) | 10 | 59 | 31 | 1118.81 |

Table 3. Physical and properties of jute fiber.

| Physical Property | Jute Fiber |
|---|---|
| Density (g/cm$^3$) | 1.4-1.5 |
| Elongation at break (%) | 1.8 |
| Cellulose content (%) | 50-57 |
| Hemicellulose (%) | 13.6-20.4 |
| Lignin content (%) | 8-10 |
| Ash (%) | 0.5-2 |
| Pectin (%) | 0.2 |
| Wax (%) | 0.5 |
| Moisture (%) | 12.6 |
| Tensile strength (MPa) | 300-700 |
| Young's modulus (GPa) | 10-30 |
| Diameter (μm) | 160-185 |
| Lumen size (μm) | 12 |

Table 4. Properties of Natural Rubber

| Material | Yield stress [MPa] | Ultimate stress [MPa] | Density [Kg/m$^3$] | Modulus [MPa] |
|---|---|---|---|---|
| Natural Rubber | 0.05 | 0.05 | 987.18 | 0.45 |

## 2.2. Test Details

Two body abrasion test according to ASTM D5963/ ISO4649 is the most commonly used method to find the abrasive properties of elastomers and compounds containing elastomers. This method consists of a rotating drum which is wrapped with abrasive paper (Grit size = 60 and length of paper = 400mm) as the abrasive medium over which the specimen to be tested is moved. The samples used are as shown in Figure 2 and the schematic arrangement is shown in Figure 3.

The DIN abrader used to perform two-body abrasion test in the present study is shown in Figure 4.

Hollow drills are used to obtain the sample, which is later positioned in the sample holding location of DIN abrader.

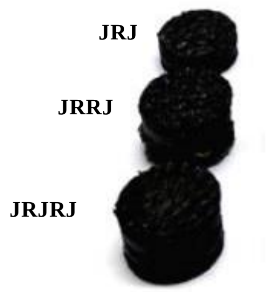



Fig. 2. Specimens for two body abrasion test

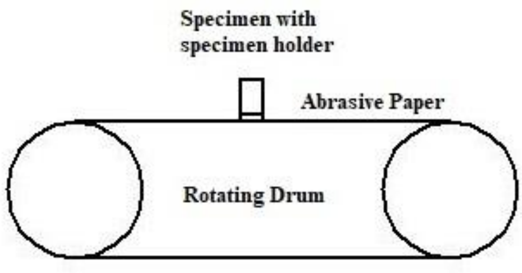



Fig. 3. The schematic arrangement of two body abrasion

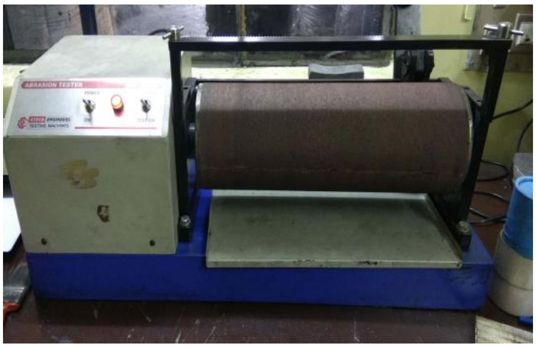



Fig. 4. DIN abrader (DIN 53516)

The drum is set to rotation motion and at the same time, the sample moves laterally. The diameter and the length of the cylindrical drum are 150 mm and 500 mm respectively. The rotational frequency of the abrader is 40 rpm. Method B of ASTM D5963 is used to carry out the test. Precision weighing balance is made use of to measure the weight of the sample before and after the test. Mass and volume losses are found out using Eq. 1 and Eq. 2 respectively. Three different loads of 9.81 N, 12.26 N and 14.71 N along with three different abrading distances of 0.4 m, 0.8 m and 1.2 m are used to carry out the experiment. The densities of the composites are determined by standard water displacement method.

$$Mass\ Loss = Initial\ Weight - Final\ Weight \quad (1)$$

$$V_l = M_l / \rho \quad (2)$$

where $M_l$ is the loss of mass (gms) and the density of the composite is represented by ρ (g/m$^3$). The specific wear rate (m$^3$/Nm) is calculated using Eq. 3

$$K_s = V_l / LxD \quad (3)$$

where $V_l$ is volume loss (m$^3$), the load applied is represented by L (N) and sliding distance D (m). Abrasion resistance index (ARI) is calculated using Eq. 4.

