Optimization on the Dry Sliding Wear Behaviour of Mercerized Coconut Inflorescence Fibril Fortified Unsaturated Polyester Composites

S Karthik1*, VP Arunachalam2, M Prem Sundhar 3, R Raghul 4, C Sukumar5
1 Asst Professor, Dept. of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, Tamil Nadu - 641008
2 Professor, Dept. of Mechanical Engineering, SNS College of Technology, Coimbatore, Tamil Nadu – 641035
3, 4, 5 UG Students, Dept. of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, Tamil Nadu - 641008
*Corresponding author E-Mail ID: karthik.prince20@gmail.com

Abstract The contemporary work emphasizes the importance of using coconut inflorescence fibril as a viable alternate to manmade fibril in polymer matrix composites for application components undergoing wear. The extracted inflorescence fibril from coconut tree is exposed to mercerization treatment with 5% wt/vol of aqueous solution. The composite samples were fabricated by varying the fibril content (10, 20, 30 and 40 wt %) of fibril/polyester matrix. The composite specimens were subjected to wear test employing a pin on disc tribometric setup under dry sliding state. Design of experiments inspired taguchi analysis is employed for wear analysis. The experiments were performed for 16 trial runs for the load (5, 10, 15, 20 N), sliding distance of (250, 500, 750 and 100 m) and sliding velocity of (6.3, 12.5, 19 and 25.3 m/s) as the operating parameters. The parametric analysis revealed fibril content is the more inducing parameter which have a notable impact on the wear behaviour of the composites ensued by sliding distance. Artificial Neural Networks (ANN) is adopted to forecast the dry sliding wear behaviour of the composites over a broad scope of test conditions. The extensive experimentation leads to the conclusion that fortification of inflorescence fibril to the polyester resin resulted in improvement of wear resistance up to optimum fibril content and then decrease in wear resistance was observed when the fibril content increases. Finally SEM analysis was performed on the wornout surfaces to study the governing mechanism such as ploughing, wedge formation and fibril pullouts.

Keywords: Coconut inflorescence fibril, Unsaturated Polyester resin, Taguchi analysis, Artificial Neural Network, SEM.

1. Introduction
Plant based fibrils classified as lignocellulose materials offer more advantages such as biodegradability; non-toxic has received more interest towards application components ranging from automobile to aerospace with specific mechanical characteristics. Natural fillers which are
used for reinforcement with polymer matrix exhibits outstanding mechanical and thermal characteristics [1]. Increasing environmental legislations forced researchers to develop ecofriendly, biodegradable and sustainable composite materials. Several researchers worked on different natural organic fibrils namely Sisal [2], Sugarcane Bagasse [3], Alfa [4], Jute [5], Bamboo [6], Hemp [7], and Flax [8], as fibrils for reinforcement with polymer matrix. However natural fibrils offer much drawback compared to synthetic fibrils such as fibril/matrix incompatibility while bonding, deterioration of mechanical properties, and hydrophilic tendency. To overcome the above drawbacks surface treatments such as alkalization [9], acetylation [10], and use of silane coupling materials [11] are done on the surface of organic fibrils which in turn offers improved fibril-matrix compatibility and high resistance to moisture. Natural fibrils can be extracted coconut tree namely spathe [12], husk, coir [13]. In this connection one natural fibril from coconut tree named inflorescence [14] is extracted and reinforced with unsaturated polyester resin to study the mechanical properties of the composites for different fibril volume fraction over increasing fibril ends [15,16]. The inflorescence fibril reinforced polymer composites exhibited superior mechanical characteristics compared to other natural fibrils reinforced polymer composites of coconut tree. Therefore the present work emphasizes on making inflorescence fibril as a viable replacement for artificial fibrils to be fortified with polymer matrix for application against wear [17] and also study the wear behaviour of coconut inflorescence fibril fortified unsaturated polyester composites. Design of experiments inspired Taguchi analysis was followed for the parametric analysis on the wear characteristics and to forecast the dry sliding wear behaviour of coconut inflorescence fibril fortified unsaturated polyester composites. The influence of load on the wear behaviour was also studied under steady state condition.

