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Experimental investigation and development of sustainable natural fiber based reinforced composite

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ABSTRACT

Sustainable development goal is the development of such as materials, which might not drop the negative impact over the environment, ecology and society and has long resiliency or life if bring into use. In today's era, the world is concentrating on alternative materials that are naturally recyclable and friendly to the environment. In place of synthetic fibres, renewable natural fibres now offer an alternative polymer composite material. Pollution of the environment has become unavoidable due to the toxic gas emissions from burning large quantities of residual rice straw fibres. As we know that natural fiber and epoxy resin is ascertained as momentous composite material amongst other composite materials due to its multipurpose usage in engineering, versatility cum unique mechanical properties, low-cost fabrication, renewable, biodegradable, and recyclable. In the presented research work, analysis of mechanical Behavior, of rice straw and bamboo fiber hybrid composite. To analysis same, in this research work a hybrid composite was created by first treating rice straw fibre with sodium hydroxide in an alkali process and then combining the treated rice straw sheet in stacking sequences with bamboo fiber. The testing results show that the specific tensile strength and flexural strength of rice straw fiber combined with bamboo fiber is greater than another hybrid composite. In addition to that, the hardness of rice straw fiber combined with bamboo fiber is also found greater than the other hybrid composite. The discussed hybrid composite fabrication scheme, testing, analysis and results represented graphically throughout the presented research work.

KEYWORDS

natural fiber • mechanical behavior • alkali treatment • sustainable material development

