Research Article

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Mechanical characterization and machining performance evaluation of rice husk/epoxy an agricultural waste based composite material

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Abstract: Natural fibers from agricultural waste have received more attraction than traditional synthetic fibers in recent years. In present investigation epoxy/rice husk composite has been fabricated to utilize the agricultural waste which can be recycled easily and overcome the pollution problems due to smoke and fine silica ash. Study of interfacial bonding and dispersion of rice husk in epoxy resin has been studied through scanning electron microscope image. Characterization of fabricated composites has been done by mechanical properties. Ultimate tensile strength, Young’s Modulus and hardness are highest at 10 wt.% of rice husk particle and their values are 66.5 MPa, 616.46 MPa and 16.8 HV respectively. Machinability of epoxy/rice husk composites has been determined through drilling operation. Effect of feed rate (0.1, 0.2 and 0.3 mm/rev), speed (300, 600 and 900 rpm) and wt.% of reinforcement (10, 15 & 20) have been studied on machinability of epoxy/rice husk composites. Taguchi L27 orthogonal array has been applied to conduct the experiments to evaluate the performance characteristics viz thrust force and torque. Weight percentage was found the most significant factor for machinability followed by feed rate and speed.

Keywords: Rice Husk; Epoxy; Machinability; Drilling

1 Introduction

Much of the agricultural by-products are not used economically. The good example of this is bagasse, rice husk (RH), sugarcane leaves, etc. which are either burned in the field or thrown out. This creates several environmental problems like air pollution, smoke formation and loss of soil moisture. To make efficient use of agricultural by-products, an integrated approach at the level of farmers and industries are required. The aim of this study is the reuse of agricultural waste which may be profitable, pollution free and economically viable for the farmers and industries. Among various natural polymers, cellulose natural fibers are envisioned as the most suitable way to solve environmental related issues [1] and increase the income of farmers. It is estimated that on an average paddy consists of about 20-22 percent husk, 5-8 percentage bran and 70-72 percentage rice. If the husk is burnt, the ash of husk contains the highest proportion of silica. It is also estimated that paddy produces about 0.20 tonnes of husk and every tonne of husk produces about 0.18 to 0.20 tonnes of ash [2]. Rice husk is a by-product of rice milling and around 18.3 million tons of rice husks is produced every year. Rice husk is the agricultural waste which is mostly burned and creates pollution problems due to smoke and fine silica ash. The content of silica ash depends on the climatic conditions, variety and geographical location [3].

In present investigation, epoxy resin is used as matrix material which has large industrial applications like adhesives, electronic implements, coating and aerospace structures. They exhibit excellent properties like good adhesion, heat and chemical resistance, electrical and mechanical insulation and low shrinkage on curing [4–10]. The hardener is chemically active compounds which convert epoxy resin into hard, infusible thermostes and promoted the crosslinking reaction either by poly-addition or by homo-polymerization [11].

Nowadays the most prominent example of agricultural waste is Rice Husk (RH) which has been used as a reinforcing material extensively. The global production of
rice is 700 million tons per annum and thus has great potential as reinforcing fiber. Yang et al. [12] fabricated rice husk reinforced polypropylene composites and found that they have enhanced mechanical properties that cannot be obtained otherwise. Rosa et al. [13] also used rice husk flour as reinforcement in same matrix material by melt extrusion process and concluded that there is decrease in tensile strength with increase in reinforcement. Many researchers used polyethylene matrix with rice husk and reported significant effect of reinforcement on mechanical properties of composite material [14–19]. Epoxy resin and wood flour based composite was developed and its tribological behavior was studied by Dwivedi et al. [20] and analyzed that there are effective increases in load carrying capacity and decrease in wear resistance of matrix material. In the year 2012, Oozioko [21] recorded uniform wear rate behavior of reinforcing material with increase in temperature from 850°C to 950°C. The composite was made from rice husk ash and epoxy resin by manual stirring method and contain 10, 20, 30 and 40 wt.% of reinforcement and obtained results showed uniform behavior for wear rate and specific wear rate.

Another important aspect studied in this paper is machining performance evaluation of the fabricated composite material. Sonbaty et al. [22] examined the effects of process parameters on the thrust force, torque and surface roughness in drilling of fiber-reinforced composite materials. It has been demonstrated from the result that epoxy resin, cutting speed has insignificant effect on maximum thrust force whereas cutting speed and feed has significant influence on minimum surface roughness. Palanikumar et al. [23] utilized grey relation analysis with Taguchi Technique to obtain the optimal machining condition. Experiments were carried out through L\textsubscript{16} 4-level orthogonal array in order to investigate the effects of spindle speed, feed on maximum thrust force, minimum delamination factor. Shivakumar and Guggari [24] analyzed the effect of machining parameters viz. spindle speed, feed and drill diameter on the tool life during the machining of composites. They studied that the composite materials have appealing aspects like the moderately high compressive quality, great versatility in creating thick composite shells, low weight and erosion resistance.

