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# INFLUENCE OF CHEMICAL SURFACE MODIFICATION ON MICRO-WEAR CHARACTERISTICS OF SUGARCANE NANOCELLULOSE EPOXY NANOCOMPOSITES

**Mohit H**
*Department of Mechanical Engineering, National Institute of Technology, Tiruchirappalli, India*
hemathmohit@gmail.com

**Arul Mozhi Selvan V**
*Department of Mechanical Engineering, National Institute of Technology, Tiruchirappalli, India*
arulmozhi@nitt.edu

## Abstract

*The waste sugarcane bagasse is the primary agricultural biomass of sugarcane industry and its main constituents is cellulose. These waste sugarcane bagasse can also be applied as reinforcement material in polymer matrix composites. In this present work, the nanocellulose fibers extracted from sugarcane bagasse using salt solution and alkaline treatment process. Sugarcane nanocellulose fiber reinforced epoxy nanocomposites were manufactured by wet layup method. This investigation has been conducted to exhibit the utilization of plant cellulose fiber as the potential reinforcement of synthetic fibers in tribo-composites. The dry sliding wear experiments designed and carried out as per central composite design to determine influence of 3 variable factors such as sliding velocity, sliding distance and load on the wear characteristics of epoxy nanocomposites. From ANOVA (Analysis of variance), it is observed that all three independent parameters plays an important role in the wear characteristics of epoxy* *nanocomposites, as proven from scanning electron microscope. Simultaneously minimize these tribological characteristics, desirable values of the parameters were depicted to be 5.94 m/s, 5 km and 5 N for sliding velocity, distance and load respectively. From normal probability curves, it is signified that there is a good agreement within the RSM models and experimental results.*

**Keywords**

Coefficient of Friction; Epoxy Resin; Nanocellulose; Response Surface Methodology; Salt Solution Treatment; Wear

## 1. Introduction

The shortage of energy and environmental pollution have considered a grave, which leads to attention on advancement of economic and environmental friendly materials (Gandini & Lacerda, 2015; Li et al., 2009). The plant cellulose fibers generally incorporated to replace the synthetic fibers as reinforcement and filler materials, due to lower cost, easily accessible, good biocompatibility and reproducibility (Satyanarayana et al. 2009; Bledzki et al., 2012; Gilfillan et al., 2012). In this context, the plant cellulose fibers are kind of biomass resources and have become essential reinforcement materials to polymer matrices (Liu et al., 2019). In recent decades, certain plant fibers such as silk, jute, sisal, bamboo, rice-husk, sugarcane bagasse and cornstarch have been reinforced in polymers. These reinforcements improves mechanical, degradation, crystallization, and thermal characteristics (Feng et al., 2013; Feng et al., 2011; Su et al., 2011). The sugarcane bagasse is an agricultural residue obtained from sugar and alcohol industries has huge output annually with by products such as rind and bagasse, which eliminated as waste. Presently, the sugarcane bagasse utilized conventionally in generation of electricity and production of pulp and paper. There are various utilization of sugarcane bagasse such as protein rich cattle feed and ethanol production. These techniques are immature or complex and processes considered as uneconomical, which restrict their extensive utilization in industries. Sugarcane bagasse fiber mainly consists of 50% of cellulose, 25% of both lignin and hemicellulose and they associate with each other by covalent and hydrogen bonds. Furthermore, the sugarcane bagasse fibers has enormous benefits such as easy to storage, replaceable and reproducible. The bagasse fibers have various applications as the reinforcement in commercial plastic materials (Pandey et al., 2000; Sun et al., 2004; Sun and Cheng, 2002).

Epoxy polymers characterized with superior properties such as high temperature performance, rigidity, and chemical resistance. Other properties of epoxy resins are protection from chemical corrosion, adhesive characteristics besides with broad range of chemical curing materials. During the curing process, it produces a complex network chain is poor. It is fragile along lower viscoelastic characteristics & thermal stability. It also responsible to restrict higher performance adhesives and coatings (Saba et al., 2016; Gabr et al., 2014). Epoxy polymers are acquired to change, by reinforcing some additives or modifiers to extend its different field of applications (Jawaid et al., 2015). Presently the most promising method is to reinforce certain micro and nano particles such as metal oxides, silica, nanoclay and nanocellulose. During the process of polymerization to develop, the polymer based composite materials for upcoming engineering applications (Saba et al., 2015). These type of polymer-based nanocomposites are multiphase solid engineering materials. It contains higher tensile stiffness, strength, and aspect ratio within the polymer to assign special characteristics of practical and industrial applications (Pillai & Rennecker, 2016).

The compatibility of plant cellulose fibers and composite matrix straightly influences on fiber-matrix bonding strength (interface). In this context, weaker bonding strength does not involve effective transmission of stress from matrix to plant cellulose fibers. This effect tends to weaker polymer laminates with lower mechanical characteristics and smaller life span. From last few decades, scientists investigated on the impact of chemical surface treatments of plant cellulose fibers on physical, mechanical, interface bonding strength, morphological and tribological characteristics of polymer composites (Liu et al. 2019). The tribological characteristics of polymer incorporated with plant cellulose is an interesting area in the tribology field in current decades (Yousif et al., 2010). The engineering components depends on tribological effects like abrasion & adhesion. By demonstrating tribological characteristics of plant cellulose incorporated laminates is necessary as interpreting structural characteristics of laminates. Many investigation has been carried out on studying the wear characteristics of plant cellulose reinforced laminates like friction & wear of the polymer based laminates incorporated using oil palm, jute and bamboo (Chand & Dwivedi, 2006; Yousif & El-Tayeb, 2008; Chin & Yousif, 2009; Nirmal et al., 2012). Valasek et al. (2018) fabricated alkali treated brown/ white coir incorporated composites and studied the effect of chemical surface treatment on abrasive wear and mechanical properties. The investigation concluded that chemical treatment improved interaction within epoxy resin and wear resistance of composites. Shalwan and Yousif (2014) targeted at modifying the surface of date palm fiber utilized from sodium hydroxide and enhancing wear resistance characteristics of date palm fiber epoxy composites. Liu et al. (2019) manufactured silane treated corn stalk fiber reinforced polymer composites. From the investigation, it is concluded that silane treated fibers have better wear resistance than raw sample. Many investigations shows the varied tribological characteristics depend on the reinforcement types applied in the laminates. Furthermore, limited investigations carried out on the outcomes of plant cellulose nanofibers on wear characteristics of polymer nano-laminates.

Certain types of nanoparticles (biological) like cellulose nanofibers and cellulose nano-crystals which is obtained from biomass(renewable) presently drawing larger attention. It contains lower thermal expansion, higher modulus, higher benefits to environment, higher surface area and cheaper materials. It can be applied as an alternative to micro-size particles in laminates (Pillai & Rennecker, 2016). Cellulose nanofibers contains both amorphous and crystalline phases. It possess extra-ordinary mechanical characteristics as compared with other plant cellulose and synthetic fabrics. Many techniques has been utilized to derive the nanofibers from cellulosic (high-pressure homogenizing, pulp heating and cryo crushing) (Li et al., 2014). In recent decades, the nanoparticles extracted from cellulose attracted researchers, with improved mechanical, electrical, thermal and biodegradation of polymer characteristics (Abraham et al., 2012; Li et al., 2014). Cellulose nanofibers produces flexible, filamentous and web like network chains. It also have interesting mechanical characteristics such as greater strength and substantial plastic deformation. It expands its utilization in nano-laminates and developed base materials (Li et al., 2014). Now range of thermoplastics and thermoset are reinforced with cellulose nanofibers under lower loading of fillers. As an outcome in the generation of irreversible aggregates at higher content of fillers (Babee et al., 2015).