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Introduction

The sustainable material development (SMD) stated to develop the materials, which have sustainability if usage to fabricate goods/products such as making the ply, bed, doors of houses etc under least cost along with promoting the minimum pollution [1]. It is seen that the construction sectors are a major contributor to socio-economic development is interdependent pillar of sustainability. The materials provide the best reliable construction if material is good in nature [2]. It is seen that the composite materials are available in broad range for different civil engineering work, products' fabrications. The reinforcing matrix material is identified as a prominent sustainable material within the contemporary context. Composite materials derived from natural fibers are typically selected in various industrial applications [3]. This phenomenon transpires due to reduced expenses and density, environmental sustainability, recyclability, and low mass. The predominant cereal crop is Oryza sativa, and the external layer of rice straw is classified as a byproduct of agricultural practices [4]. Most waste is burned, which pollutes the air then this wastage is utilised commercially to avoid this. Additionally, it can be used to produce biofuel, paper, fertiliser, and animal feed [5]. The reinforcement materials have the strength as well as stiffness and matrix material have capability to transfer the stresses [6]. Natural fibers are readily available and easily sourced. Collaborative efforts between industries and researchers aim to replace synthetic fibers with natural alternatives in response to environmental concerns and increasing global demand [7]. S. Kirubai et al. [8] analysis of mechanical behavior on natural fiber-based silica filled hybrid composite material. This study the effect of filler material on silica with jute and Rice straw hybrid composites. The outcome demonstrates that the fibre matrix interface was enhanced by combining natural fibre with synthetic filler. Preeti Beniwal et al. [9] advancement in the tensile characteristics of composites made of polylactic acid and reinforced by rice straw fibres. When the modified fibres were added to polylactic acid (PLA), composite films were produced that demonstrated improved thermal stability and crystallinity. The mechanical tests showed that the film of tensile strength had improved by 95 % and that its toughness had improved by roughly 600 %, thus improving compatibility among the matrix material and reinforcement. Singh et al.' [10] analysis the performance of rice straw reinforced fiber composite material. As a result, shows, that the improper usage of rice straw directly affects both material costs and environmental protection. Rice straw has been identified as a potential energy source and a useful waste product with a number of specific advantages as research is shifting towards reducing carbon footprints. Bowen Feng et al. [11] analysis the behavoir of alkali treatment rice straw reinforcement cement composites. The right amount of rice straw fibres additive greatly enhanced the modified cement specimens, while an excessive amount of the reserve impact was seen. These findings support theoretical research on the utilisation of rice straw fibres in cemented composites and reduce the environmental pollution generated by those fibres. Santosh Kumar et al. [12] analysis the wear behaviour of polylactic acid (PLA) composites supplemented with rice straw fibres. The experimental results show that applied stress and fibre loading significantly affect composite wear loss. Wear loss increases with a rise in applied normal load, Still, when fibre loading increases, the composites' abrasive wear loss decreases. M.H.M. Hamdan et al. [13] investigated the mechanical parameters of a PLA polymer composite reinforced with rice husk filler and treated with maleic anhydride, polypropylene, and polyethylene, they found that tensile and flexural strength of the composite decreased with increasing rice husk concentration. Eduardo Cesar Pachla et al. [14] studied that the rice husk and rice straw are used sustainably in cellular composites. Straw was added, which decreased the compressive strength by 15 % while increasing the flexural strengths. When rice straw was added, sound absorption increased, and the sound lining values were statistically comparable. Yashas et al. [15] studied the polymers matrix composite and stated that the matrix material is non-bio deformable and might attain the biodegradable by moderately changing fibers with natural fibers. Newly, Wang et al. [16] examined the tensile strength characteristics of natural fibre reinforced polymer composites and noted that while natural fibre tensile strength attributes are good, they can be changed when using synthetic fibres, such as carbon or glass, to reinforce plastic materials. Rong et al. [17] studied the effects of chemical behaviours of fiber epoxy composite and stated that the bond among the fibers and matrix scan be improved by emphasizing the chemical behavior. Arpitha et al. [18] moderately changed the glass fiber with bamboo fiber and considered the effects of hybridization, and indicated that the fillers added natural fiber epoxy composites gives major progress in mechanical property. Rajesh et al. [19] explained that the surface treatment by NaOH and the hybridization increase the mechanical behavior of polymer composites matrerial. Megahed et al. [20] studied the mechanical behavior of rice straw and glass fiber reinforced epoxy composite. The alkali treatment method was used for making rice straw sheet. Ranjan et al. [21] investigated the mechanical properties of rice straw fiber hybrid epoxy reinforced biodegradable composite. The presence of lignin in rice straw causes poor bonding among the fiber and matrix material. Zhang et al. [22] studied about the fabrication and treatment process of lignocellulosic reinforced particleboard composite (made from rice straw and coir fiber). The treating composite material is increasing the wet ability of the rice straw surfaces on surface smaller contact angle. Xie et al. [23] studied the rice straw fiber and bamboo fiber, which are used as reinforcement cement-based composite. The mechanical property of the composite can be enhanced using fiber, the authors stated. Vijaya et al. [24] investigated that, the mechanical property of bamboo glass fibers hybrid composite material increases the ecological. Ismail et al. [25] investigate the mechanical behavior of rice straw fiber-based hybrid composite. The authors tested the three-point bending strength of rice straw reinforced composites material and concluded that flexural strength increases with the enhancement of a polyvinyl alcohol percentage in a composite material. Nguyen and Mangat [26] studied that, the analysis the property of rice straw fiber based reinforced with alkali-active cementitious composites. sodium hydroxide (NaOH) was used to treat the rice straw fibre. The rice straw fiber has a very optimistic effect on the alkali treatment process in the composite. Lokesh et al. [27] analysed the mechanical property of bamboo fiber-based reinforced polymer hybrid composite material. The author found that the flexural strength of bamboo fiber epoxy resin is increasing with increasing fiber loading. The impact property of a composite material is increasing with the rise of fiber, contained in composite. Tensile property, flexural property, and impact property are highly affected by the sodium hydroxide-treated fibers used [28].

The objective of this study is to develop a sustainable hybrid composite using rice straw and bamboo fibers reinforced with epoxy resin. It aims to reduce agricultural waste and environmental pollution by utilizing renewable natural fibers. The research focuses on enhancing mechanical properties such as tensile strength, flexural strength, and hardness through hybridization. Overall, the goal is to promote eco-friendly, cost-effective, and high-performance bio-based composite materials.

Materials and Method

Materials

Rice straw. The rice crop residue is light in weight as well as biodegradable and the most appropriate for the filler in the composite material. The rice straw (Table 1) is using in the place of plastic fiber in composite material. Nowadays almost everyone uses harvesters for harvesting crops, and after that, they leave the crop residue there. Then burn it to sow the next crop. The burning of the rice straw causes the emission of toxic fumes, and two to three months later the clouds are black. Due to which the environment is gated populated. Hence, the rice straw is easily collected, and it is available for free [28].