2 Materials and methods

Three different epoxy/rice husk composites i.e. the particulate form of husk, hybrid (particulate mixed with full rice husk in equal composition) and rice husk were used as a reinforcement material in the experiment.

2.1 Materials

In the present investigation epoxy resin, CY-230 has been used as the matrix material having epoxy equivalent rate and HY-951, a yellowish-green colored liquid as hardener. Rice Husk was purchased from local rice mill for reinforcement in composites at nominal price. However, hardener and matrix were purchased from M/s Excellence Resins Limited, India. The casting was done in rectangular mould made up of Perspex Sheets of 9 mm thickness. The dimensions of the mould was 150×120×20 mm\textsuperscript{3}.

2.2 Alkaline treatment

Rice Husk (RH) was washed thoroughly in fresh water to remove dust and dirt and then dried for the whole day in sunlight to remove moisture content. Now 5% solution of KOH was made by taking 5gm KOH in 100 ml of water. Then rice husk was washed and soaked for 30 min. Then alkali treated [25] RH was dried for 2 days in sunlight. After that, a part of rice husk was grinded in the form of 425-micron size powder [26].

2.3 Casting

To fabricate the composites epoxy was put in beakers then husk/RH particulates/mixture of particulate and husk (hybrid) were added (10, 15 & 20 wt.%) and mixed with mechanical stirrer at 3000 rpm at 110°C for 1 hr in electric oven. Then the solution was allowed to cool down to 45°C after which hardener was added. Hardener and epoxy were taken in the ratio 10:1. Before pouring the solution in mould, silicon grease and M-Seal were applied to the mould to stop the matrix flow. Then resulting mixture was poured into the mould and allowed to stand still, the mixture solidifies for 2 days [26]. Testing of samples was done at room temperature which is about 34°C in laboratory with relative humidity and atmospheric temperature is about 62% and 99.7 kPa.

2.4 Scanning Electron Microscopy

The fracture surfaces of tensile test were examined directly by scanning electron microscope (SEM) JEOL JSM-IT 100. Before conducting the experiment gold plating on each
specimen was done. Square samples were cut from fractured specimens and then the samples were placed inside a chamber in which an electron beam falls at an accelerating voltage of 5 kV.

### 2.5 Mechanical testing

Tensile, compressive, hardness and impact strength of epoxy/rice husk composites have been determined. For tensile test specimens were clamped on 25 kN ADMET made servo controlled Universal Testing Machine and pulled until failure. During the test, crosshead was moved upward with a constant rate of 1 mm/min meanwhile change in specimen dimension and applied load were measured. Compression test was conducted in similar manner as tensile test, except that the force is compressive and the specimen contracts along the direction of the stress. Specimen for tensile tests was $152 \times 20 \times 5$ mm$^3$ with the gauge length of 50 mm having fillet 24 mm. Whereas for compressive tests cylindrical specimen was used having 20 mm length and 10 mm diameter.

The impact strength of fabricated composites was determined with an Izod impact test. The impact testing was done on the sample size $60 \times 10 \times 10$ mm$^3$ having 45$^\circ$ notch as per ASTM D256 [27] standard. Notch was made in the sample with the help of V- Needle File at $t/2$ to $t/3$ depth. Hardness was measured by using digital Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136$^\circ$, was forced into the material under a load. The load of 0.6 kgf was applied for dwell period of 3 seconds and after that unloading was done.

### 2.6 Drilling processes

In present study number of drilling experiments were carried out on a HURCO VM-10 CNC machine to evaluate effect of feed rate (0.1, 0.2 and 0.3 mm/rev), wt.% and speed (300, 600 and 900 rpm) on machinability of epoxy/RH composites. Drilling operation was performed on $150 \times 150 \times 10$ mm$^3$ size specimen to drill 9 mm hole in the specimen. In present study HSS drill bit having 9mm diameter was used to perform the operation. A 4-component Kistler piezoelectric dynamometer with multi-component sensor was used to measure the forces, moments and torque. The dynamometer system was composed of a dynamometer (Kistler 5034A3) and multichannel charge amplifier (Kister 5034A3). The probe of dynamometer was attached to amplification system which connects the data acquisition system. DYNOWARE software was used for data acquisition system. Taguchi L$_{27}$ orthogonal array has been applied to conduct the experiments and evaluation of performance characteristics viz thrust force and torque. Figure 1 represent sample prepared compression testing, impact testing and composite plate after drilling process.