2. Materials and methods
2.1 Fibre Extraction
The inflorescence fibre used in this present investigation is extracted from coconut tree. Fig.1.a shows the inflorescence that is yellow colour present in coconut tree. The procedure for extracting fibrils from coconut inflorescence is by which the inflorescence is subjected to retting for a period of ten days followed by removing the primary fleshy layers by malleting to extract the fibre from inflorescence. Fig.1.b shows the extracted coconut inflorescence fibre. Then the extracted fibres are dehydrated in sunlight to drain the moisture present in the fibres. The length of the inflorescence fibril varies from 250 mm to 300 mm and diameter of the fibril is about 0.51 mm.
2.2 Alkali treatment
The extracted inflorescence fibril is subjected to alkalization with 5% wt/vol of NaOH solution. The fibrils were alkalized for a period of 1hr. Then the fibres are cleaned completely with distilled water to unload the alkali material present in the fibres followed by fibril drying under room temperature to wipe the moisture present. Alkalization of inflorescence fibril results in removal of hydroxyl group by which the micro voids present in the fibre cells are removed. As a result the stress transfer capacity between the fibre cells gets improved. Also the fibre surfaces become rougher due to removal of primary and secondary layers thereby interfacial bonding with the matrix gets improved.

2.3 Matrix material
The matrix material chosen unsaturated polyester resin owing to its commercially availability and it is mixed with Methyl Ethyl Ketone (Accelerator) and Cobalt Naphthalene (Catalyst) to cure the resin by maintaining a liquor ratio of 10:1:1 for the fabrication of the composite samples.

2.4 Composite fabrication
The alkalized inflorescence fibril and the matrix material with 10:1:1 weight ratio are mixed and specimens are fabricated using cylindrical test tubes by varying the fibril content of inflorescence fibre/epoxy matrix as 10, 20, 30 and 40 wt % respectively. After curing for 24 hours the specimens are taken from the test tubes by breaking it. Fig.2 shows the specimens fabricated and finally the specimens are sized as per ASTM G-99 standard of length 35 mm and diameter of 10mm.
Fig.2 Fabricated Composite Sample using test tubes

2.5 Dry sliding wear
A pin on disc based dry sliding wear setup was employed to investigate the wear nature of the above prepared inflorescence fibril fortified unsaturated polyester composites. EN-32 hardened steel disc with 62 HRC and surface roughness of 6 μm Ra, 60 mm track radius of 8 mm thickness is used. As the disc rotates the specimen is fixed. A series of tests are conducted by increasing the load to 5, 10, 15, and 20 N with four sliding velocities of 6.3, 12.5, 19 and 25.3 m.s⁻¹. The change in weight of the composite is noted and then wear rate is calculated using the equation

\[ W_s = \frac{\Delta m}{\rho \times t \times V_s \times N} \]

where \( \Delta m \) is the change in weight composite (g), \( \rho \) is the composite density (g/mm³), \( t \) is the time (s), \( V_s \) is the sliding velocity (m.s⁻¹), and \( N \) is the load (N). Fig.3.a shows the wear test setup with control panel and fig.3.b shows the rotating disc with abrasive paper used in this study.
2.6 Taguchi Experimental design

The experimental design inspired from Taguchi model which is widely used by researchers is employed for parametric analysis of the control factors. In this current work of dry sliding wear test of inflorescence fibril fortified unsaturated polyester composites four factors are selected namely sliding velocity, sliding distance, load and fibre weight fraction at four level which is on based on Taguchi’s $L_{16}$ orthogonal array as shown in Table 1. In accustomed design $4^4 = 256$ tests has to be done whereas by the use of taguchi design it is enough to perform 16 runs thereby reducing time and cost of experimentation. The signal to noise ratio parameters are classified into three classes, smaller the better, large the better and nominal is the best. In present article “smaller the better” was chosen because wear is expressed by smaller value and the expression for the S/N ratio to be smaller is expressed by

$$S/N = -10\log\frac{1}{n}\left(\sum Y^2\right)$$

Where $n$ is the observation count and $Y$ is the noted data.
Table.1. Level of the control factors

| Control Factors | Levels  | \( A \) | \( B \) | \( C \) | \( D \) | Units |
|-----------------|---------|--------|--------|--------|--------|-------|
| Fibre Content   | I       | 10     | 20     | 30     | 40     | wt%   |
| Load            | II      | 5      | 10     | 15     | 20     | N     |
| Sliding Velocity| III     | 6.3    | 12.5   | 19     | 25.3   | m/s   |
| Sliding Distance| IV      | 250    | 500    | 750    | 1000   | m     |

3. Results and Discussions
The wear rate of mercerized inflorescence fibril fortified unsaturated polyester composites was found for all the 16 trials along including the respective S/N ratio’s as presented in Table.2. Minitab 15 was employed for design of experiments. Fig.4. represents the primary influential plots of S/N ratio of individual control factors. The control factors of group \( A_3B_3C_3D_2 \) leads to the lower wear rate for alkali treated inflorescence fibril reinforced unsaturated polyester composite which is shown in figure 4.