$$ARI = \left( \Delta m_1 / \Delta m_t \right) x \left( \rho_t / \rho_1 \right) x100 \quad (4)$$

Where: $\Delta m_1$: mass loss of standard rubber #1 test piece (mg); $\Delta m_t$: mass loss of test specimen in mg; $\rho_t$: density of test specimen in mg/m$^3$; $\rho_1$: density of standard rubber #1 test piece in mg/m$^3$.

Three samples in each configuration of the composite are tested and their mean value is considered. The factors and their levels used in the present study is presented in Table 5.

Table 5. Process parameters for two body wear

| Factors (Designation) | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| Composite configuration | JRJ | JRRJ | JRJRJ |
| Abrading distance | 0.4 m | 0.8 m | 1.2 m |
| Load | 9.81 N | 12.26 N | 14.71N |

## 3. RESULTS AND DISCUSSIONS

### 3.1 SN Ratio

The experimentation plan is charted according to Taguchi's L9 orthogonal array. The specific wear rate is chosen to be the response of each trial and is calculated using Eq. (1-3). Since the wear rate has to be minimized, the SN ratio is calculated using "smaller the better" criteria given by Eq. 5.

$$S/N = -10x\log_{10}\left( \sum y^2 / n \right) \quad (5)$$

where 'y' is the responses for the given factor level combination and 'n' is the number of responses in the factor level combination.

Table 6 provides the responses and the SN ratio for all the trials considered and Table 7 provides the responses for SN ratio. It is conclusive from the responses of SN ratio that, abrading distance influences the specific wear rate followed by composite configuration and load

Table 6. Response and SN ratio for the trials

| Composite configuration | Abrading distance in m | Load in N | Specific wear rate x $10^{-7}$ in m$^3$/Nm | SN ratio |
|---|---|---|---|---|
| 1 | 1 | 1 | 0.56 | 4.9253 |
| 1 | 2 | 2 | 0.42 | 8.1085 |
| 1 | 3 | 3 | 0.29 | 10.2895 |
| 2 | 1 | 2 | 0.56 | 4.5737 |
| 2 | 2 | 3 | 0.44 | 7.0200 |
| 2 | 3 | 1 | 0.29 | 11.3255 |
| 3 | 1 | 3 | 0.82 | 2.2972 |
| 3 | 2 | 1 | 0.43 | 6.8681 |
| 3 | 3 | 2 | 0.32 | 9.7860 |

Table 7. Response table for SN ratio

| Level | Composite Configuration | Abrading Distance | Load |
|---|---|---|---|
| 1 | 7.774 | 3.932 | 7.706 |
| 2 | 7.640 | 7.332 | 7.489 |
| 3 | 6.317 | 10.467 | 6.536 |
| Delta | 1.457 | 6.535 | 1.171 |
| Rank | 2 | 1 | 3 |