From the literature review, it is observed that chemical treatment on natural fibers improves the performance, which is expensive and needs skilled labours and sophisticated facilities. It is also noticed that higher filler in polymer matrices creates weaker bonding within the polymer matrix. In this present investigation, a new and innovative technique is approached for the extraction of nanocellulose fiber. The cellulose nanofibers are reinforced in epoxy to enhance the wear resistance and reduce the coefficient of friction of the epoxy nanocomposites. The objective of this investigation is to determine the influence of sliding velocity, sliding distance and load at different chemical treatment process to improve the wear resistance characteristics. The response surface methodology was applied to study the effects of the varying parameters. The derived formula, which explains the relation between the response output and variable parameters in the tribological properties of epoxy nanocomposites. Then, the outcome results were compared with the experimentation under the optimum condition for studying the accuracy of the derived formula with possible errors. The collected outcomes can guide the usage of agricultural wastes such as sugarcane bagasse and advancement of novel or improved technology for the manufacturing of polymer based nanocomposites.

## 2. Materials and Methods

### 2.1. Extraction of Sugarcane Nanocellulose Fibers

The waste sugarcane bagasse was obtained from different juice shops and sugarcane factories, Tamilnadu, India in the form of stalks. The collected stalks were dried in sunlight for two days to eliminate the water content and odor. After the drying process, the bagasse was cleaned with tap water and dirt particles were removed (Raw bagasse sample – SRS). The cleaned bagasse was soaked in the salt solution (sodium chloride with tap water in the ratio of 10:1 under 6.5 pH) for two days in the atmospheric condition (Salt solution treatment – SST) and then dried in sunlight for 8 hours to remove the moisture content. After salt solution treatment process, bagasse samples were treated under 0.1 N NaOH solution for 4 hours in 100 ºC to remove the lignin content (Alkaline treatment – SAT). From three different treatment processes, the sugarcane bagasse was shifted to industrial grinder and crusher to convert into powder particles. The nano mesh of average 50 nm size is utilized to separate the nanocellulose.

### 2.2. Fabrication of nanocellulose epoxy nanocomposites

The epoxy polymer LY556 and hardener HY951 were used in this investigation, supplied from Sakthi Fiber Glass, Inc. Chennai, India. Epoxy based polymer nanocomposites were manufactured by reinforcing 10 wt.% of SRS, SST and SAT nanocellulose fibers through wet layup method. The nanocellulose fibers were mixed with epoxy resin and stirred using ultrasonicator probe to obtain the uniform dispersion throughout the matrix. After the stirring process, the HY951 (10 wt.%) acts as curing agent was poured into the resin mixture to cure. The mixture poured in the mild steel mould and remained to curing process for 6 hours under atmospheric condition (room temperature). The grease oil applied in mould to control the elimination of polymer based nano-laminates. The similar approach also utilized for the production of neat epoxy polymer laminates without nanoparticles as controlled specimen.

### 2.3. Experimental Design

General RSM experimentation, termed as central composite design considered in current investigation with Design Expert 9.0 statistical analysis. From the central composite design approach, three independent factors such as sliding velocity, sliding distance and load were employed at five coded regions (-2, -1, 0, +1 and +2) to generate the experimentation process as shown in table 1. Experimentation work contains 15 different runs with mean of three samples for every run given in table 2. Sequence of the experimentation shuffled to eliminate the influence of unconstrained factors.

**Table 1:** *Parameters in Central Composite Design*

| **Factors** | **Usage of Levels** | | | | |
|---|---|---|---|---|---|
| | Very Low (-2) | Low (-1) | Medium (0) | High (+2) | Very High (+2) |
| Sliding velocity in m/s | 1.95 | 4 | 7 | 10 | 12.05 |
| Sliding distance in km | 3.29 | 5. | 7.5 | 10 | 11.71 |
| Load in N | 1.27 | 4 | 8 | 12 | 14.73 |

**Table 2:** *Central Composite Design*

| **Expt.** | **Different types of run** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | XIII | XIV | XV |
| **Sv in m/s** | 4 | 7 | 4 | 10 | 10 | 10 | 10 | 4 | 4 | 7 | 7 | 12.05 | 1.95 | 7 | 7 |
| **Sd in km** | 10 | 11.71 | 5 | 10 | 5 | 10 | 5 | 5 | 10 | 7.5 | 7.5 | 7.5 | 7.5 | 3.29 | 7.5 |
| **L in N** | 12 | 8 | 4 | 4 | 12 | 12 | 4 | 12 | 4 | 1.27 | 14.73 | 8 | 8 | 8 | 8 |

### 2.4. Characterization

The pin on disc micro wear testing approach in dry condition considered to study the wear characteristics under room temperature. In the wear testing process, the pin was impacted stationary on the rotating disc. The specimen as pin were removed from the nanocomposite material with the 3 mm diameter and 15 mm length. The disc material was EN21 stainless steel. From the experimental design, the sliding velocity, sliding distance and applied load was varied which is shown in table 1. For every condition, three repetitive tests were conducted to determine the errors in the wear testing process.

The microstructure of the fabricated epoxy nanocomposites studied from SEM (scanning electron microscope) (FE-SEM, Hitachi, Europe) from wear surface of the tribological testing. During the examination, the specimens were gold-coated using sputtering machine to protect from accumulation of electrical charge and examined with accelerating voltage (15 kV).

## 3. Results and Discussion

### 3.1. Tribological Characteristics

The tribological characteristics of sugarcane nanocellulose epoxy nanocomposites were examined using ANOVA to determine influence of 3 factors like sliding velocity, sliding distance and load on wear rate and coefficient of friction. The ANOVA results given in table 3 and 4 for rate of wear and friction coefficient respectively. The ANOVA table exhibits the sum of squares and mean sum of squares of each factor whereas the f-ratio and p-value shows the ratio between the average error and mean square effect. From the confidence level (95%), p-value is lesser than the 0.05 which could be considered as significant. Both the p-values and F-ratio are also given in table 3 and 4. It can observed that the effects of sliding velocity, distance & load as well as the interaction effects like velocity x distance (AB), velocity x load (AC) and distance x load (BC) are also statistically significant for both the wear and friction coefficient of sugarcane nanocellulose epoxy laminates reinforced with SRS, SST and SAT type of fibers. The polynomial equation with statistical significance developed from certain combinations of calculations for the factors and ANOVA outcomes for wear and friction coefficient. This equation, verifies quantitatively the influence of factors with statistical significance in coded level (-2, -1, 0, +1, +2) is as displayed as follows in equation (1) - (6) for wear & friction coefficient respectively.