Table.2. Experiment Design using L\(_{16}\) orthogonal array

| Expt.No | Fibre Content (wt%) | Load (N) | Sliding Velocity (m/s) | Sliding Distance (m) | Wear (m\(^3\)/N-m) | S/N ratio (dB) |
|---------|---------------------|----------|------------------------|----------------------|---------------------|----------------|
| 1       | 10                  | 5        | 6.3                    | 250                  | 10.831              | -20.6256       |
| 2       | 10                  | 10       | 12.5                   | 500                  | 8.784               | -18.672        |
| 3       | 10                  | 15       | 19                     | 750                  | 9.395               | -19.3048       |
| 4       | 10                  | 20       | 25.3                   | 1000                 | 11.293              | -21.4789       |
| 5       | 20                  | 5        | 12.5                   | 750                  | 10.985              | -21.2387       |
| 6       | 20                  | 10       | 6.3                    | 1000                 | 12.319              | -21.6584       |
| 7       | 20                  | 15       | 25.3                   | 250                  | 11.034              | -20.6528       |
| 8       | 20                  | 20       | 19                     | 500                  | 8.891               | -18.9112       |
| 9       | 30                  | 5        | 19                     | 1000                 | 7.395               | -17.1769       |
| 10      | 30                  | 10       | 25.3                   | 750                  | 7.983               | -17.9755       |
| 11      | 30                  | 15       | 6.3                    | 500                  | 4.859               | -14.1537       |
| 12      | 30                  | 20       | 12.5                   | 250                  | 6.892               | -16.6138       |
| 13      | 40                  | 5        | 25.3                   | 500                  | 10.958              | -20.6415       |
| 14      | 40                  | 10       | 19                     | 1000                 | 11.123              | -21.3472       |
| 15      | 40                  | 15       | 12.5                   | 1000                 | 10.932              | -20.7062       |
| 16      | 40                  | 20       | 6.3                    | 750                  | 12.472              | -21.7169       |
3.1 Results of confirmation experiment

To validate the experimental data directed by Taguchi confirmatory test is done by setting new parameters. In the previous analysis the better combination of parameters are identified. The confirmation experiments are done by new set of parameters setting $A_3B_3C_3D_2$ to predict the wear characteristics of mercerized inflorescence fibril fortified unsaturated polyester composites. The predicted S/N ratio value is 17.747 dB with an error of 1.0654. Table.3. shows the predicted and actual S/N ratio and error %.

Table.3. Results of Confirmation experiments

| Specific Wear rate Level | Optimal condition | Predicted S/N ratio (dB) | Experiment S/N ratio (dB) | Error (%) |
|--------------------------|-------------------|--------------------------|--------------------------|-----------|
| $A_3B_3C_3^D_2$          | 17.747            | 18.913                   |                          | 1.065     |

3.2 ANOVA for specific wear rate of CIF-Polyester Composites

The statistical significance of control factors like fibril content, load, sliding distance and sliding velocity on the wear characteristics of the samples is determined by Analysis of Variance (ANOVA) on the Taguchi experimental results. Minitab 15 is used for experimental analysis of
ANOVA. The high significant parameters (very small p-values) are indicated on the last column of the table. Table 4. shows the results of ANOVA for wear behaviour of mercerized inflorescence fibril fortified unsaturated polyester composites. From the table it was found that fibril content (p = 0.001) and sliding distance (p = 0.010) have much impact on wear rate and load (p = 0.067) and sliding velocity (p = 0.047) have very less impact on wear behavior. Table 4. shows the ANOVA for specific wear behaviour of CIF-unsaturated polyester composites and Table 5. show the response of influencing parameters on the minimum sliding wear of alkali treated inflorescence fibril reinforced unsaturated polyester composites.

Table 4. ANOVA for specific wear rate of mercerized inflorescence fibril fortified unsaturated polyester composites

| Source            | DF  | Seq SS   | Adj SS  | Adj MS  | F      | P      |
|-------------------|-----|----------|---------|---------|--------|--------|
| Fibre Content     | 3   | 50.6382  | 50.6382 | 16.8794 | 138.61 | 0.001  |
| Load              | 3   | 2.7129   | 2.7129  | 0.9043  | 7.43   | 0.067  |
| Sliding Velocity  | 3   | 3.5335   | 3.5335  | 1.1778  | 9.67   | 0.047  |
| Sliding Distance  | 3   | 10.7780  | 10.7780 | 3.5927  | 29.50  | 0.010  |
| Residual Error    | 3   | 0.3653   | 0.3653  | 0.1218  |        |        |
| Total             | 15  | 68.0279  |         |         |        |        |