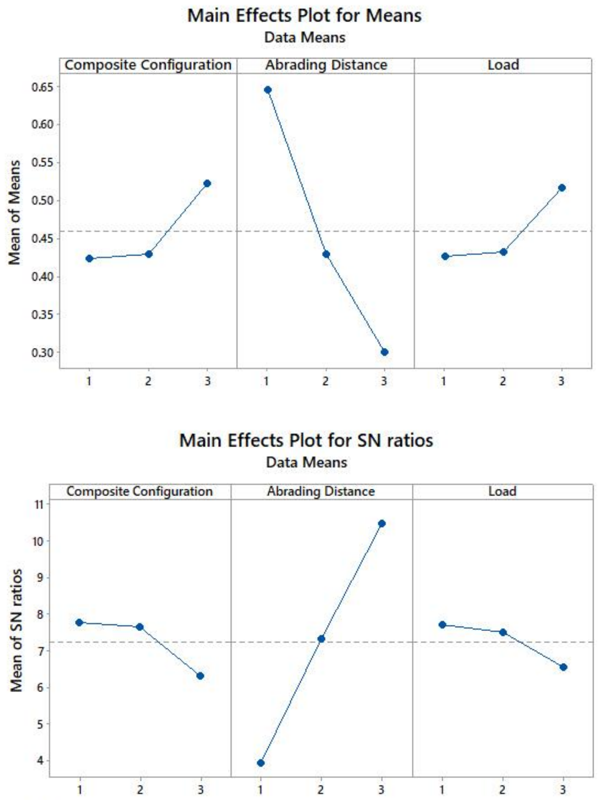



Fig. 5. Main effect plots for means and SN ratios

From, the main effect plots are shown in Figure 5, it can be said that as the factor A (Composite configuration) with level 1 (JRJ) yields lower wear rate, followed by level 2 (JRRJ) and level 3 (JRJRJ).

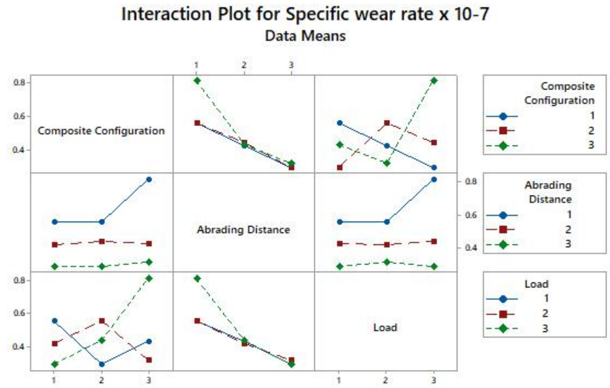



Fig. 6. Interaction plots for means and SN ratios

At the same time, the wear rate is found to be minimum at level 3 (1.2m) of factor B (Abrading distance) and level 1 (9.81N) of factor C (Load). This is attributed to the fact that at an abrading distance of 1.2m, rubber is exposed to abrasive medium and rubber being high wear resistant material results in lower weight loss and thus lower specific wear rate. For better resistance of wear, the composite with stacking sequence JRJ configuration has to be selected with the highest sliding distance (1.2m) and minimal load (9.81N). The Figure 6 shows the interaction plots from which it is evident that there exists an interaction between the factors since the lines are not parallel to each other.

### 3.2. ANOVA

ANOVA is used to statistically determine the significant factors as it indicates to what extent the process parameter influences the response. Table 8 provides the ANOVA values for specific wear rate. A higher value of F in the table indicates that the particular factor influences the response to a greater extent

Table 8. ANOVA for weight loss

| Source | DF | SS | MS | F value | P Value | % Cont. |
|---|---|---|---|---|---|---|
| Composite Configuration | 2 | 0.01500 | 0.01500 | 3.34 | 0.127 | 7.15 |
| Abrading Distance | 2 | 0.18027 | 0.18027 | 40.11 | 0.001 | 85.98 |
| Load | 2 | 0.01215 | 0.01215 | 2.70 | 0.161 | 5.79 |
| Error | 6 | 0.00224 | 0.00449 | | | 1.06 |
| Total | 12 | 0.20966 | | | | 100 |
| S= 0.0670406, R-sq = 90.22 %, R-sq (adj) = 84.36 % | | | | | | |

Accordingly, the factor B (abrading distance) has the highest F value of 40.11 indicating that the parameter affecting the wear in the composite is sliding distance followed by composite configuration and load. This is also supported by the percentage contribution value with factor B contributing 85.98% for the specific wear rate as compared to factor A and C which contributes only 7.15% and 5.79% respectively. The R-sq values is more than 90% which indicates that the model developed gives good results and helps to predict the weight loss values within experimental conditions.

### 3.3. Regression Analysis

Regression analysis is carried out for the present model and the regression equation is developed which is provided in Eq. 6.

Specific Wear Rate = 0.6156+0.05 Composite Configuration-0.1733 Abrading Distance+0.045 Load (6)

In order to validate the regression model developed, the experimental results are compared with the predicted results as shown in Table 9. The Figure 7 provides a comparison of experimental and predicted specific wear rate.

