Original Article

Synergy of rice-husk filler on physico-mechanical and tribological properties of hybrid Bauhinia-vahlii/sisal fiber reinforced epoxy composites

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\textbf{A B S T R A C T}

In this research, the effect of rice husk fillers were investigated on physical, mechanical and sliding wear properties of on hybrid Bauhinia-vahlii-weight (BVW) and Bauhinia-vahlii-weight/sisal (BVWS) fibers reinforced hybrid composites. The rice husk content was hybridized by loading variation of 0, 2, 4 and 6 wt\% with 6 wt\% BVW and combined 6 wt\% BVW-Sisal fiber reinforced epoxy composites. The physical and mechanical properties like void fraction, water absorption, tensile strength, flexural strength, hardness, and impact energy in this research were found to be greatly influenced by rice-husk content. Moreover, the impact energy was found to be slightly decreased, owing to possible decrease in the deformability of the resin constituent. Rice husk filled BVWS composites exhibited improved tensile strength (34.42\%), flexural strength (33\%), and hardness (7.1\%) as compared to BVW composites at all filler loading. The influence of selected control factors: sliding velocity, rice husk contents, normal load and sliding distance on specific wear rate of composites was investigated by Taguchi experimental design. Analysis of variance (ANOVA) was carried out to analyze the influence of each selected control factor on specific wear rate. The evaluated results demonstrate that rice husk content and sliding velocity were found to emerge the most noteworthy control factors among the others. Furthermore, the wear scars were analyzed by scanning electron microscopy to establish the governing wear mechanisms. This research established that the addition of rice husk fillers with optimum variation reflects the improvement in mechanical and wear performance of natural fiber based epoxy composites.

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1. Introduction

In polymeric material, plant fibers are extensively used as reinforcing materials for several applications like electronic device, pedestrian bridges, toys, roofing, door panels, multipurpose table, door frame etc. The polymeric products derived from plant fiber have several benefits over other materials (light weight, cost effective, proficient mechanical properties and biologically efficient). In the past decades, broad researches are reported on manufacturing and characterization of polymer composites reinforced with most common plant fibers such as sisal, coir, jute, kenaf and hemp [1-4]. Beyond its several benefits of plant fiber based composites, there are also some drawbacks like; high water absorption due to presence of hydroxyl group in cellulose fibers and lower mechanical potency as compared to synthetic fibers (carbon, Kevlar and glass). These inherent limitations of plant fiber reinforced composites can be successfully diminished by hybridization with synthetic fibers/fillers or plant fiber/filler and also surface modification of such fibers with alkali, sodium hydroxide, and graft copolymerization [5,6]. Now days, the evolution of polymer composites reinforced with two or more different types or shapes fibers was suggested to counterbalance their short-comings, and thereby ensuring in an incontrovertible hybrid impression [7-11].

The synergy of filler in fiber reinforced composites has been made popular research activity in the composite manufacturing industries. Accordingly, mechanical and tribological properties of the resulting materials are considerably changed by the addition of fillers [12,13]. The prosperous results were evolved out mainly in mechanical performance by the introduction of agro-waste filler as a reinforcing agent in polymer composites [14]. Low product cost and the ability to produce lightweight structures were the remaining major achievements. Agro-waste like rice husk, coir, pine bark, wheat straw and plant gum-resin [15-18] were used as natural fillers and noteworthy accomplishments extensively encouraged the follow-up researches to formulate several hybrid polymer composites of enhanced mechanical properties at low cost. Kumar et al. [19] investigated the physical, mechanical and tribological properties of grevia optiva fiber/bio-particles hybrid polymer composites. They revealed that the grevia optiva fiber reinforced composites (GOFC) filled with the rice husk/wheat straw exhibited higher hardness, impact energy, and wear resistance properties as compared to unfilled GOFC. Zafar and Siddiqui [20] focused on the natural fiber polymer composites reinforced with mustard cake and wheat straw. They observed that the higher tensile strength was attained with 5 wt% of rice husk/mustard cake whereas superior flexural strength was achieved at 15 wt% of rice husk/mustard cake reinforced in polymer composites. In other investigation Kumar et al. [21] carried out the research on the effect of pine needles and mustard cake on the mechanical and wear properties of sisal fiber based polymer composites. They reported that the agro-waste fillers (mustard cake and pine needle) had the potential to boost the mechanical and sliding wear properties of sisal fiber based polymer composites. Among several agricultural wastes, rice husk could be very promising material as a natural filler in polymer composites. China, India, Indonesia are the big rice producing country, and there is a significant issue of disposal of rice husk. This issue can be minimized by using rice husk as filler in polymer composites.