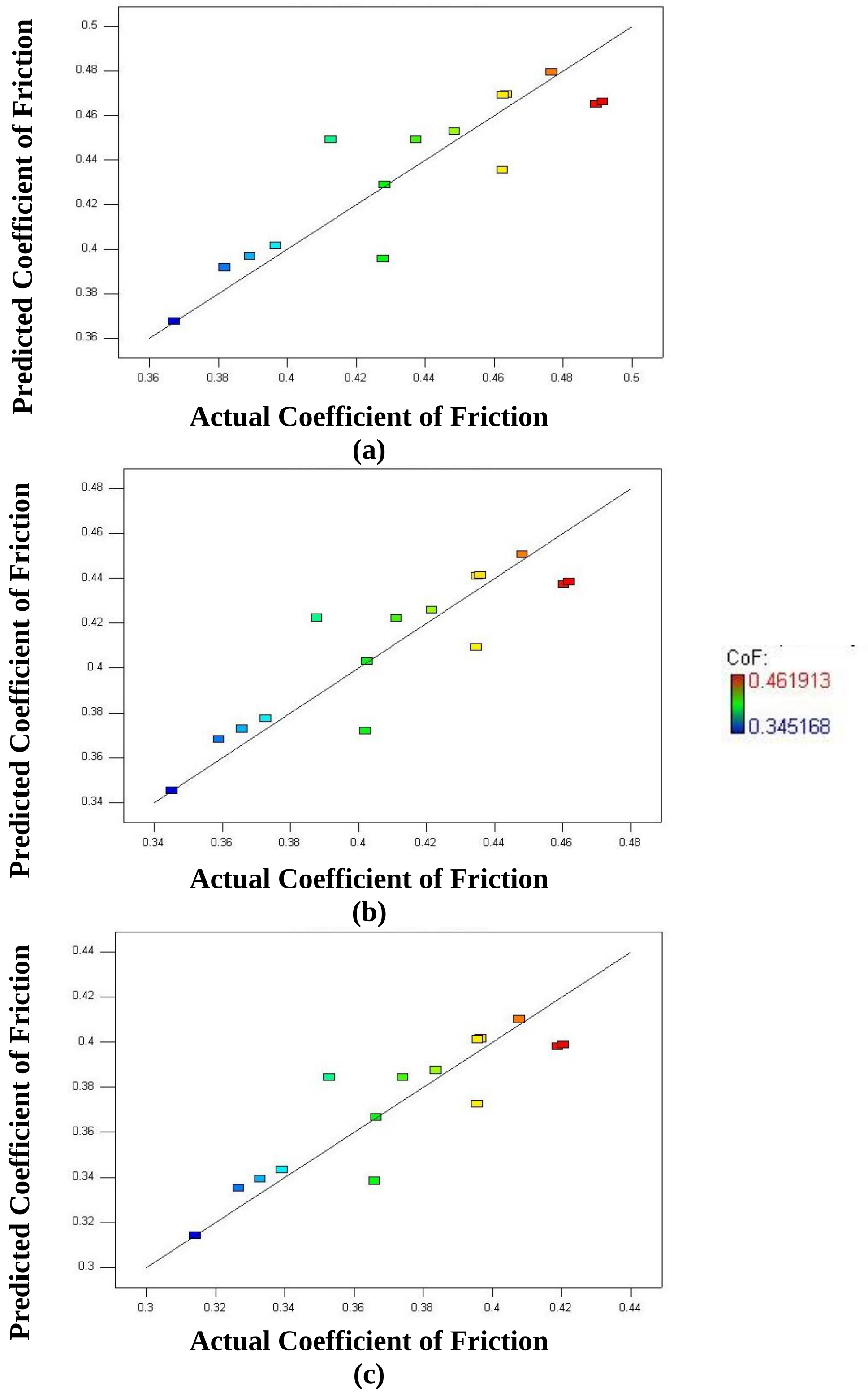
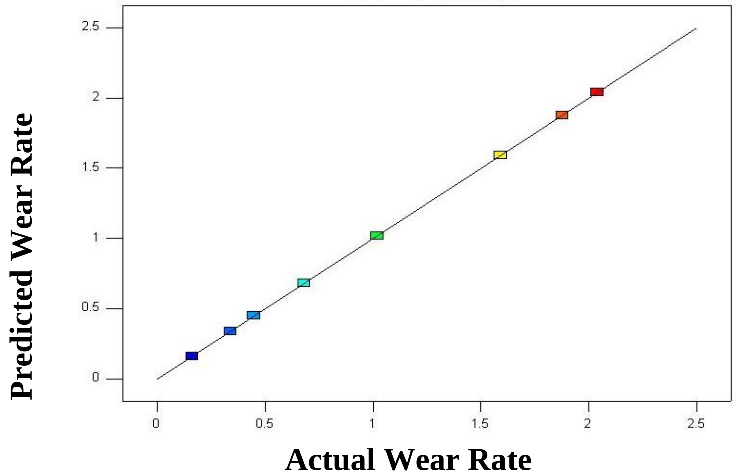
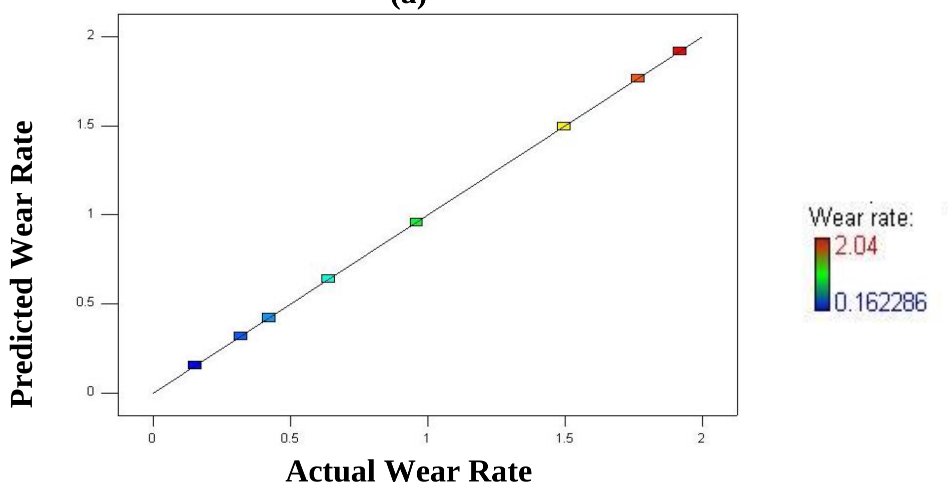