Table 9. Comparison of experimental and predicted values

| Composite configuration | Abrading distance [m] | Load [N] | Expt.Sp. Wear rate x $10^{-7}$ [$m^3$/Nm] | Predicted Specific Wear rate x $10^{-7}$ [$m^3$/Nm] | % error |
|---|---|---|---|---|---|
| JRJ | 0.4 | 9.81 | 0.56 | 0.54 | 4.05 |
| JRJ | 0.8 | 12.26 | 0.42 | 0.41 | 2.61 |
| JRJ | 1.2 | 14.71 | 0.29 | 0.28 | 3.20 |
| JRRJ | 0.4 | 12.26 | 0.56 | 0.63 | -12.91 |
| JRRJ | 0.8 | 14.71 | 0.44 | 0.50 | -14.54 |
| JRRJ | 1.2 | 9.81 | 0.29 | 0.24 | 17.00 |
| JRJRJ | 0.4 | 14.71 | 0.82 | 0.73 | 11.30 |
| JRJRJ | 0.8 | 9.81 | 0.43 | 0.46 | -7.90 |
| JRJRJ | 1.2 | 12.26 | 0.32 | 0.34 | -4.90 |

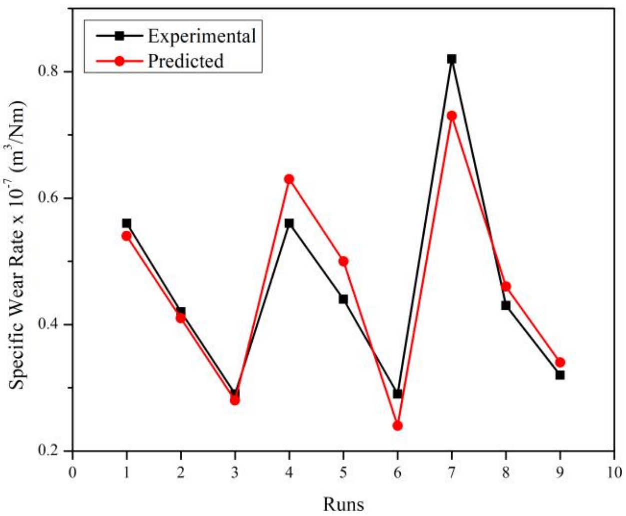


Fig. 7. Comparison of experimental and predicted specific wear rate

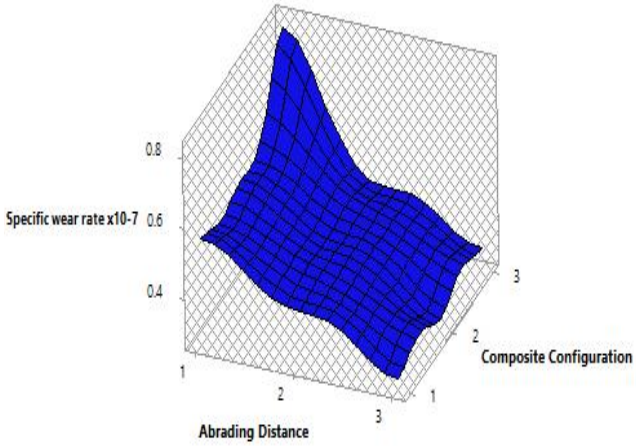
It is found from the comparison of experimental and predicted wear rate that the error percentage is within 15% which indicates that the developed regression model is acceptable and feasible to predict the wear rate within the range of experimental conditions.