Table 5. Response table for minimum sliding wear of alkali treated inflorescence fibril reinforced unsaturated polyester composites.

| Level | Fibre Content (wt%) | Load (N) | Sliding Velocity (m/s) | Sliding Distance (m) |
|-------|---------------------|----------|------------------------|----------------------|
| 1     | -20.02              | -19.92   | -19.54                 | -19.81               |
| 2     | -20.62              | -19.91   | -19.31                 | -18.09               |
| 3     | -16.48              | -18.70   | -19.19                 | -20.06               |
| 4     | -21.10              | -19.68   | -20.19                 | -20.26               |
| Delta | 4.62                | 1.00     | 1.22                   | 2.16                 |
| Rank  | 1                    | 4        | 3                      | 2                    |

3.3 Load vs Wear

Fig. 5. shows the influence of load on wear behaviour of alkali treated inflorescence fibril fortified unsaturated polyester composites for varying fibril content (wt %). The load is varied from 5 N to 20 N to study the wear behaviour over varying volume fraction of inflorescence fibril reinforced unsaturated polyester composites with constant sliding distance of (250 m), sliding velocity of (12.5 m/s). The composites with 10 wt% of fibril content showed higher wear rate which concludes that inadequate fibril to support the matrix material. Ploughing and wedge formation may be the governing mechanism for maximum wear behaviour in the composite samples. Addition of fibrils to the matrix resulted in improved wear behaviour of the
inflorescence fibril fortified unsaturated polyester composites. The brittle nature of the matrix is transformed to ductile nature by fortification of fibrils which makes the polyester to exhibit shearing resistance thereby matrix disintegration is reduced. The inflorescence fibril fortified unsaturated polyester composites with 30 wt% showed minimum wear rate. This is owing to enhanced adhesion between the interface of the fibril and the matrix. The sample with 40 wt% of fibril content showed increased wear rate compared to 30 wt% composites which is due to improper fibril wetting which results in poor interfacial adhesion between the fibril/matrix [16].

3.4 SEM analysis
To probe the worn surfaces, scanning electron microscope was adopted. Fig.6.a shows the pure polyester matrix subjected to sliding wear where higher wear rate was observed due to the absence of inflorescence fibril to support the matrix. Fig.6.b shows the wedge formation in the scrape surface of the composites occurred due to the axial splitting of composite surface. Fig6.c shows the fibril pullout in the composite as a result of poor adhesion between the interface of inflorescence fibril and matrix.
Fig. 6.a Worn surface of pure epoxy

Fig. 6.b. Wedge formation on worn composites

Fig. 6.c Fibril pullout in worn surface of the composites with fibril content of 40 wt%

4. Conclusion

Based on the dry sliding wear characterization study of coconut inflorescence fibril fortified unsaturated polyester composites the following conclusions are derived.

a) It is possible to reinforce coconut inflorescence fibril with polyester matrix and composites can be manufactured by hand layup technique.

b) The minimum wear behaviour of inflorescence fibril reinforced unsaturated polyester composites is achieved by parametric optimization of taguchi analysis based on design of experiments. The optimal combination of parameters that is 30 wt% of fibril content, load of 15 N, 19 m/s sliding velocity and 500 m sliding distance contribute to minimum wear rate of mercerized inflorescence fibril fortified unsaturated polyester composites.

c) ANOVA analysis helped in identifying the contributing parameters of tribological wear. Based on the analysis fibril content (p = 0.001), sliding distance (p = 0.010) and sliding velocity (p = 0.047) have greater impact on the wear behaviour. However load (p = 0.067) have least significance on the tribological wear behaviour of inflorescence fibril fortified unsaturated polyester composites.
d) The tribological wear behaviour of the inflorescence fibril fortified unsaturated polyester composite is influenced by fibril content, sliding distance and sliding velocity. The fibril content of 30 wt% contributes to minimum wear rate of the composites which is due to enhanced adhesion between fibril/matrix owing to alkalization of inflorescence fibril. When the fibril content is raised to 40 wt% increase in wear was observed which concludes that partial matrix filling in the composites and also improper fibril wetting which resulted in poor adhesion between the interface of fibril and matrix.

e) SEM analysis was done to study the worn surface morphology of the inflorescence fibril fortified unsaturated polyester composites. Wedge formation was found as a result of axial splitting of composite surface. And also fibril pullouts were observed for composites with 40 wt% which is due to poor adhesion between the interface of inflorescence fibril and matrix.
Reference

[1]. Michael A. Fuqua, Shanshan Huo & Chad A. Ulven, “Natural Fiber Reinforced Composites, Polymer Reviews”, 52:3, 259-320, 2018.