In this work, a recently new class of bast fiber i.e. Bauhinia vahlii weight (BVW) belonging to Caesalpiniaceae family was used as a cellulosic fiber. The BVW fibers were extracted from the outer cell of Bauhinia vahlii climber plant and Agava sisalana (Sisal) were used as reinforcing fiber in epoxy composites. The influence of various weight percent loading of rice husk filler (0 wt%, 2 wt%, 4 wt% and 6 wt%) on physical (void fraction, water absorption) and mechanical properties (tensile, flexural, impact and hardness) of BVW and BVWS (Bauhinia vahlii-Sisal) hybrid epoxy composites were investigated. Both BVW and sisal fibers were reinforced at 6 wt% each in the preparation of mono/dual-fiber composites in this work. Here, the primary motive is to find out how the rice husk filled BVW and BVWS epoxy composites behave under physical and mechanical attributes. Secondly the set of experiments developed by Taguchi’s parameter was applied in designing to measure the damage due to sliding wear and finally to decide the optimal parameter settings for minimizing the wear rate by using the Minitab 18 statistical software. Furthermore, the analysis of variance (ANOVA) method was applied to analyze the effect of control factors on specific sliding wear rate of composites.

2. Experimental details

2.1. Materials

The epoxy (LY556) resin and its respective hardener were procured from the Mangalam Polymer Limited, India with a density of 1.25 g/m³. Rice husk in particulate form was collected from the farmers of Punjab, India. The chemical composition of rice husk contains cellulose (16-22%), lignin (20-27.5%), and ash (15-30%). The plant fibers, BVW (density: 1.45 g/cm³) and Sisal (density: 1.33 g/cm³) in the bi-axial mat form were purchased from UBB, Uttarakhhand, India. The extraction process for rice husk and sisal fiber was discussed in detail by various researchers [22-25], and the extraction process for BVW bast fiber discussed in the forthcoming section. Fresh stems were cut from Bauhinia vahlii climber plant and barks were manually separated by hand, which was very long and itself used as rope. The bark fiber may be dried in sunlight or shade. Then, their bundles were stored in a dry place. The pictorial view of Bauhinia Vahlii fiber plant, extracted fiber and bi-directional mat form is presented in Fig. 1(a)-(c) and the image of rice husk is shown in Fig. 1(d). The SEM images of BVW fiber at different magnifications (952× and 2.48k×) are shown in Fig. 2(a) and (b). The structure of the BVW fiber was obtained as ribbon like-network structure. The SEM images reflect the surface roughness which leads to impart a higher strength and good bonding features with plastic resin [26].
2.2. **Fabrication of composite specimens**

Rice husk at 2.4, and 6 wt% loading was thoroughly mixed with epoxy LY556 matrix by using hand stirrer and gradually poured into the wooden mold of dimension 300 mm × 300 mm × 10 mm, previously coated with silicon spray and permitted to cure and the escaping of the air bubbles was achieved by the hand roller. The hybrid samples were made by the embedded of plant fiber layer by layer. Three samples were cut from each composites for assessment of average value with error (±) of all evaluated properties in this research. The fabricated samples are designated according to their composition in Table 1 and the fabricated plates of BVW-R and BVWS-R composites are shown in Fig. 3.

2.3. **Measurements**

2.3.1. **Physical measurement**

Samples of appropriate dimension were cut using a hacksaw for physico-mechanical characterization. Resin, and reinforcement (fiber and filler) were used under this research. The theoretical density was assessed by Agarwal and Broutman method of the samples [27]. The buoyancy principle was used for evaluating the experimental density of fabricated composites. The volume of void fraction can be calculated by giving Eq. (1). The swelling behavior of the fabricated composites was estimated as per the ASTM: D570-99 standard. Three test samples were prepared and each of dimension (25 mm × 25 mm × 5 mm) in rectangular form. The sample weight was taken before immersing in distilled water having the potential of hydrogen values of 7. After immersion, the sample was taken out of the water and wiped with tissue paper. These samples weigh with precision of 10⁻² mg weighing machine. The percentage of moisture absorption

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**Table 1 – Designation and composition of the composites.**