Bamboo. Bamboo fiber (Table 1) is widely used as reinforcement material in the composite because it is a predominant behavioral property, such as strong, flexible, antibacterial, and biodegradable. The sweat is very quickly absorbed and evaporated by the bamboo fiber. Bamboo fiber is luxurious, shiny, and breathable. The micro-hole is present in the cross-segment of the bamboo fiber which is loading to as moisture absorption and ventilation [29].

Table 1. Chemical property of rice straw and bamboo fiber [30,31]

Property	Density, g/cm^3	Young modulus, GPa	Poisson ratio	Cellulose, wt. %	Hemicellulose, wt. %	Lignin, wt. %
Rice straw fiber	1.6	2.427	1.0	38.94	20.95	6.922
Bamboo fiber	0.9	35–46	0.35	42.3–49.1	24.1–27.7	23.8–26.1

Epoxy resin and hardener. Epoxy is a polymer type of matrix material. The basic function of epoxy resin is to hold the fibers together and transfer the load between the fibers. Epoxy resin (Table 2) is widely used in manufacturing applications because of its property like toughness, strong adhesion. In this, epoxy resin LY556 and curing agent hardener HY951 are used for making the composite. The resin and hardener were mixing with a ratio of 10:1 [32].

Table 2. Property of epoxy resin [33,34]

Sr.no.	Property	Epoxy resin
1	Density, g/cm^3	1.10–1.41
2	Young modulus, GPa	3
3	Poisson ratio	0.4

Making sheets from rice straw fibers

The rice straw was collected from or on the farm. Impurity ware was removed, and the alkali treatment process was conducted at home. In the alkali treatment process, the adhesion property of fiber is improved. After removing impurities, the straw was cut into 5 mm length as in Fig. 1(a). Then the rice straw was washed by running water and removed from the waste material in the straw. Then the rice straws are soaked in 2 wt. % of sodium NaOH for 36 h. Sodium hydroxides are buying 250 g near the store. Rice straw is treated with sodium hydroxide and breakdown of a bundle of smaller fiber. This developed the rough surface structure that causes enhanced fiber-matrix adhesion between fiber and matrix. Then the rice straw was boiled for 2 h until the rice straw becomes soft, as shown in Fig. 1(b). Then the rice straw fiber was washed with thoroughly running water. Then the rice straws are crushed with a pestle as shown in Fig. 1(c). After crush, the rice straws are put into the mould. The mesh passed through the roller to remove the excess quantity of water shown in Fig. 1(d). Then the water come-out through the screen. Then the rice straw is uniformly distributed into the mould shown in Fig. 1(e). Then rice straw fiber dried into the sunray. The alkali treatment process was completed [32,35].