[2]. Ranganathan, S., Gopal, S., Magudeeswaran, T., and Rangasamy, R., “Exploration of Dry Sliding Wear Behaviour of Sisal Fiber Reinforced Cashew Nut Shell Liquid and Epoxy Polymer Matrix Composite as an Alternative Friction Material in Automobiles,” SAE Technical Paper 2019-28-0173, 2019.

[3]. A. Balaji, B. Karthikeyan, J. Swaminathan & C Sundar Raj, “Effect of Filler Content of Chemically Treated Short Bagasse Fiber-Reinforced Cardanol Polymer Composites”, Journal of Natural Fibers, 16:4, 613-627, 2019.

[4]. Dalila Hammiche, Amar Boukerrou, Hocine Djidjelli, Yves Grohens, Abdelkader Bendahou & Bastien Seantier, “Characterization of cellulose nanowhiskers extracted from alfa fiber and the effect of their dispersion methods on nano composite properties,” Journal of Adhesion Science and Technology, 30:17, 1899-1912, 2016.

[5]. Tran Huu Nam, Shinji Ogihara, Hayato Nakatani, Satoshi Kobayashi & Jung Il Song, “Mechanical and thermal properties and water absorption of jute fiber reinforced poly(butylene succinate) biodegradable composites,” Advanced Composite Materials, 21:3, 241-258, 2012.

[6]. Pradeep K. Kushwaha & Rakesh Kumar, “Studies on the Water Absorption of Bamboo-Epoxy Composites: The Effect of Silane Treatment,” Polymer-Plastics Technology and Engineering, 49:9, 867-873, 2010.

[7]. K. Takemura & Y. Minekage, “Effect of molding condition on tensile properties of hemp fiber reinforced composite,” Advanced Composite Materials, 16:4, 385-394, 2017.

[8]. Umit Huner “Effect of Chemical Surface Treatment on Flax-Reinforced Epoxy Composite,” Journal of Natural Fibers, 15:6, 808-821, 2018.

[9]. Mohghan Sayanjali Jasbi, Hossein Hasani, Ali Zadhoush & Somayeh Safi, “Effect of alkali treatment on mechanical properties of the green composites reinforced with milkweed fibers,” The Journal of The Textile Institute, 109:1, 24-31, 2018.

[10]. R. M. Rowell “Acetylation of natural fibers to improve performance,” Molecular Crystals and Liquid Crystals, 418:1, 153-164, 2004.

[11]. D.T. Tran, D.M. Nguyen, C.N. Ha Thuc & T.T. Dang, “Effect of coupling agents on the properties of bamboo fiber-reinforced unsaturated polyester resin composites,” Composite Interfaces, 20:5, 343-353, 2013.

[12]. S. Vijayakumar, T. Nilavaranas, R. Usharani, L. Karunamoorthy, “Mechanical and Microstructure Characterization of Coconut Spathé Fibers and Kenaf Bast Fibers Reinforced Epoxy Polymer Matrix Composites,” Procedia Materials Science, 5, 2330-2337, 2014.

[13]. Vinod Kadam, Sajal K. Chattopadhyay, Ashok Bharimalla & Bindu Venugopal, “Mechanical Characterization of Brown and Green Coconut Husk,” Journal of Natural Fibers, 11:4, 322-332, 2014.
[14]. Soundararajan Karthik, V.P. Arunachalam, “Investigation on the Tensile and Flexural Behavior of Coconut Inflorescence Fiber Reinforced Unsaturated Polyester Resin Composites,” Mater. Res. Express 7: 015345, 2020.

[16]. Priyadarshi Tapas Ranjan Swain, Sandhyarani Biswas, “Abrasive Wear Behaviour of Surface Modified Jute Fiber Reinforced Epoxy Composites”, Materials Research, 20(3): 661-674, 2017.

[17]. Soundararajan, R., S. Karthik, P. Ashoka Varthanan, A. Achith Devanand, M. Venkat Balaji, P. Sharath Nandha, and S. Sivaraman. "Automotive Brake Pad By Using, Functionally Graded Hybrid Composites And Their Behaviour." 2018.

[18]. Sendil, P. M., Karthik Soundarrajan, R. Elango, and M. Akilesh. "Wear Behavior of Functionally Graded Automotive Brake Pad on Hybrid Composite." International Research Journal of Automotive Technology 1, no. 1 29-34, 2018.

[19]. S., Ranganathan, S., Kumar K, S., and Bojan, S.G., “Tribological Behaviour of Carbon Fibre Reinforced Bio Degradable Material as an Alternative Frictional Brake Pad in Automobiles,” SAE Technical Paper 2020-28-0513, 2020.