### 3 Results and discussion

#### 3.1 SEM image

The scanning electron microscopes of the fractured tensile test specimen are shown in Figure 2. It can be clearly seen that in Powder reinforced composite smooth surfaces are reduced and the voids are easily visible. It is evident that there is an inhomogeneous mixture of RH Powder and RH with epoxy that leads to some micro cracks in the matrix material in Mixture reinforced composite. The tensile fractured specimen of Husk reinforced composite showed uniform crack propagation and surface roughness with many tear lines. All these reasons are responsible for reduction of tensile strength of the composite.

#### 3.2 Mechanical properties

Figure 3(A-C) represents stress-strain curve of RH, RH particle and hybrid RH reinforced composites at different weight percentage. Results show that particulate RH reinforced composites show higher UTS followed by hybrid and lowest for RH reinforced composites. The highest UTS recorded was 66.5 MPa in particulate RH reinforced at 10 wt.% followed by 61 MPa and 46 MPa in hybrid RH and RH reinforced composites respectively. Variation of Young’s Modulus (as shown in Figure 2D) was same as UTS i.e. it is highest for particle RH reinforced and decreases with increase in wt.% of RH. Maximum value is observed at 10 wt.% which was about 616.46 MPa in particulate RH. Results show that increased in RH wt.% brittleness of fabricated increases due to reduction in % of elongation.

The results of compressive strength and compressive Young’s modulus for particle RH, hybrid RH and RH reinforced composites are represented in Figure 4(A-B). Optimum compressive properties were found at 10 wt.% in all three cases. Maximum ultimate compressive strength was 113.23 MPa in RH particle followed by 98.75 MPa and 81.04 MPa in hybrid RH and RH reinforced composites respectively at 10 wt.%. Highest compressive Young’s modulus recorded was 155.09 MPa in RH particle at 10 wt.% and at same wt.%
130.86 MPa and 118.75 MPa were found in hybrid RH and RH respectively. The rigidity and compressive strength of fiber are much lower as compared to that of epoxy because of which the decrease in ultimate compressive strength was recorded at higher weight percentage.

With increase in wt.% of RH the tensile/compressive strength decreases in all case due to poor interfacial bonding. Moreover, hydrophilic fiber and hydrophobic matrix result in lack of adhesion. At 20 wt.% coagulation of RH occurs due to which poor interfacial bonding between RH and epoxy take place results in poor load transfer from matrix to reinforcement which led to failure.

### 3.3 Hardness and impact test

Figure 4(C-D) represents the hardness and impact energy of fabricated composites. At 10 wt.% the maximum hardness was found which is about 16.8 HV in RH Powder reinforcement whereas for hybrid RH and RH is about 15.1 HV and 13.8 HV respectively. Impact energy of composites was increased with increase in RH content and maximum value is obtained at 20 wt.% The maximum impact energy recorded was 2377.53 J/mm² in RH followed by 1973.86 J/mm² in hybrid RH and 1546.5 J/mm² in particle RH at 20 wt.%. The increase in impact strength with increase in fiber weight is due to the fact that fiber is capable of absorbing more energy as compared to epoxy. The presence of fiber impedes crack growth because of which possibility of greater tendency for plastic deformation in the matrix increases. In case of RH reinforced composites the
impact strength is higher due to the fact that extra energy is needed to pull out RH fiber from matrix as compared particle RH.

### 3.4 Thrust force and torque

Three process parameters considered in this investigation were cutting speed, feed and weight percentage. The thrust force and torque were the response variables recorded for each run and are presented in Figure 5, 6 and 7. Results show that with increase in wt.% of RH and cutting speed for epoxy/RH composite thrust force decreases. Whereas Torque decreases with increase in wt.% and increases with increase in cutting speed for each epoxy/RH composites.

Variation of cutting force and torque for hybrid RH reinforced composites are presented in Figure 4. Decrease in cutting force and increase in torque was very negligible with increase in the cutting speed at each wt.% of RH. Whereas at 0.1 mm/min feed rate and 900 RPM with increase in wt.% of RH in epoxy/hybrid RH composites decrease in thrust force and torque was about 4.3 % and 19.55 % from 10 wt.% RH to 20 wt.% RH respectively. Similar observation was obtained for 0.2 mm/min and 0.3 mm/min feed rate at 900 RPM i.e. about 2.65 % and 3.34 % decrease in thrust force whereas about 16.79 % and 13.3 % decrease in torque respectively.