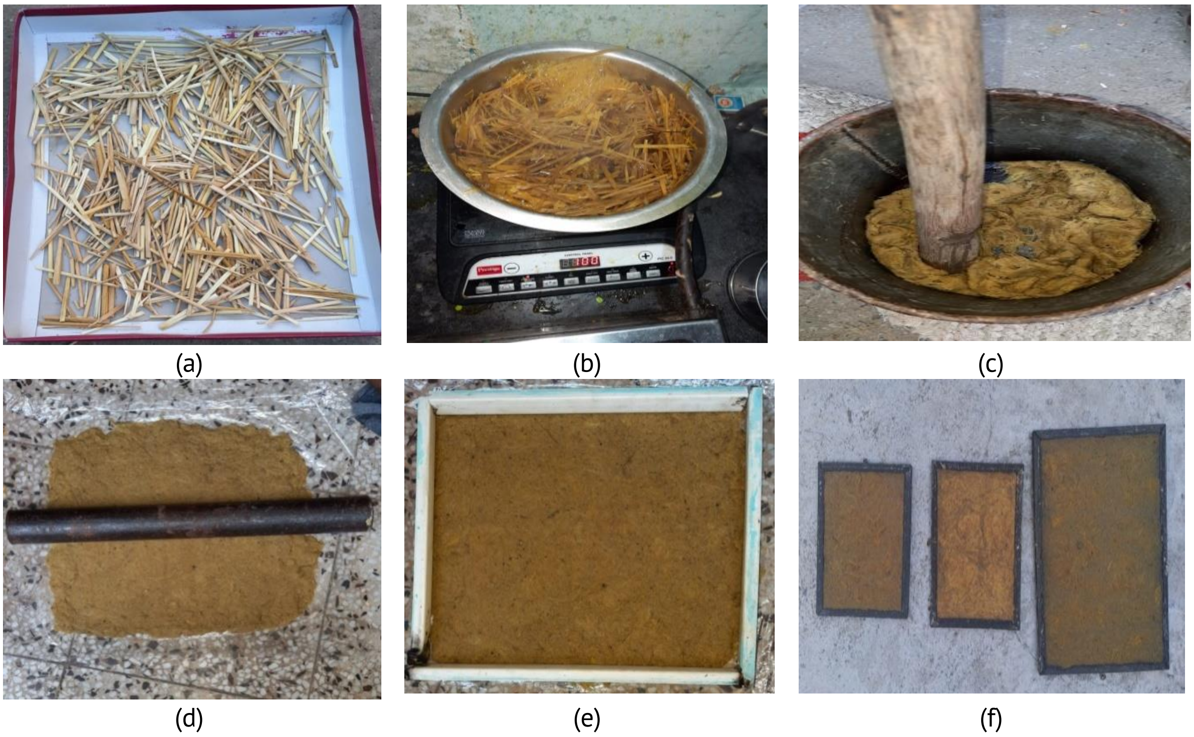

Fig. 1. Development of sheets from rice straw fiber

Fabrication process

In this research, the hand-lay-up method was using to fabricate the composite plate (Table 3). The most popular and affordable open moulding method is hand-lay-up technique because it required fewer amounts of apparatus. It is suitable for making an extensive variety of composite product from small to large. In this method, two mild steel plates are used, and the dimension of the plate is 200 × 150 mm^2. Resin and hardener mixed with the proportion is 10:1. Then the mixtures is stirred until the mixture attains a notable amount of heat. This mixture is prepared with the help of a weighing machine. Then a small amount of wax is applied to the plate. Then the fiber is placed between the plates. Both the plate is fastened with screw and tight with nut for curing in 30 h [36].

Table 3. Composition of wt. % of fiber and epoxy resin

Sr. No.	Sample code	Stacking sequence	Fiber, wt. %		Resin, wt. %
			Rice Straw	Bamboo	
1	RBR143	Rice straw / bamboo / rice straw	26.7	13.3	60
2	RB110	Rice straw / bamboo	20	20	60
3	RR100	Rice straw / rice straw	40	0	60
4	BRB214	Bamboo / rice straw / bamboo	13.3	26.7	60

Characterization

Tensile test. The tensile test measured the ultimate strength, maximum breaking strength, maximum extension, and decrease in area. The purpose of tensile testing is to select the material for an application, new product development, and proof of concept. The universal testing machine conducts the tensile test. Flat samples are typically used for the tensile test [37]. The normally used sample shapes are the straight side kind by end tab. The sample is using for testing is shown in Fig 2. Tensile tests were performed using a 10-ton capacity universal testing machine of model UTB9103 in accordance with ASTM D638 at standard. The sample dimensions 165 × 12 × 4 mm^3 as per the standard recommendation. The gauge length of the specimen is 60 mm and crosshead speed of 1 mm/min. All the testing is conducted on CIPET Raipur [38,39].

Fig. 2. Composite plate

Flexural test. The stress a material immediately before it yields in a flexure test is known as its flexural strength. It represents maximum stress experiences inside the material on its instant of yield. The material can resist deformation under the load [40]. A three-point bending test is used for determining flexural strength. This test is performed using a universal testing apparatus in accordance with ASTM D790. The sample dimensions 127 × 12 × 4 mm^3 as per the standard recommendation. The span length of the specimen is 50 mm and crosshead speed of 1 mm/min [41].

Hardness test. Hardness is the resistance of a material to localized plastic deformation. The hardness testing evaluates material properties, like strength, and wear resistances [42]. It determines whether a materials or materials behaviour is suitable for purpose you required. The performance of the hardness test is pressing the indenter into surface of the material. It determines by measuring the depth of indenter penetration. Shore hardness test is used to measure the hardness in this research [43,44].