<table>
<thead>
<tr>
<th>Designation</th>
<th>Weight percentage ratio (Epoxy/BVW/Sisal/Rice husk)</th>
<th>Bi-direction mat number (BVW/Sisal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BVW-R0</td>
<td>94/6/0/0</td>
<td>6/0</td>
</tr>
<tr>
<td>BVW-R2</td>
<td>92/6/0/2</td>
<td>6/0</td>
</tr>
<tr>
<td>BVW-R4</td>
<td>90/6/0/4</td>
<td>6/0</td>
</tr>
<tr>
<td>BVW-R6</td>
<td>88/6/0/6</td>
<td>6/0</td>
</tr>
<tr>
<td>BVWS-R0</td>
<td>94/3/3/0</td>
<td>3/3</td>
</tr>
<tr>
<td>BVWS-R2</td>
<td>92/3/3/2</td>
<td>3/3</td>
</tr>
<tr>
<td>BVWS-R4</td>
<td>90/3/3/4</td>
<td>3/3</td>
</tr>
<tr>
<td>BVWS-R6</td>
<td>88/3/3/6</td>
<td>3/3</td>
</tr>
</tbody>
</table>
was calculated by the difference of mass (before and after immersion) divide by the initial mass of the samples. The void contents and water absorption were calculated by using Eqs. (1) and (2):

\[
\text{Void contents (\%)} = \left\{ \frac{1}{w_{BVW} + w_s + w_r + w_e} - \frac{m}{\Delta h} \right\} \\
\]

(1)

where \(w\) represents the weight fraction and suffix BVW, s, r, and e indicate the Bauhinia vahlii, sisal, rice husk, and epoxy. \(m\) represent mass of specimen (g) and \(\Delta h\) is change in height of water level.

Water absorption (\%) = \(\frac{W_f}{W_i} - 1\) \times 100

(2)

where \(W_i\) and \(W_f\) are the sample weight before and after dipping in water.

2.3.2. Mechanical measurement
Hardness measurement was carried out by Vicker’s hardness tester under ASTM: E92. The tensile test was examined on Instron 1195 (Neelam Industrial Products, India). The specimen with dimension (250 mm \(\times\) 25 mm \(\times\) 3 mm) under ASTM: D3039 standard was used for developing tensile test specimens. The three point bending tests under ASTM: D790-07 standard with dimension (125 mm \(\times\) 12.7 mm \(\times\) 3 mm) was used to evaluate the flexural strength of fabricated composites. An indenter (diamond, apical angle: 136°) was indented over the sample under applied load of 1 kg for dwell time of 15 s. In every case, three samples were tested to get the average value. The ASTM: E23 was used to find out the impact energy of fabricated sample. Dimension of 55 mm \(\times\) 10 mm having 2 mm deep notch at an angle of 45° was tested for evaluation of impact energy. The test specimens for the mechanical and wear test is depicted in Fig. 4(a)–(c).

2.3.3. Wear measurement
The sliding wear test was examined on the pin-on-disk test rig as shown in Fig. 5. The standard of sliding wear test conformed to ASTM G99 test standard. The specimen of width 8 mm and depth 35 mm was kept stationary with the assistance of sample holders plus screw and was kept normal to the rotating disk as per the arranged speed, while the normal load was acted by a lever mechanism. The wear test was performed at varying applied load of 10, 15, 20, and 25 N and at different sliding velocity of 2.5, 3.5, 4.5, and 5.5 m/s. The electronic balance machine with an accuracy of \(\pm 10^{-3}\) mg is used to find out the
mass loss due to wear of the composite surface. The specific sliding wear rate (mm$^3$/Nm) of the composites was estimated by Eq. (3):

$$W_s = \frac{\Delta M}{\rho \cdot l \cdot n} \quad (3)$$

The specific wear rate is denoted by $W_s$ (mm$^3$/Nm), the mass loss due to wear during a test is designated by $\Delta M$ (g), and the density is symbolized by $\rho$. $l$ is symbol for sliding distance (m), and $n$ is the symbol for load applied to the sample in (N).