### 3.4 Response Surface Plot

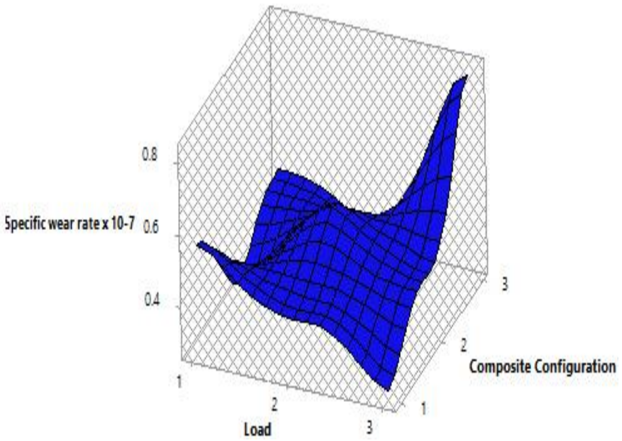
The interaction effect of the factors affecting the response is provided by the response surface plot. The response surface plot of specific wear rate vs composite configuration and abrading distance, specific wear rate vs composite configuration and load, specific wear rate vs abrading distance and load is shown in Figure 8. It is seen that the specific wear rate is minimum at the 3rd level (1.2m) of factor B (Abrading distance) and 1st level (JRJ) of factor A (Composite configuration). When composite configuration and load are compared, the specific wear rate is found to be minimum at 3rd level (14.71 N) of factor C (load) and 1st level (JRJ) of factor A (Composite configuration). This is due to the fact that rubber is exposed and abraded by the abrasive medium at an abrading distance of 1.2m and rubber being highly abrasive resistant results in lower volumetric loss resulting in reduced specific wear rate. Similarly, when abrading distance and load are compared, the minimum specific wear rate is obtained at 1st level (0.4m) of factor B (Abrading distance) and 1st level (9.81N) of factor C (Load).

### 3.5. Surface Morphology

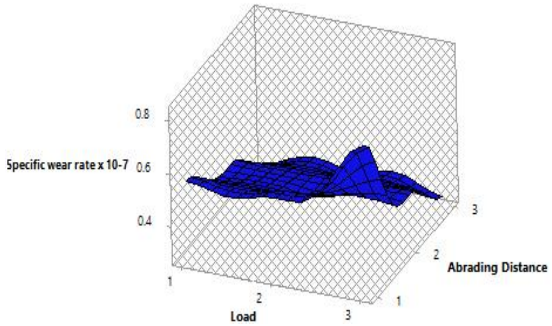
The surface morphology of the worn out composites are studied through a scanning electron microscope to predict the mechanisms of wear involved when jute and rubber are exposed to abrasive medium and the same is represented by Figure 9 (a-d).



a) specific wear rate vs composite configuration, abrading distance



b) specific wear rate vs composite configuration, load



c) specific wear rate vs abrading distance, load

Fig. 8. Response surface plot of various factors considered

One of the constituents of the composite, which is rubber, when abraded by the abrasive medium exhibits wave-like pattern as shown in Figure 9 (a). The sharpness of emery paper attaches to the harshness of the rubber, thereby stretching it leading to tearing of rubber.

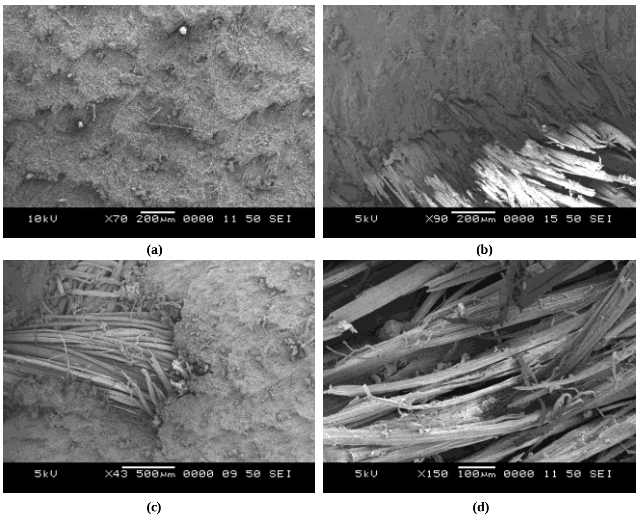


Fig. 9. Surface morphology showing wear mechanisms of constituents of the composite

The crack starts to develop with the application of force. This mechanism is responsible for the development of wave-like pattern, where waves represent the stresses asperities. The stretching of the asperities continues with the test until the uppermost part, the “tongue”, ruptures, what ultimately transposes to material loss. The waviness reduces as represented in Figure 9b and Figure 9c. As the wear advances jute is exposed to abrasive medium and begins to abrade. From this point, change in wear mechanism is observed and is dominated by fiber breakage as represented in Figure 9d.