Results and Discussion

Tensile strength

Table 4 shows the various properties of RR100, RB110, RBR143 and BRB214, such as tensile stress, and strain. Table 4 demonstrates that the tensile properties of reinforced composite material decreased with increasing fiber volume percentage due to improper bonding among the rice straw fiber and epoxy. It is found that the ultimate tensile stress of sample RR100 is 12.7 MPa and RB110 is 11.8 MPa. It can be seen that the increasing fiber wt. % of the composite reduced the tensile properties of the composite. It has been observed that the ultimate stress of RR100 is greater than RB110. It is found that the ultimate tensile stress sample RBR143 is 1.21 MPa and BRB214 is 13.5 MPa. It has been observed that the ultimate stress and strain of RBR143 is lesser than BRB214. In this study the maximum tensile strength was obtained increasing the wt. % of the resin. BRB214 sample has highest tensile property. Alkali treatment of rice straw fiber is also increasing the tensile properties of the composite. The comparative study of sample RR100 and RB110 are illustrated in Fig. 3. It is found that the ultimate tensile stress of sample RR100 is 12.7 MPa and RB110 is 11.8 MPa. It has been observed that the ultimate stress of RR100 is greater than RB110. Whereas the elongation of RB110 is better than RR100. It has also been observed that two layers of rice straw shows the excellent tensile properties and RB110 is more ductile than the RR100.

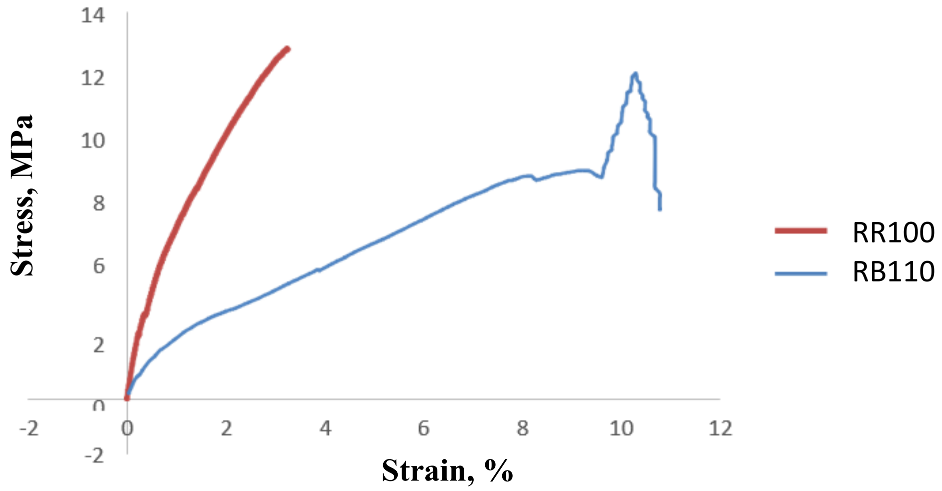

Fig. 3. Tensile strength comparison of sample RR100 and RB110 composite

Table 4. Tensile properties of tested hybrid composite

Sample	RR100 (S1)	RB110 (S2)	RBR143 (S3)	BRB214 (S4)
Ultimate stress, MPa	12.7	11.8	1.21	13.5
Ultimate strain, %	3.38	13.9	1.09	8.11