2.4. Design analysis by Taguchi method

The influence of control factors on output performance was analyzed and modeled by generating design of experiment (DOE) on MINITAB 18. It is a popular software for generating DOE. In this design work, four factors and for each factor four levels were considered as listed in Table 2 to establish Taguchi orthogonal array design. However, in actual conventional method for full factorial design, a 256 ($4^4$) runs are required to study four control factors for each of the 4 levels, and hence the Taguchi analysis was reduced to the total runs of L16 orthogonal array. After accomplishing the experiments as per as orthogonal array, the sliding wear result in the present study was converted into S/N (signal to noise) ratio data where ‘signal’ means appropriate mean value and ‘noise’ means inappropriate standard deviation value. The evaluated S/N ratio was applied to evaluate the affecting characteristics and to identify the suitable parameters through ANOVA attributes. The ‘Lower-is-better’ characteristics are used to determine the S/N ratio for minimizing the sliding wear rate as given in Eq. (4).

$$\frac{S}{N} = -10 \times \log \frac{1}{n} \left( \sum y^2 \right) \quad (4)$$

where S/N is the ratio of signal to noise; the symbol $n$ represents the count of observation and $y$ is noticed data.

3. Results and discussion

3.1. Density, void fraction, and water absorption

The evaluated void fraction of hybrid composites is enlisted in Table 3. The void fraction present in the composites was determined by the difference between theoretical and experimental density. At the time of functioning of composites some mechanical properties are significantly influenced by the presence of voids. The voids are the locations where stress is concentrated which accelerates the failure process leading to early and catastrophic failure of the composite [28]. It is difficult to prevent the creation of voids in the composite synthesized by hand layup method but maximum possible measures were adopted to restrict the creation of these voids during the synthesis of the composites. From Table 3, it is clearly observed that the void fraction of the composites is significantly influenced by the filler loading, which may be due to the involvement of natural fillers consisting lumens within cellular structure which act as voids [29]. The chemical composition of filler can be anticipated to be the main cause for the moisture absorption because it contains a large proportion of cellulose, lignin and hemicellulose. The moisture uptake by BVWS-R composites was of higher magnitude in comparison to BVW-R composites. The density of material and voids content are the factor which are strictly influenced by the moisture absorption rate. It can also be evaluated that the filler loading also affect the absorption behavior of material, and the water absorption rate increases with the addition of the rice husk filler in polymer composites. This may be due to the enhancement of hydrophilic nature of fabricated material with increase of filler loading. The maximum weight gains of 0.15–0.47% (weight fraction) were reflected by the specimens at room temperature.

<table>
<thead>
<tr>
<th>Control factors</th>
<th>Level</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding velocity</td>
<td>I</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>5.5</td>
</tr>
<tr>
<td>Filler contents</td>
<td>I</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>4</td>
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<tr>
<td></td>
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<td>Normal load</td>
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<td>II</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>25</td>
</tr>
<tr>
<td>Sliding distance</td>
<td>I</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>3000</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>4000</td>
</tr>
</tbody>
</table>

Table 3 – Physical properties of the composites.

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Theoretical density (gm/cm$^3$)</th>
<th>Void fraction</th>
<th>Water absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BVW-R0</td>
<td>1.257</td>
<td>0.325 ± 0.005</td>
<td>0.152 ± 0.010</td>
</tr>
<tr>
<td>BVW-R2</td>
<td>1.265</td>
<td>0.337 ± 0.005</td>
<td>0.190 ± 0.008</td>
</tr>
<tr>
<td>BVW-R4</td>
<td>1.273</td>
<td>0.339 ± 0.005</td>
<td>0.324 ± 0.011</td>
</tr>
<tr>
<td>BVW-R6</td>
<td>1.282</td>
<td>0.340 ± 0.005</td>
<td>0.470 ± 0.009</td>
</tr>
<tr>
<td>BVWS-R0</td>
<td>1.256</td>
<td>0.373 ± 0.006</td>
<td>0.153 ± 0.010</td>
</tr>
<tr>
<td>BVWS-R2</td>
<td>1.246</td>
<td>0.385 ± 0.006</td>
<td>0.201 ± 0.008</td>
</tr>
<tr>
<td>BVWS-R4</td>
<td>1.272</td>
<td>0.396 ± 0.006</td>
<td>0.434 ± 0.011</td>
</tr>
<tr>
<td>BVWS-R6</td>
<td>1.280</td>
<td>0.413 ± 0.007</td>
<td>0.470 ± 0.009</td>
</tr>
</tbody>
</table>