Figure 6 and 7 represent variation of thrust force and torque for epoxy/particle RH and epoxy/RH composites. In both the cases thrust force decreases with increase in wt.% and cutting speed while torque decreases with increase in wt.% and increase with increase in cutting speed. Maximum decrease in thrust force occurred for particle RH when varies from 10 wt.% to 20 wt.% at 0.3 mm/min and 300 RPM was about 10.5 %. Whereas maximum decrease in thrust force occurred for RH reinforced composites when varies from 10 wt.% to 20 wt.% at 0.3 mm/min and 300 RPM was about 13.25 %.

The results of ANOVA for thrust force for particle RH reinforced composites (Table 1) reveals that wt.% has the highest contribution followed by feed rate and cutting speed. Similar result has been obtained for torque. This indicates that wt.% is the most significant factor in max,

![Figure 3: Stress-strain curve for epoxy based composites reinforced with (A) particle RH, (B) hybrid RH, (C) RH and (D) Young's modulus](image-url)
imizing thrust force. This is due to the reason that more force is required to drill hole in hard material and it is observed from previous tests also that at 10 wt.% the strength and hardness are maximum. Moreover, it is observed that torque increases more rapidly with increase in feed rate whereas it decreases with increase in cutting speed. This can be attributed to the fact that chip loading speed and shear area increases with increase in feed rate which in turn increases the torque. The P-Value of for speed in thrust

Figure 4: (A) Ultimate compressive strength, (B) Compressive Young’s modulus, (C) Hardness and (D) Impact energy

Table 1: ANOVA data for thrust force and torque for powder RH reinforced Composite

| Source | DOF | Sequential SS | Adjusted SS | Adjusted MS | F       | P        | % C |
|--------|-----|---------------|-------------|-------------|---------|----------|-----|
| %      | 1   | 14.1158       | 14.1158     | 14.1158     | 86.5689 | 0.0000   | 66.51|
| Feed   | 1   | 3.7503        | 3.7503      | 3.7503      | 17.6281 | 0.0003   | 17.67|
| Speed  | 1   | 0.4831        | 0.4831      | 0.4831      | 2.9630  | 0.0986   | 2.28 |
| Error  | 23  | 2.8744        | 2.8744      | 0.1631      |         |          | 13.54|
| Total  | 26  | 21.2236       |             |             |         |          | 100  |

ANOVA analysis for torque

| %      | 1   | 0.0076       | 0.0076      | 0.0076      | 2187.61 | 0.0000   | 77.53|
| Feed   | 1   | 0.0010       | 0.0010      | 0.0010      | 291.23  | 0.0000   | 11.23|
| Speed  | 1   | 0.0002       | 0.0002      | 0.0002      | 48.34   | 0.0004   | 2.25 |
| Error  | 23  | 0.0008       | 0.0008      | 0.0004      |         |          | 8.99 |
| Total  | 26  | 0.0089       |             |             |         |          | 100  |
force indicates that the effect of speed on thrust force is non-significant.

The results of ANOVA for thrust force for hybrid RH composites (Table 2) reveals that weight percentage has the highest contribution (78.44%) followed by feed rate (12.57%) and cutting speed (2.47%). Whereas for torque, contribution of wt.%, feed rate and cutting speed are about 83.45%, 10.92% and 1.23% respectively. ANOVA analysis for thrust force for RH reinforced composites (Table 3) reveals that weight percentage has the highest contribution (82.59%) followed by feed rate (10.57%) and cutting speed (2.45%). Whereas for torque contribution of wt.%,
feed rate and cutting speed are about 79.59%, 11.84% and 6.91% respectively.

4 Conclusions

From the above results following conclusions can be made:

1. SEM images show that inhomogeneous mixture of RH Powder and RH with epoxy that leads to some micro cracks in the matrix material in Mixture reinforced composite which result in reduction of tensile strength of the composite.

2. The tensile properties viz. Ultimate Tensile Strength, Young’s Modulus and Percentage Elongation decreases with increase in RH fiber weight percentage.
3. Due to improper adhesion between hydrophilic fiber and hydrophobic epoxy matrix the reduction in tensile properties was observed.

4. Rice husk particle reinforced bio-composite at 10 weight percentage showed best results and was also statistically proven.

5. At 10 wt.% maximum hardness was found 16.8 HV in Powder reinforced composites followed by 15.1 HV in Mixture reinforced composites and 13.8 HV in Husk reinforced composites.

6. Impact energy of composites was increased with increase in RH content and maximum value is obtained at 20 wt.%.

7. With increase in wt.% of RH and cutting speed for epoxy/RH composite thrust force decreases. Whereas Torque decreases with increase in wt.% and increases with increase in cutting speed for each epoxy/RH composites. Similar result was obtained for hybrid RH and particle RH composites.

8. ANOVA analysis for thrust force for RH, particle RH and hybrid RH composites reveals that weight percentage has the highest contribution followed by feed rate and cutting speed.

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