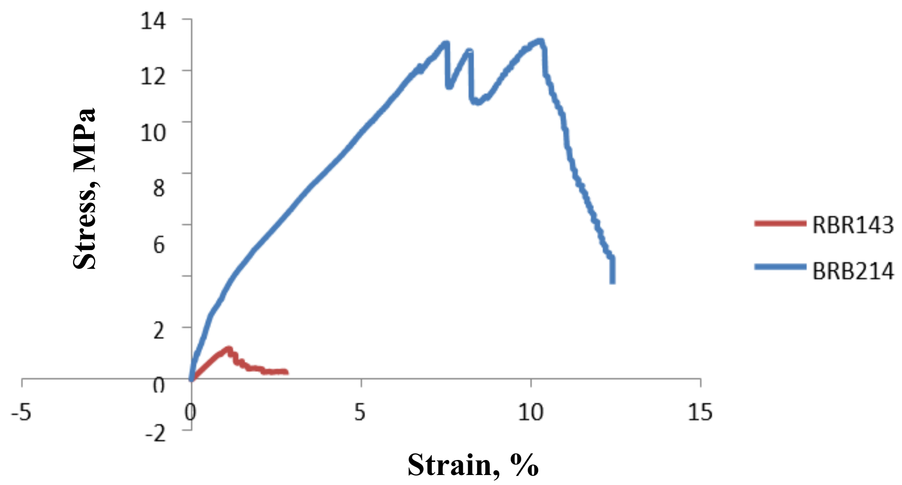

Fig. 4. Tensile strength comparison of sample RBR100 and BRB110 composite

The comparative study of sample RBR143 and BRB214 are illustrated in Fig. 4. In this graph, it is found that the ultimate tensile stress sample RBR143 is 1.21 MPa and BRB214 is 13.5 MPa. It has been observed that found that BRB214 has excellent tensile properties. Sample RBR214 has resin wt. % is more than the other sample than adhesion quality of this composite is more. The stress strain curve found from tensile test of hybrid composite is shown in a single graph for comparison. The tensile strength found to be highest for sample BRB214 and lowest for RBR143. The tensile strain found to be highest for sample RB110 and lowest for RBR143. Figure 5 shows all composition and demonstrated that the following sequences are as under:
Tensile stress=> BRB214>RR100>RB110>RBR143.
Tensile strain=> RB110>BRB214>RR100>RBR143.

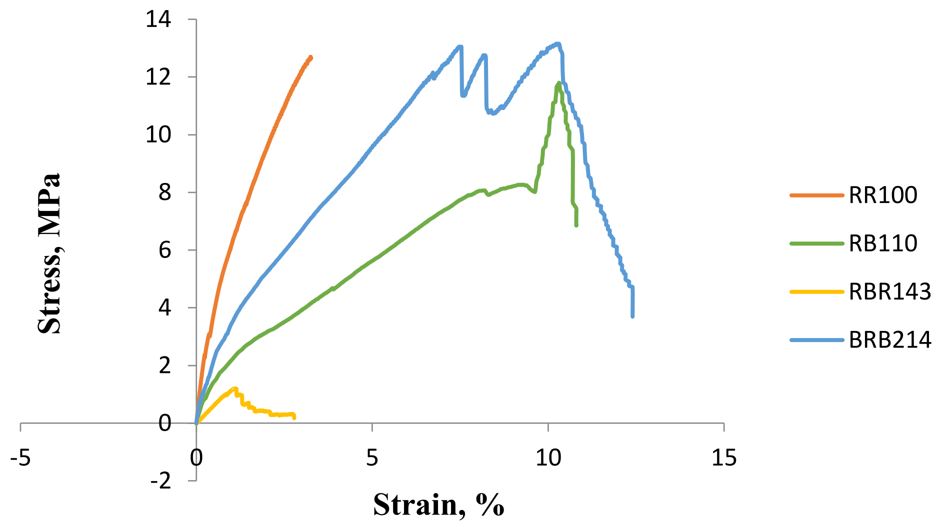

Fig. 5. Tensile strength comparison for all hybrid composite

Flexural property

Table 5 shows the various properties of RR100, RB110, RBR143 and BRB214, such as flexural stress, and strain. It is found that the ultimate stress of the sample RR100 is 8.35 MPa and RB110 is 6.49 MPa. Table 5 shows that the flexural properties of reinforced composite material decreased with increasing fiber volume percentage due to improper bonding among the rice straw fiber and epoxy. It has been observed that the ultimate stress and strain of RR100 is greater than RB110. It is found that the ultimate stress of the sample RBR143 is 5.49 MPa and BRB214 is 8.3 MPa. It has been observed that the ultimate stress and strain of RBR143 is lesser than BRB214. The comparative study of sample RR100 and RB110 are illustrated in Fig. 6. It is found that the ultimate stress of the sample RR100 is 8.35 MPa and RB110 is 6.49 MPa. From the graph in Fig. 6 it can also be seen that the value of flexural strength reduced from 36 to 52 %. This is because of improved in fiber volume and reduces the epoxy resin presence among the composite material. The value of flexural strength reduced with increasing fiber wt. % in the composite. It has been observed that the ultimate stress and strain of RR100 is greater than RB110. It has also been observed that two layers of rice straw shows the excellent flexural properties and RB110 is more ductile than the RR100.