3.2. Mechanical characterization

3.2.1. Impact energy and Hardness

The toughness property of reinforcement, the nature of inter-facial region and friction work required to extract the fiber/filler from the matrix are the primary factors on which the impact energy of the as-fabricated composites depends on. Among all the factors, the nature of interface region is remarkably significant and is directly linked to the toughness of materials. The amount of energy absorbed by the composites was evaluated by Charpy V-notch test and the result is presented in Fig. 6. It was observed that the impact energy of the fabricated materials was slightly declined, and this declination may be attributed to the addition of rice husk fillers which restricted the deform-ability behavior of the resin constituent in a similar explanation as reported by Bledzki et al. [30]. The toughness ability of the materials was found to be reduced which may be due to random inclination of the filler contents. The evaluated results of impact energy ranged from (1.2 ± 0.083 to 0.4 ± 0.087) Joule for BVW-R composites, to (1.86 ± 0.070 to 0.8 ± 0.071) Joule for BVWS-R composites with (0–6 wt%) of rice husk filler. It is manifested from Fig. 7 that the hardness of composites increases considerably as the rice husk was increased by weight percent loading. The hardness varied from 38.31 ± 0.52 to 45.2 ± 0.85 H<sub>v</sub> for BVW-R composites and 41 ± 0.61 to 47.31 ± 0.97 for BVWS-R with rice husk contents (0–6 wt%). For both BVW-R as well as BVWS-R composites, the maximum hardness was witnessed at 6 wt% of rice husk addition. Similar observation was found by Mishra and Padhee [31], where rice husk (10, 15, and 20 wt%) and fly ash (fixed 5 wt%) were used as reinforcing agents and the epoxy as matrix material. They revealed that the hybrid rice husk/fly ash epoxy composites at 10 wt% attained higher impact energy and hardness as compared to 15–20 wt% epoxy composites.

3.2.2. Tensile strength and flexural strength

It is evident from Fig. 8 that the tensile strength of the BVW-R and BVWS-R composites increases significantly as the weight percent of the rice-husk filler is increased. As compared to fiber reinforced epoxy composites, there is a ~34.77% and ~34.32% enhancement in tensile strength with 6 wt% loading of rice husk filler in to BVW-R and BVWS-R composite respectively. The increment in the tensile strength of BVW-R and BVWS-R composites can be attributed to strong adhesion between the interface of fiber/filler and matrix enabling it to bear a large tensile stress.

Many polymer composites, when used in structural industry, are susceptible to fail in bending, hence it becomes...
imperative to study of flexural characteristics of as-fabricated composite. The variations of flexural strength of both BVW-R and BVWS-R composites with 0–6 wt% filler content are displayed in Fig. 9. A continuous enhancement in flexural strength was observed in both BVW-R and BVWS-R composites with weight percent loading of rice-husk filler. There was a considerable 33% improvement in flexural properties of 6 wt% BVW-R as compared to BVWS-R composite (without filler). The BVWS-R composites exhibited 29.47%, 25.6%, and 25.06% enhancement in flexural strength as compared to BVW-R composites with different filler loading (2–6 wt%). Thus the present research indicates the prospect of enhancement in mechanical properties of natural fiber based epoxy composites by the addition of suitable percentage of rice husk contents.

3.3. Wear analysis

3.3.1. Taguchi experimental design analysis

The evaluated value of S/N ratio (BVW-R and BVWS-R composites) of specific wear rate is shown in Table 4 and depicted in Fig. 10. The influence of control factor on sliding specific wear rate were determined by using S/N ratio. The control factor which has the highest value of S/N ratio gives the optimum wear rate [11]. The overall mean value of S/N ratio of the sliding wear rate was found to be 144.08 db and 147.97 db for BVW-R and BVWS-R composite respectively. The response table of composites for S/N ratio is presented in Table 5 (panel 1) and panel 2. The delta value was find out by the subtraction of maximum and minimum value of S/N ratio and the ranking of control factor was done according to the delta value. The highest value of delta demonstrates greater influence on specific sliding wear rate. From Table 5 (panel 1) and panel 2, it was found that filler content had significant effect on wear rate followed by sliding velocity, normal load, and sliding distance. The plot of mean of S/N ratio with respect to considered control factor is shown in Figs. 11 and 12. From Figs. 11 and 12, the factor grouping of A1, B3, C2 and D2 (of sliding velocity: 2.5 m/s, filler loading: 4 wt%, normal load: 10 N, and sliding distance: 2000 m) gives minimum specific wear rates for BVW-R composites and the factor combination of A1, B3, C2, and D4 for BVWS-R epoxy composites. It was interpreted that sliding wear rate decreased with increases of rice husk filler content up to 4 wt% and beyond this, the wear rate increased. This may be due to filler particles act as barrier between rotating disk
and composite material to retain the wear loss. Conversely, the inferior wear properties were obtained as the normal load and sliding distance increased from 10 to 25 N and 1000 to 3000 m. For similar test conditions, the BVWS-R composites exhibited higher wear resistance than BVW-R epoxy composites for all fabricated filler loading. This may be correlated to the good interfacial adhesion between the combined (sisal/bauhinia Vahlii) fiber, rice husk filler and matrix. This research establishes that the wear resistance property of the natural fiber reinforced composites depend upon the filler contents and can be improvised by adopting a suitable filler contents.