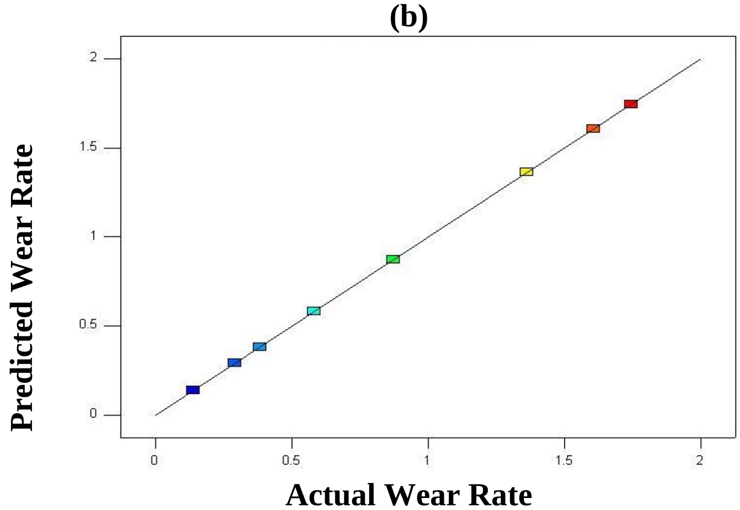

**Figure 1:** *Predicted vs actual values for coefficient of friction (a) SRS, (b) SST and (c) SAT*




**(a)**




**(b)**




**(c)**

**Figure 2:** *Predicted vs actual values for Wear Rate (a) SRS, (b) SST, (c) SAT*

$$WR_{SRS} = 1.02 - 2.82 \times 10^{-16} \times A + 0.34 \times B + 0.51 \times C + 2.94 \times 10^{-16} \times AB + 3.92 \times 10^{-16} \times AC + 0.17 \times BC - 3.50 \times 10^{-15} \times A^2 + 4.61 \times 10^{-15} \times B^2 + 4.55 \times 10^{-15} \times C^2 \quad (1)$$

$$WR_{SST} = 0.96 - 1.93 \times 10^{-16} \times A + 0.32 \times B + 0.48 \times C - 2.95 \times 10^{-16} \times AB + 2.84 \times 10^{-16} \times AC + 0.16 \times BC - 1.59 \times 10^{-15} \times A^2 - 1.21 \times 10^{-15} \times B^2 + 6.12 \times 10^{-15} \times C^2 \quad (2)$$

$$WR_{SST} = 0.87 + 9.24 \times 10^{-17} \times A + 0.29 \times B + 0.44 \times C + 7.50 \times 10^{-17} \times AB - 1.76 \times 10^{-16} \times AC + 0.15 \times BC - 6.54 \times 10^{-17} \times A^2 + 2.22 \times 10^{-16} \times B^2 + 2.11 \times 10^{-16} \times C^2 \quad (3)$$

$$CoF_{SRS} = 0.37 - 5.20 \times 10^{-3} \times A - 1.13 \times 10^{-3} \times B + 3.87 \times 10^{-3} \times C - 0.022 \times AB - 6.98 \times 10^{-3} \times AC - 0.013 \times BC + 0.027 \times A^2 + 9.29 \times 10^{-3} \times B^2 + 0.037 \times C^2 \quad (4)$$

$$CoF_{SST} = 0.35 - 4.89 \times 10^{-3} \times A - 1.06 \times 10^{-3} \times B + 3.64 \times 10^{-3} \times C - 0.021 \times AB - 6.56 \times 10^{-3} \times AC - 0.012 \times BC + 0.026 \times A^2 + 8.73 \times 10^{-3} \times B^2 + 0.035 \times C^2 \quad (5)$$

$$CoF_{SAT} = 0.37 - 4.45 \times 10^{-3} \times A - 9.66 \times 10^{-4} \times B + 3.31 \times 10^{-3} \times C - 0.019 \times AB - 5.97 \times 10^{-3} \times AC - 0.011 \times BC + 0.023 \times A^2 + 7.95 \times 10^{-3} \times B^2 + 0.032 \times C^2 \quad (6)$$

Whereas WR is the wear and CoF is the friction coefficient

**Table 3:** *ANOVA Outcomes for Wear*

| Source | SRS | | | | SST | | | | SAT | | | | Rem. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SoS | df | MoS | Pv | SoS | df | MoS | Pv | SoS | df | MoS | Pv | |
| **Block** | 0 | 2 | 0 | | 0 | 2 | 0 | | 0 | 2 | 0 | | Significant |
| **Model** | 5.36 | 9 | 0.59 | 0.002 | 4.73 | 9 | 0.526 | 0.002 | 3.92 | 9 | 0.43 | 0.002 | |
| **A** | 0 | 1 | 0 | 0.386 | 0 | 1 | 0 | 0.386 | 0 | 1 | 0 | 0.386 | |
| **B** | 1.57 | 1 | 1.57 | 0.847 | 1.39 | 1 | 1.39 | 0.847 | 1.15 | 1 | 1.15 | 0.847 | |
| **C** | 3.55 | 1 | 3.55 | 0.514 | 3.13 | 1 | 3.13 | 0.514 | 2.592 | 1 | 2.59 | 0.514 | |
| **AB** | 0 | 1 | 0 | 0.017 | 0 | 1 | 0 | 0.017 | 0 | 1 | 0 | 0.017 | |
| **AC** | 0 | 1 | 0 | 0.374 | 0 | 1 | 0 | 0.374 | 0 | 1 | 0 | 0.374 | |
| **BC** | 0.23 | 1 | 0.23 | 0.118 | 0.204 | 1 | 0.204 | 0.118 | 0.169 | 1 | 0.16 | 0.118 | |
| **$A^2$** | 0 | 1 | 0 | 0.001 | 0 | 1 | 0 | 0.001 | 0 | 1 | 0 | 0.001 | |
| **$B^2$** | 0 | 1 | 0 | 0.131 | 0 | 1 | 0 | 0.131 | 0 | 1 | 0 | 0.131 | |
| **$C^2$** | 0 | 1 | 0 | 0.000 | 0 | 1 | 0 | 0.001 | 0 | 1 | 0 | 0.001 | |
| **Residual** | 0 | 8 | 0 | | 0 | 8 | 0 | | 0 | 8 | 0 | | |
| **Lack of Fit** | 0 | 5 | 0 | | 0 | 5 | 0 | | 0 | 5 | 0 | | |
| **Pure Error** | 0 | 3 | 0 | | 0 | 3 | 0 | | 0 | 3 | 0 | | |
| **Cor Total** | 5.36 | 19 | | | 4.73 | 19 | | | 3.92 | 19 | | | |