Table 5. Flexural properties of tested hybrid composite

Sample id	RR100 (S1)	RB110 (S2)	RBR143 (S3)	BRB214 (S4)
Ultimate stress, MPa	8.35	6.49	5.49	8.3
Ultimate strain, %	3.262	1.056	1.87	3.734

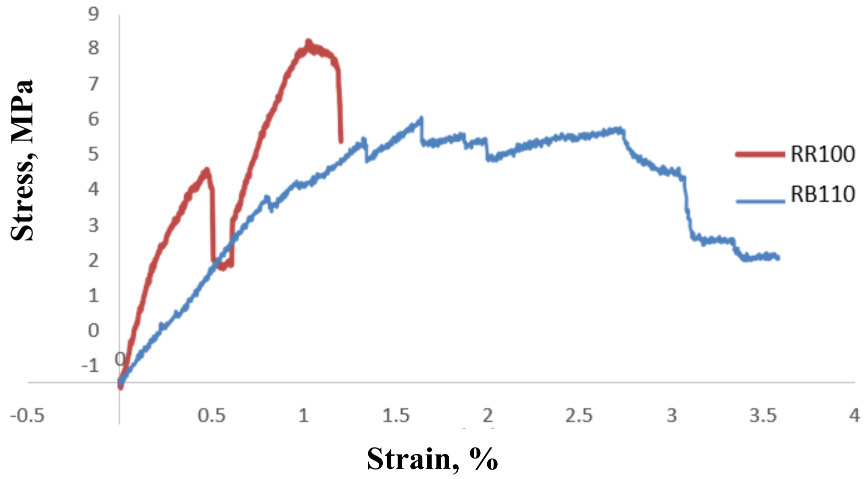

Fig. 6. Flexural strength comparison of sample RR100 and RB110 composite

The comparative study of sample RBR143 and BRB214 are illustrated in Fig. 7. The introduction of the alkali treatment of rice straw fiber increases the bonding of fiber and resin hence it increases flexural strength of the composite. It is found that the ultimate stress of the sample RBR143 is 5.49 MPa and BRB214 is 8.3 MPa. It has been observed that the ultimate stress and strain of RBR143 is lesser than BRB214. It has also been observed that BRB214 has the excellent flexural properties. The stress-strain curve found from flexural test of hybrid composite is shown in a single graph for comparison. The flexural strength found to be highest for sample RR100 and lowest for RBR143. The tensile strain found to be highest for sample BRB214 and lowest for RB110. From Fig. 8 shows all the composition and demonstrated that the following sequences are as under:
Ultimate stress=> RR100>BRB214>RB110>RBR143.
Ultimate strain=> BRB214>RR100>RBR143>RB110.