3.3.2. Analysis of variance and effect of control factor

The effect of control factors (sliding velocity, filler content, normal load, and sliding distance) on specific sliding wear rate was analyzed by ANOVA and it was carried out on testing data using MINITAB18. Table 6 (panel 1) and panel 2 depicted the ANOVA result with the specific sliding wear rate of BVW-R and BVWS-R specimens. The percentage of contribution (P value) of the factors was shown in the last column of the table, and this

<table>
<thead>
<tr>
<th>Sliding velocity (m/s)</th>
<th>Rice husk content (wt%)</th>
<th>Normal load (N)</th>
<th>Sliding distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel 1: Specific wear rate of BVW-R composites</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>146.4</td>
<td>142.0</td>
<td>140.0</td>
</tr>
<tr>
<td>2</td>
<td>142.9</td>
<td>144.0</td>
<td>142.1</td>
</tr>
<tr>
<td>3</td>
<td>142.6</td>
<td>147.0</td>
<td>143.4</td>
</tr>
<tr>
<td>4</td>
<td>144.4</td>
<td>143.5</td>
<td>143.2</td>
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<tr>
<td>Delta</td>
<td>3.8</td>
<td>5.2</td>
<td>2.0</td>
</tr>
<tr>
<td>Rank</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Panel 2: Specific wear rate of BVWS-R composites</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>150.9</td>
<td>144.5</td>
<td>148.6</td>
</tr>
<tr>
<td>2</td>
<td>146.7</td>
<td>147.9</td>
<td>149.3</td>
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<td>Rank</td>
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<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>
value was used to test the significance of each control factor and interaction between these factors. Least F value gives the statistically highest significant influence on the specific wear rate of composites. From Table 6 (panel 1), it is interpreted that the filler content ($P = 0.008$) and sliding velocity ($P = 0.016$) has the foremost contribution to specific sliding wear rate of BVW-R composites and factor like normal load ($P = 0.084$) and sliding distance (0.670) has the least influence on specific
sliding wear rate. Similarly, for BVWS-R specimen (panel 2), the order of significance of ($P = 0.029$) for filler content and ($P = 0.118$) for sliding velocity respectively, have the foremost contribution to the specific sliding wear rate of the BVWS-R composites and the factor such as a normal load ($P = 0.393$) and sliding distance ($P = 0.512$) have least effect. Therefore, for this investigation, it can be clearly shown that the filler content has a noteworthy effect, whereas sliding distance has least influence as compared to other noteworthy factors as far as specific sliding wear rate is desired.

3.3.3. Worn surface morphology
SEM (ZEISS EVO-18) was used to examine the wear surface profile and the wear mechanism of fabricated composites as per to the Taguchi orthogonal array (Table 3). Wear rate was minimum at the location where weight fraction of filler was higher and the surface was planer. There was some severe deterioration of BVW-R and BVWS-R composite surface when applied load was higher and the sliding distance was increased. The wear and tribological characteristics can be easily found out by comparing the surface of fabricated composites at different parameter conditions. Fig. 13(a) and (b) displays the distribution of filler particulates in the BVW-R and BVWS-R specimens. At sliding velocity of 2.5 m/s, filler content of 2 wt%, at normal load of 15 N and sliding distance of 2000 m (Table 3, Experiment 2), the ploughed mark can be observed (Fig. 14(a) and (b)) along the rubbing surface of BVW-R and BVWS-R epoxy composites, and under this operating condition, the specific wear rate of BVWS-R composite ($4.01 \times 10^{-8} \text{mm}^3/\text{N.m}$) was lesser in comparison to BVW-R specimen ($2.90 \times 10^{-8} \text{mm}^3/\text{N.m}$).