**Table 4:** *ANOVA Outcomes for Friction Coefficient*

| Source | SST | | | | SAT | | | | SRS | | | | Rem. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SoS | df | MoS | Pv | SoS | df | MoS | Pv | SoS | df | MoS | Pv | |
| **Block** | 0.0016 | 2 | 0.001 | | 0.0014 | 2 | 0.001 | | 0.001 | 2 | 0.00 | | Significant |
| **Model** | 0.0344 | 9 | 0.003 | 0.002 | 0.0304 | 9 | 0.003 | 0.002 | 0.025 | 9 | 0.00 | 0.002 | |
| **A** | 0.0003 | 1 | 0.001 | 0.386 | 0.0003 | 1 | 0.001 | 0.386 | 0.000 | 1 | 0.00 | 0.386 | |
| **B** | 1.74e-005 | 1 | 1.74e-005 | 0.847 | 1.53e-005 | 1 | 1.53e-005 | 0.847 | 1.27e-005 | 1 | 1.2708e-005 | 0.847 | |
| **C** | 0.0002 | 1 | 0.001 | 0.514 | 0.0001 | 1 | 0.001 | 0.514 | 0.001 | 1 | 0.001 | 0.514 | |
| **AB** | 0.0039 | 1 | 0.003 | 0.017 | 0.0034 | 1 | 0.003 | 0.017 | 0.002 | 1 | 0.00 | 0.017 | |
| **AC** | 0.0003 | 1 | 0.001 | 0.374 | 0.0003 | 1 | 0.001 | 0.374 | 0.000 | 1 | 0.00 | 0.374 | |
| **BC** | 0.0013 | 1 | 0.001 | 0.118 | 0.0011 | 1 | 0.001 | 0.118 | 0.001 | 1 | 0.00 | 0.118 | |
| **$A^2$** | 0.0106 | 1 | 0.010 | 0.001 | 0.0094 | 1 | 0.009 | 0.001 | 0.007 | 1 | 0.00 | 0.001 | |
| **$B^2$** | 0.0012 | 1 | 0.001 | 0.131 | 0.0010 | 1 | 0.001 | 0.131 | 0.001 | 1 | 0.00 | 0.131 | |
| **$C^2$** | 0.020 | 1 | 0.020 | 0.000 | 0.0177 | 1 | 0.017 | 0.001 | 0.014 | 1 | 0.01 | 0.001 | |
| **Residual** | 0.0035 | 8 | 0.000 | | 0.0031 | 8 | 0.001 | | 0.002 | 8 | 0.00 | | |
| **Lack of Fit** | 0.0035 | 5 | 0.001 | | 0.0031 | 5 | 0.001 | | 0.002 | 5 | 0.00 | | |
| **Pure Error** | 0 | 3 | 0 | | 0 | 3 | 0 | | 0 | 3 | 0 | | |
| **Cor Total** | 0.0395 | 19 | | | 0.0349 | 19 | | | 0.028 | 19 | | | |

All the statistical and non-statistical significance terms are considered which is shown in equations (1) to (6). It can be examined from the coefficients that load have highest effect on wear rate followed by sliding distance and velocity. The probability curves analyzed to evaluate efficiency of developed formulation. Figure 1 and 2 exhibits relationship within predicted and actual quantities of wear & friction coefficient respectively. Various points are deviations of actual points from fitted or predicted quantities. Figure also signifies that generated equation is efficient due to the residual in confirmation of every output is minimum, whereas residuals appeared at the diagonal line. The interaction of AB, AC & BC considered displaying 3D surface plots of wear rate with individual factors. The response surface curve is showing the vertical axes have response output and two horizontal axes presents the two significant factors, by maintaining third factor constant.

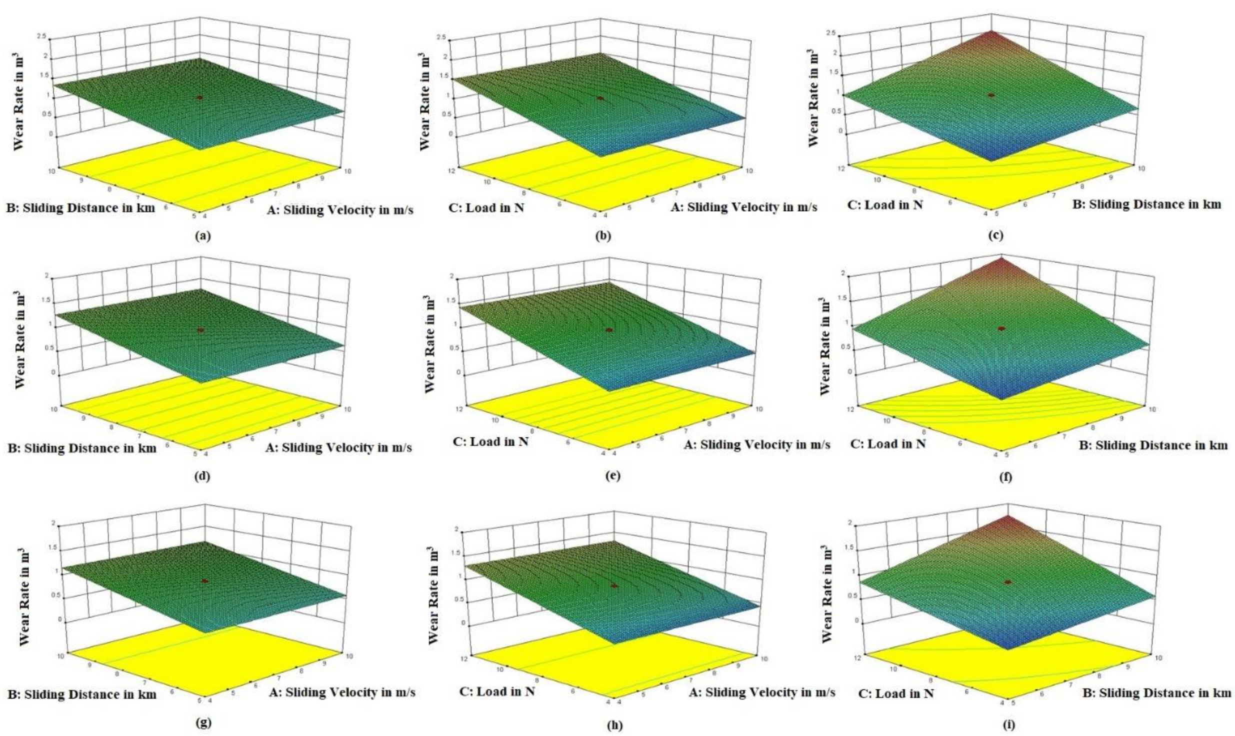



**Figure 3:** *3D surface graph for wear rate of sugarcane nanocellulose epoxy nanocomposites (a) SRS-AB, (b) SRS-AC, (c) SRS-BC, (d) SST-AB, (e) SST-AC, (f) SST-BC, (g) SAT-AB, (h) SAT-AC and (i) SAT-BC*