## 4. CONCLUSIONS

The main aim of this work is to investigate the effect of rubber and study the effect of material and process parameters on the tribological behavior of jute/rubber flexible composite. An experimental study of the wear behavior of three different configurations of the flexible composites is carried out using two bodywear at varied abrading distance and load. Based on the experimental investigations, It is found from the responses of SN ratio and ANOVA that, abrading distance is the significant factor influencing the specific wear rate compared to composite configuration and load. The regression model developed is found to acceptable and feasible to predict the wear rate within the range of experimental conditions. Increase in the abrading distance and reducing the load, the volumetric wear loss of the proposed composites with abrading distance being the significant factor affecting wear loss. The volumetric wear loss and specific wear rate of the composite is significant when jute is exposed to abrading surface compared to rubber. The inclusion of rubber enhances the wear resistance of the polymeric composites under dry wear condition. The specific wear rate of all the proposed composites reduces with increased abrading distance and reduced load. Specific wear rate of JRJ is least followed by JRRJ and JRJRJ indicating JRJ has better wear resistance compared to JRRJ and JRJRJ for the chosen range of abrading distance and load. The wear mechanism of the rubber involves the development of wave-like pattern where the waves represent the stressed asperities. The rupturing of the uppermost part, the “tongue” takes place with continued stretching of the asperities. This ultimately leads to material loss. On the other hand, fiber breakage dominates the wear mechanism of the composite, when jute is being abraded. Flexible composites are dominated by rubber and thus characterized with better resistance against abrasive wear making them a potential candidate for sacrificial structural applications such as claddings.

## 5. ACKNOWLEDGMENT

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**6. REFERENCES**

1. *ASM Handbook,* (1992). Materials Park, USA: ASM International.
2. Bhowmick, A., (1982). *Ridge formation during the abrasion of elastomers*. Rubber chemistry and technology, 55(4), 1055–1062.
3. Briggs, G.A.D., Briscoe, B.J., (1976). *Effect of roughness on rubber friction when waves of detachment are present,* Nature, 262, 381–382.
4. Chang, H.W., (1982). *Correlation of wear with oxidation of carbon-carbon composites,* Wear, 80(1), 7–14.
5. Champ, D.H., Southern, A. G. T., (1974). *Fracture mechanics applied to rubber abrasion,* Am. Chem. Soc. Coat. Plast. Div. Prepr, 34(1), 237.
6. Southern, A. G. T., (1979). *Studies of rubber abrasion*. Rubber chemistry and technology, 52, 1001–1018.
7. El-Sayed, et al., (1995). *Friction and wear properties of polymeric composite materials for bearing applications,* Wear, 184(1), 45–53.
8. Friedrich, K., Lu, Z. and Hager, A. M., (1995). *Recent advances in polymer composites' tribology,* Wear, 190(2), 139–144.
9. Grosch, K.A., Schallamach, A., (1965). *Relation between abrasion and strength of rubber*. Trans. Inst. Rubber Ind, 41, 80–82.
10.Grosch, K., (1990). *The abrasion of rubber,* in: K. Anil, S.K.De Bhowmick (Eds.), Fractography of Rubbery Materials, London: Elsevier Ltd.
11.Hutchings, I. M., (1992). *Tribology; Friction and Wear of Engineering Materials*, London: CRC Press.
12.Mallik, P.K., (2008). *Fiber Reinforced Composites*. 3rd edn. New York: CRC Press.
13.Pulford, C. T. R., (1983). *Antioxidant effects during blade abrasion of natural rubber,* Journal of Applied Polymer Science, 28(2), 709–713.
14.Sare, I. R., Mardel, J. I. and Hill, A. J. (2001) *Wear-resistant metallic and elastomeric materials in the mining and mineral processing industries — an overview,* Wear, 250, 1–10.
15.Schallamach, A., (1952). *Abrasion pattern on rubber,* Trans. Inst. Rubber Ind, 256–258.
16.Schallamach, A., (1963). *Abrasion and tyre wear,* London: MacLaren.
17.Vishwanath, B., Verrnab, A. P., Raoc, C. V. S. K., (1993). *Effect on reinforcement on friction and wearof fabric reinforced polymer composites,* Wear, 167, 93–99.
18.Xie, Y., *et al.,* (2015). *Wear resistance of materials used for slurry transport,* Wear, Elsevier, 332–333, 1104–1110.

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