Referring Fig. 15(a) and (b), it can be interpreted that with increase in the rice-husk filler content to 4 wt%, at 2.5 m/s sliding velocity, 20N normal load, and 3000 m sliding distance the wear rate decreases to $3.67 \times 10^{-8} \text{mm}^3/\text{N.m}$ and $1.56 \times 10^{-8} \text{mm}^3/\text{N.m}$, respectively (Table 3, Experiment No. 3) for BVW-R and BVWS-R composite respectively. This declination in wear rate may occur due to better filler/fiber–matrix interfacial bonding strength resulting in greater resistance offered by the composite against sliding damage. With further
increase in sliding velocity to 3.5 m/s, the filler/fiber and matrix interfacial debonding takes place in BVW-R and BVWS-R composites leading extensive filler pulverization which results in higher frictional heat generation along the interfacial contact surface. At sliding distance of 1000 m and normal load 25 N (see Table 3, Experiment No. 7). The micro crack, micro-cutting and micro-ploughing are executed on the worn surface of composites and the matrix removal is more in BVW-R composites (Fig. 16(a)) as compared to BVWS-R composites (Fig. 16(b)).

Moreover, further rise of sliding velocity to 4.5 m/s for 6 wt% rice husk filler reinforced BVW-R/BVWS-R epoxy composites at lower sliding distance of 1000 m (see Table 3, Experiment No. 12), the wear surface shows both filler and resin fracture/elimination, and the removal of resin along sliding direction along the worn zone of composites as shown in Fig. 17(a) and (b). The matrix fracture, intermolecular bond, debonding of interfacial adhesion, and declination of surface energy are the cause of removal of material in composites. Thus, the wear resistance decreases with increase of material removal rate [32].

At maximum sliding velocity (5.5 m/s) for 4 wt% rice husk filled BVW-R and BVWS-R composites (see Table 3, Experiment No. 15), several cracks and patches are occurred over the rubbed surface (Fig. 18(a) and (b)) and these patches act as barrier and protect the resin from harm by the tough surface asperities on the counter disk and hence helpful in diminishing the specific sliding wear rate. From the above discussion, it is accomplished that at greater sliding velocity (5.5 m/s) and filler content of 4 wt%, but medium normal load of 20N, and sliding distance of 3000 m, a better wear resistance is offered by both the BVW-R and BVWS-R composites (3.85 × 10^{-8} mm^2/N m and 1.44 × 10^{-8} mm^2/N m).

4. Conclusions

In this study agro waste such as rice husk as filler, epoxy as matrix material, and Bauhinia vahlii weight and Bauhinia vahlii weight/sisal fiber at fixed 6 wt% loading of each were used to fabricate the hybrid composites and the physical, mechanical, and wear properties were studied. The following concluding outcomes attained from this study are:

- Rice husk, as agro-waste, is emerged as a potential filler reinforcement in natural fiber epoxy composites. The physical properties (void fraction and water absorption) in BVV-R composites is slightly better as compared to BVWS-R composites. This might be due to more OH group available due to inclusion of Sisal fiber in BVWS-R composite.
- On increasing in wt% loading of rice husk content in both BVW-R and BVWS-R epoxy composites, mechanical properties (tensile strength, flexural strength, and hardness) were increased due to the settling mechanism and better interfacial adhesion. The highest value mechanical properties was achieved at 6 wt% rice husk content among all the fabricated composites whereas impact energy is found to slightly deteriorated because of decreasing the deform-ability of the resin constituent.
- Sliding wear characteristics and their optimized controlling factors were effectively evaluated by using Taguchi experimental L16 orthogonal array and ANOVA. It was perceived that for like test conditions, BVWS-R composites exhibited superior wear resistance as compared to BVV-R composites at all filler loading. The optimum test run condition for the fabricated composites were; sliding velocity of 5.5 m/s and filler content of 4 wt%, normal load of 20 N, and sliding distance of 3000 m.
- The ANOVA results expressed that sliding velocity and rice husk contents were noteworthy control factor for the specific sliding wear rate. Normal load and sliding
distance caused a maeger effect on specific sliding wear rate.

- The worn surface micrographs of the BVW-R/BVWS-R composites demonstrated that the individual or combined action of micro-cracks, micro-cutting and micro-ploughing were mainly the major accountable sources for different wear behavior in the hybrid polymeric composites.

**Conflicts of interest**

The authors declare no conflicts of interest.

**REFERENCES**