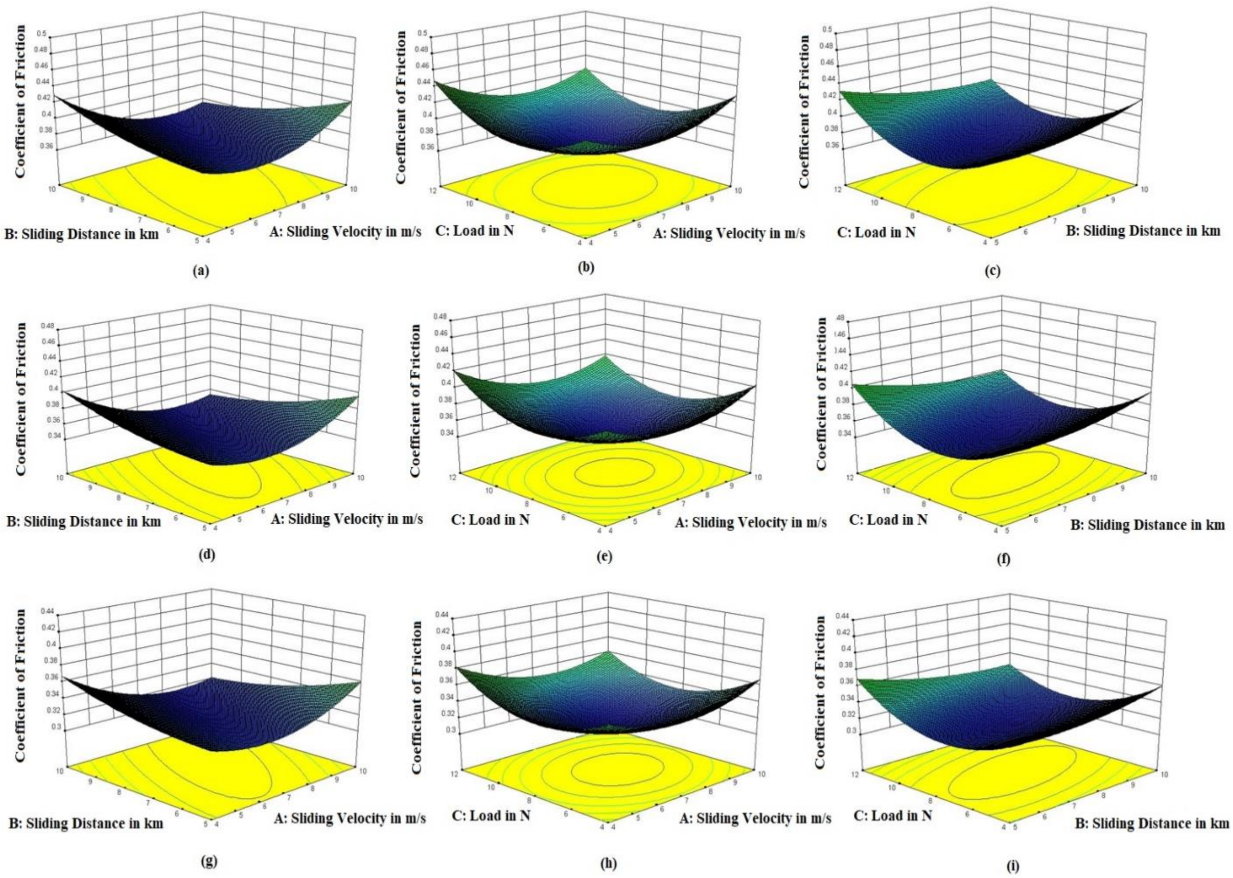



**Figure 4:** 3D *surface graph for coefficient of friction of sugarcane nanocellulose epoxy nanocomposites (a) SRS-AB, (b) SRS-AC, (c) SRS-BC, (d) SST-AB, (e) SST-AC, (f) SST-BC, (g) SAT-AB, (h) SAT-AC and (i) SAT-BC*

Figure 3 and 4 for the 3D surface plot of wear and friction coefficient respectively. The interaction effect of sliding velocity and sliding distance states that the wear rate of the composites increases with the increase in sliding distance, whereas the increment in velocity reduces wear and remains constant. Similarly in coefficient of friction, the increase in sliding distance, the value of coefficient of friction (CoF) improves, but the increase in sliding velocity, the CoF value decreased up to 6 m/s, remains constant until 8 m/s and increased above 9 m/s. By considering the interaction of sliding velocity and load (AC), the wear of the laminates increased with increment in load & remain constant at velocity. In CoF, different trend observed, by increasing both the load and sliding velocity, firstly it decreased and then increased. Therefore, it is clearly examined that there is no effect for sliding velocity in wear & friction coefficient. Consider the interaction distance & load (BC), it is clearly observed that increment of both load and sliding distance consequently improve wear and coefficient of friction of the fabricated epoxy nanocomposites. Furthermore, both load & distance highly affects wear characteristics of material. Similar trend also found in rest of the SST and SAT fiber reinforced epoxy nanocomposites which shows that both load and sliding distance plays a significant role in the wear behavior of the epoxy nanocomposites.

### 3.2. Minimization of Tribological Properties

From the optimization investigation of the tribological characteristics, the output responses are simultaneously minimize the wear rate and coefficient of friction. A generalized approach to determine the multiple output optimization concept is to utilize desirability, useful technique to remove dimensionality of the simultaneous optimization, which is equal to 1. From this method, each output is modified into desirability formula, which varies from 0 and 1. From the optimization work, the desirability formula is smaller better which is shown in equation (7) in overall form.

$$d = \begin{cases} 1 & y < T \\ \left(\frac{y-U}{T-U}\right)^r & T \le y \le U \\ 0 & y > U \end{cases} \qquad (7)$$

From equation 3.7, y is response output, U is upper limit of the response, T is response target and r is weight factor (Ghasemi et al., 2016). The desirability formula contains four outputs in the work which can be measured from the equation (8).

$$D = \sqrt[3]{d_1(WR(x)) \times d_2(CoF(x))} \qquad (8)$$

From equation 8, the desirability of tribocomposites, vector of designed factor, desirability formula relates to first and second response are denotes to D, x, $d_1$ and $d_2$ respectively. Desirability formula of epoxy nanocomposites calculated from Design Expert 9.0 Statistical analysis software and weight factor is considered as 0.5. While simultaneously minimizing wear & friction coefficient at the optimal case (D = 0.876) in epoxy nanocomposites reinforced with SST, SAT and SRS fibers have sliding velocity, sliding distance and load are in 5.81 m/s, 5 km and 5.56 N respectively. From table 3.3 displays the levels of factors under mentioned condition and from the response surface methodology experimental design, the desirability function depicts the wear rate and coefficient of friction behavior of epoxy nanocomposites. Moreover, the desirability functions are most significant at minimizing the tribological characteristics. The confirmation experiment was conducted under the optimized case of three types of epoxy nanocomposites. The wear rate and coefficient of friction values obtained from confirmation experiments are compared with optimized data from RSM which is given in table 5.

**Table 5:** *Confirmation experimental results for optimum condition*

| Optimal values | Optimal variables | | | |
|---|---|---|---|---|
| | Prediction | | Confirmation experiment | |
| | Wear rate | CoF | Wear rate | CoF |
| **SRS** | 0.437 | 0.380 | 0.435±3.67% | 0.376±0.86% |
| **SST** | 0.431 | 0.360 | 0.427±1.68% | 0.354±0.97% |
| **SAT** | 0.404 | 0.323 | 0.398±3.37% | 0.317±0.75% |

### 3.3. Optimum Tribological Properties

The confirmation experiment again performed in pin on disc micro wear testing machine. In this context, the continuous rotation steel counter face slide among surface of the epoxy nanocomposite specimen. From the experimental results of the optimum condition (sliding velocity, sliding distance and normal loads), it can be examined that wear & friction coefficient reduced for SST, SAT & SRS epoxy nanocomposites. It is clearly observed that SAT fiber epoxy nanocomposites have both lower wear & friction coefficient and overall tribological properties reduced by 10.36% as compared with other types. Interestingly, the decrement in both wear rate and coefficient of friction is significant for medium normal loads under micro level. This effect is due to the presence of alkali treated nanocellulose particles in the contact surface. Another reason is ability of nanocellulose fibers to withstand in bending and compression loads as observed from the literature (Alamri & Low, 2012; Leyland & Matthews 2000; Saba et al., 2017). Similar results were observed from other researchers (Barari et al., 2016).