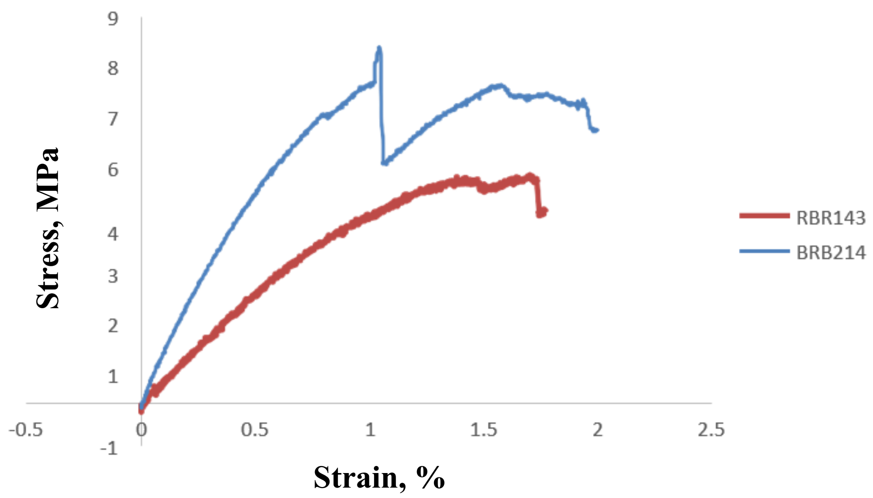

Fig. 7. Flexural strength comparison of sample RBR100 and BRB110 composite

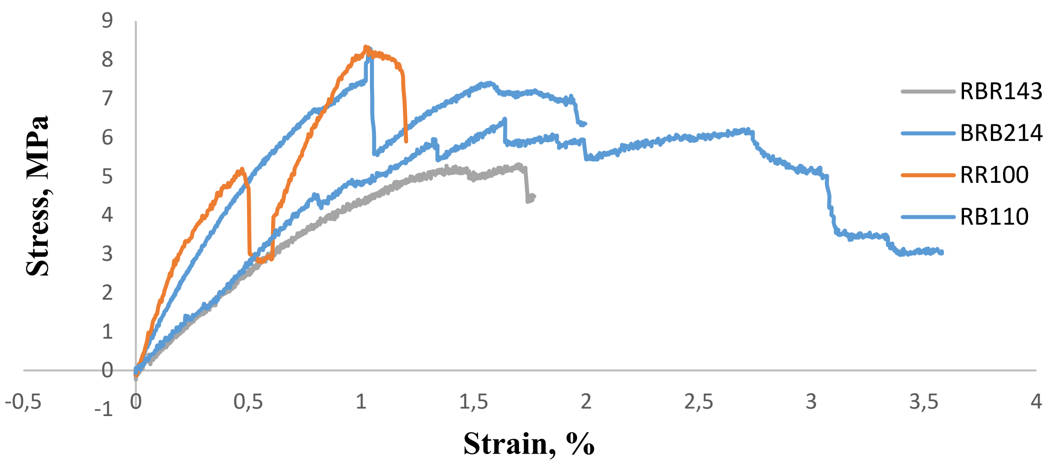

Fig. 8. Flexural strength comparison for all hybrid composite

Hardness test result

Shore hardness test is used to measure the hardness in this research. It analyses a material's resistance to an indenter-like spring-loaded needle penetrating it. An equipment known as a durometer is used to perform the shore hardness test. It loads an indenter using a calibrated spring. Then the hardness is then determined by the indenter's penetration depth under load. The specimen BRB214 is a maximum value of hardness (Fig. 9). Table 6 had given the hardness test result value of all hybrid composite fabricated material.

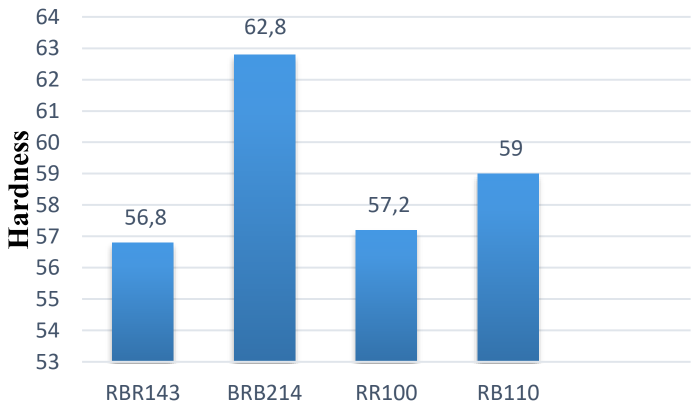

Fig. 9. Hardness test result in bar graph

Table 6. Hardness test result of fabricated material

Sample id	**RBR143**	**BRB214**	**RR100**	**RB110**
Hardness	56.8	62.8	57.2	59

Conclusion

SMD is found as one of the important fields in today's era. Concern about SMD, the researchers are focusing on developing the materials into two aspects such as materials must have the composition of natural polymers and have the low manufacturing cost and high resiliency for long period of time targeted the SDG. Natural composites/ polymers reduce by environmental effect and provide healthy life to society as well as ecosystem (promote to social ecology), where on other hand high resiliency means materials have sustainability. Therefore, as results, the authors attempted to fabricate the materials by using natural polymers and tested the mechanical properties of same. In this work, sustainability of said material is measured in the terms of tensile, flexural, hardness of rice straw fiber/bamboo fiber mat/epoxy resin hybrid composites. Random rice straw fibers were changed to mat form with the better distribution to improve the mechanical behavior of the composite.

Based on the testing results, the following conclusions can be a drawn:

1. The successful fabrications of a rice straw sheet and bamboo fiber hybrid epoxy composite.
2. The tensile strength of RR100 composite is 7.6 % more than RB110 and BRB214 composite is 82 % of RBR143.
3. The flexural strength of RR100 composite is 22 % more than RB110 and BRB214 composite is 33 % of RBR143.
4. The hardness value is maximum for BRB214 (62.8) and minimum for RBR143 (56.8).

After comparison, it is summarized that RR100 composite has good tensile as well as flexural strength however in case of hardness BRB214 can be referred for civil engineering field.

Credit authorship contribution statement

All authors contributed to the study conception. Material preparation was performed by **Yugendra Kumar Sahu**, **Shubhra Vishwas** Sc, data collection and analysis were performed by **Yugendra Kumar Sahu**. The supervision of the manuscript by **T.V. Arjunan** Sc and **Samarjit Singh** Sc. All authors read and approved the final manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

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