### 3.4. Wear worn surface of epoxy nanocomposites

The important role of nanocellulose fibers on the wear behavior can be understand, by three different composite samples selected for the comparison. The worn surfaces examined by using SEM analysis. Design of worn surface clearly predicts the composition dependent wear characteristics. All the SST, SAT and SRS epoxy nanocomposites samples were subjected to optimum condition of sliding velocity, sliding distance and normal loads. The worn surface is damaged is reduced by alkali treated nanocellulose fibers to the epoxy matrix. This decreased the wear rate and coefficient of friction while comparing with other two types of epoxy nanocomposites, as it supports matrix in lower extent. Therefore, the explanation for higher resistance of wear in nanocomposites is load-bearing capability of sugarcane nanocellulose fibers in polymer.

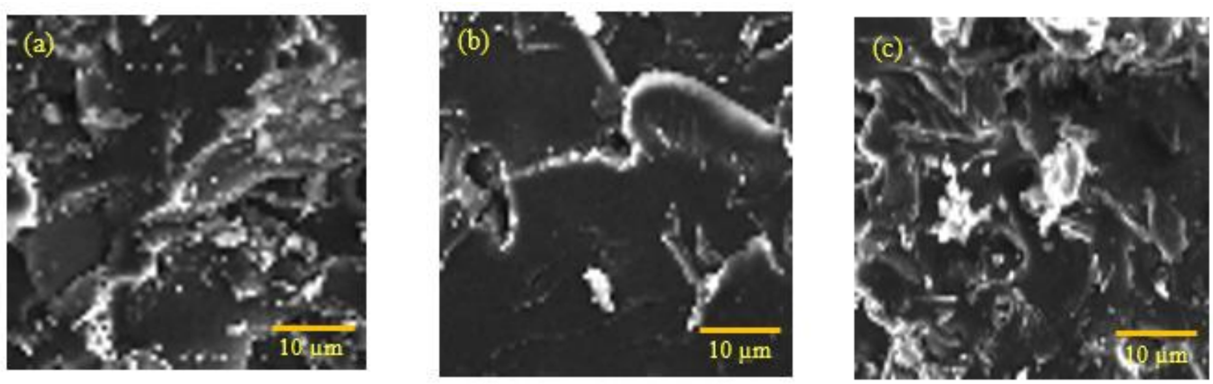



**Figure 5:** *Worn surface of epoxy nanocomposites (a) SRS, (b) SST and (c) SAT*

Figure 5 (a), (b) and (c) shows the worn surface of epoxy nanocomposites reinforced with SRS, SST and SAT nanocellulose fibers under the optimum condition of 5.81 m/s of sliding velocity, 5 km of sliding distance and 5.56 N of normal load. It is clearly observed that the both the treated fibers have no cracks and wear rate and coefficient of friction of the nanocomposites reduced to the strong bonding and lesser deterioration of materials in the matrix. Moreover, in SRS epoxy nanocomposites, the bonding between epoxy matrix and sugarcane nanocellulose was broken at optimum condition (Islam and Saadi, 2018). Hence the nanocellulose fibers was not capable to withstand at load which leads to comparably higher wear rate than other two types of treated fibers under optimum condition. Similar results also observed in other investigations (Barari et al., 2016; Nahas, 2018).

## 4. Conclusion

The cellulose fibers extracted from waste sugarcane bagasse applied as reinforcement polymeric materials. In this present investigation, sugarcane nanocellulose epoxy nanocomposites reinforced with SRS, SST and SAT fibers fabricated using wet layup method. The experimental design conducted using response surface methodology (central composite design) using Design Expert 9.0 statistical analysis software at three independent factors like velocity, distance & normal loads. The results attained from the ANOVA shows that the normal load have direct influence on wear and friction coefficient. Furthermore, effect of distance on wear and friction coefficient decreased with higher level of sliding velocity. From the desirability formula, the various tribological properties such as wear rate and coefficient of friction both were optimized and validated with confirmation experiment to verify the efficiency of the developed polynomial model, Results obtained from response surface methodology combined with desirability are in good agreement with those examined in SEM analysis. The tribological characteristics of the SAT fibers lower wear rates and coefficient of friction than other two types. This effect is due to production of film on surfaces, tends to decrement in straight contact of nanocomposites with aspects of counter face. But in the same optimum condition, the SRS fibers have comparably higher coefficient of friction and wear rate. This shows that there is no correlation within velocity and friction coefficient/ wear loss observed. Under higher loading of nanocellulose fibers and higher loading effects decrease the wear resistance, due to weaker interfacial bonding within the matrix of the material observed in SEM and 3D surface graphs. In other investigations, the silane treatment process also improves the tribological properties of polymer composites. In future perspective, the sugarcane bagasse fiber reinforced polymer nanocomposites appears to be bright, due to they are light in weight, cheaper, biodegradable and environmentally friendly as compared with synthetic fibers. These type of nanocomposites applied in automobiles and furniture industries, due to better wear resistance characteristics under the optimum condition.

## References

Abraham E., Elbi P., Deepa B., Jyotish kumar P., Pothen L., Narine S., & Thomas S. (2012). X-ray diffraction and biodegradation analysis of green composites of natural rubber/ nanocellulose. Polymer Degradation and Stability, 97, 2378-2387. https://doi.org/10.1016/j.polymdegradstab.2012.07.028

Alamri H., & Low I. M. (2012). Microstructural, mechanical and thermal characteristics of recycled cellulose fiber-halloysite-epoxy hybrid nanocomposites. Polymer Composites, 33(4), 589-600. https://doi.org/10.1002/pc.22163

Babee M., Jonoobi M., Hamzeh Y., & Ashori A. (2015). Biodegradability and mechanical properties of reinforced starch nanocomposites using cellulose nanofibers. Carbohydrate Polymers, 132, 1-8. https://doi.org/10.1016/j.carbpol.2015.06.043

Barari B., Omrani E., Moghadam A. D., Menezes P. L., Pillai K. M., Rohatgi P. K. (2016). Mechanical, physical and tribological characterization of nano-cellulose fibers reinforced bio-epoxy composites: An attempt to fabricate and scale the green composite. Carbohydrate Polymers, 147, 282-293. https://doi.org/10.1016/j.carbpol.2016.03.097

Bledzki A. K., Mamun A. A., Bonnia N. N., & Ahmad S. (2012). Basic properties of grain by products and their variability in polypropylene composites. Industrial Crops and Products, 37, 427-434. https://doi.org/10.1016/j.indcrop.2011.05.010

Chand N., & Dwivedi U. (2007). High stress abrasive wear study on bamboo. Journal of Materials Processing Technology, 183(2), 155-159. https://doi.org/10.1016/j.jmatprotec.2006.09.036

Chin C., & Yousif B. (2009). Potential of kenaf fibers as reinforcement for tribological applications. Wear, 267(9), 1550-1557. https://doi.org/10.1016/j.wear.2009.06.002

Feng Y. H., Li Y. J., Xu B. P., Zhang D. W., Qu J. P., & He H. Z. (2013). Effect of fiber morphology on rheological properties of plant fiber reinforced poly(butylenes succinate) composites. Composites Part B: Engineering, 44, 193-199. https://doi.org/10.1016/j.compositesb.2012.05.051

Feng Y. H., Zhang D. W., Qu J. P., He H. Z., & Xu B. P. (2011). Rheological properties of sisal fiber/ poly(butylene succinate) composites. Polymer Testing, 30(1), 124-130. https://doi.org/10.1016/j.polymertesting.2010.11.004

Gabr M. H., Phong N. T., Okubo K., Uzawa K., Kimpara I., & Fujii T. (2014). Thermal and mechanical properties of electrospun nanocellulose reinforced epoxy nanocomposites. Polymer Testing, 37, 51-58. https://doi.org/10.1016/j.polymertesting.2014.04.010

Gandini A., & Lacerda T. M. (2015). From monomers to polymers from renewable resources: recent advances. Progress in Polymer Science, 48, 1-39. https://doi.org/10.1016/j.progpolymsci.2014.11.002

Ghasemi F. A., Ghasemi I., Menbari S., Ayaz M., & Ashori A. (2016). Optimization of mechanical properties of polypropylene/ talc/ graphene composites using response surface methodology. Polymer Testing, 53, 283-292. https://doi.org/10.1016/j.polymertesting.2016.06.012

Gilfillan W. N., Nguyen D. M. T., Sopade P. A., & Doherty W. O. S. (2012). Preparation and characterization of composites from starch and sugarcane fiber. Industrial Crops and Products, 40, 45-54. https://doi.org/10.1016/j.indcrop.2012.02.036

Islam M. A., & Saadi M. A. S. R. (2018). Production and characterization of green polymer composite with natural fillers. Matter: International Journal of Science and Technology, 4(2), 137-148. https://doi.org/10.20319/mijst.2018.42.137148

Jawaid M., Alothman O. Y., Saba N., Tahir P. M., & Khalil H. (2015). Effects of fibers treatment on dynamic mechanical and thermal properties of epoxy hybrid composites. Polymer Composites, 36, 1669-1674. https://doi.org/10.1002/pc.23077

Leyland A., & Matthews A. (2000). On the significance of the H/E ratio in wear control: a nanocomposite coating approach to optimized tribological behavior. Wear, 246(1), 1-11. https://doi.org/10.1016/S0043-1648(00)00488-9

Li W., Wu Q., Zhao X., Huang Z., Cao J., Li J., & Liu S. (2014). Enhanced thermal and mechanical properties of PVA composites formed with filamentous nanocellulose fibrils. Carbohydrate Polymers, 113, 403-410. https://doi.org/10.1016/j.carbpol.2014.07.031

Li Y. D., Zeng J. B., Li W. D., Yang K. K., Wang X. L., & Wang Y. Z. (2009). Rheology, crystallization, and biodegradability of blends based on soy protein and chemically modified poly (butylene succinate). Industrial Engineering and Chemistry Research, 48, 4817-4825. https://doi.org/10.1021/ie801718f

Liu Y., Xie J., Wu N., Wang L., Ma Y., & Tong J. (2019). Influence of silane treatment on the mechanical, tribological and morphological properties of corn stalk fiber reinforced polymer composites. Tribological International, 131, 398-405. https://doi.org/10.1016/j.triboint.2018.11.004

Nahas M. N. (2018). The fracture behavior of random fiber-reinforced composite specimens. Matter: International Journal of Science and Technology, 4(2), 63-73. https://dx.doi.org/10.20319/mijst.2018.42.6373

Nirmal U., Hashim J. & Low K. (2012). Adhesive wear and frictional performance of bamboo fibers reinforced epoxy composite. Tribology International, 47, 122-133. https://doi.org/10.1016/j.triboint.2011.10.012

Pandey A., Soccol C. R., Nigam P., & Soccol V. T. (2000). Biotechnological potential of agro-industrial residues L: sugarcane bagasse. Bioresource Technology, 74(1), 69-80. https://doi.org/10.1016/S0960-8524(99)00142-X https://doi.org/10.1016/S0960-8524(99)00143-1

Pillai K. V., & Renneckar S. (2016). Dynamic mechanical analysis of layer-by-layer cellulose nanocomposites. Industrial Crops and Products, 93, 267-275. https://doi.org/10.1016/j.indcrop.2016.02.037

Saba N., Jawaid M., Alothman O.Y., Paridah M., & Hassan A. (2015). Recent advances in epoxy resin, natural fiber-reinforced epoxy composites and their applications. Journal of Reinforced Plastics and Composites, 0731684415618459.

Saba N., Safwan A., Sanyang M. I., Mohammad F., Pervaiz M., Jawaid M., Alothman O. Y., & Sain M. (2017). Thermal and dynamic mechanical properties of cellulose nanofibers reinforced epoxy composites. International Journal of Biological Macromolecules, 102, 822-828. https://doi.org/10.1016/j.ijbiomac.2017.04.074

Saba N., Tahir P. M., Abdan K., & Ibrahim N. A. (2016) Fabrication of epoxy nanocomposites from oil palm nano filler: mechanical and morphological properties. Bioresources, 11, 7721-7736. https://doi.org/10.15376/biores.11.3.7721-7736

Satyanarayana K. G., Arizaga G. G. C., & Wypych F. (2009). Biodegradable composites based on lignocellulosic fibers: an overview. Progress in Polymer Science, 34, 982-1021. https://doi.org/10.1016/j.progpolymsci.2008.12.002

Shalwan A., & Yousif B. F. (2014). Investigation on interfacial adhesion of date palm/ epoxy using fragmentation technique. Materials and Design, 53, 928-937. https://doi.org/10.1016/j.matdes.2013.07.083

Su S. K., & Wu C. S. (2011). Polyester biocomposites from recycled natural fibers: characterization and biodegradability. Journal of Applied Polymer Science, 119, 1211-1219. https://doi.org/10.1002/app.32808

Sun J. X., Sun X. F., Zhao H., & Sun R. C. (2004). Isolation and characterization of cellulose from sugarcane bagasse. Polymer Degradation and Stability, 84(2), 331-339. https://doi.org/10.1016/j.polymdegradstab.2004.02.008

Sun Y., & Cheng J. (2002). Hydrolysis of lignocellulosic materials for ethanol production: a review. Bioresource Technology, 83(1), 1-11. https://doi.org/10.1016/S0960-8524(01)00212-7

Valasek P., D' Amato R., Muller M., & Ruggiero A. (2018). Mechanical properties and abrasive wear of white/ brown coir epoxy composites. Composites Part B: Engineering, 146, 88-97. https://doi.org/10.1016/j.compositesb.2018.04.003

Yousif B, & El-Tayeb N. (2008). Adhesive wear performance of T-OPRP and UT-OPRP composites. Tribology Letters, 32(3), 199-208. https://doi.org/10.1007/s11249-008-9381-7

Yousif B., Lau S. T., & McWilliam S. (2010). Polyester composite based on betelnut fiber for tribological applications. Tribological International, 43(1), 503-511. https://doi.org/10.1016/j.triboint.2009.08.006