Effect of Rice Husk Ash on the tensile strength of Epoxy based bio-composite

Abstract

Rice husk is a major agricultural waste which has very little practical application for the farmers. It has been used as a fibre with various resins to produce composites. If burnt it produces ashwhich contains 90% Silica which has high abrasive strength and can contribute to mechanical strength of composites. In the present work RHA was obtained by incinerating RH at about 600^0C for 6 hours. The ash obtained with this procedure is shiny white in colour and rich in silica. The ash obtained by this process was mixed in various weight proportions with epoxy and powdered rice husk to obtain bio composites. Mechanical tests were conducted to assess the strength of the composite. It was observed that incorporation of RHA as a fibre improved various mechanical properties upto a certain weight proportion where after it started decreasing. SEM tests were conducted to understand the failure mechanism. It can be concluded that RHA can be a suitable fibre for bio composites up to a limited range. In future however better casting techniques can be developed to utilize the abrasive strength of this abundant resource.

Keywords:Rice Husk, Epoxy, SEM

1. Introduction

It is estimated that the production of rice husk worldwide is approximately 700 million tons[**1**], of this 22% of this is husk (175 million tons) **[2]**. This waste has no practical use. Plenty of research work has been carried out to utilize rice husk as fibre with polymer matrix. Team of Yang et al.[3] have done an extensive work on utilizing RH with polypropylene as the matrix material. It was reported that the tensile strength slightly decreased with increasing filler loading. Tensile modulus however increased. It was also seen that the impact strength decreased with increasing filler content. In a different study**[4]** the same composition of filler and matrix was used and the same results have been obtained and the tensile strength has reduced by around 50% for 40% RH. In a similar study conducted with Epoxy and RH, the tensile strength reduced with increasing RH content and 20% RH wt % was seen to give the highesttensile strength.

This can be attributed to the opposing natures of fibre (hydrophilic) and polymer (hydrophobic) due to which the adhesion is improper. There is also the tendency of rice husk to agglomerate due to which the tensile strength decreases as filler loading is increased **[6].** A different number of studies concerning the same compositions **[7-11]** have conclusively proven that the increase in filler loading is detrimental to the tensile strength of the composite obtained.

"Hybrid composites for improving the matrix-dominated properties of continuous fibre reinforced composites were first developed in 1982" **[12]**.

"The chemical composition of Rice husk, RH from different regions was analyzed and found to have an average composition of 80% organic matter and 20% ash" **[13]**. "Rice husk ash, RHA is 92% silica and can be beneficial in improving the mechanical properties due to the inherent properties of silica. RHA was used in a study as reinforcement in Aluminum alloy ($AlSi_{10}Mg$) Matrix Composites" **[14].** "In another study Rice husk derived silica was used to develop natural rubber composites and experiments have been conducted for mechanical properties"**[15].** Composite materials were obtained by filling polypropene with raw and thermally treated rice husks **[16]** at filler contents from 1 to 20%. "The physicochemical properties were determined. A slight increase was observed in the tensile strength of the composites based on white rice husk ash WRHA and aerosil AR at degree of filling up to 3%. Recently Sisal fibre based polymer composites were developed" **[17].** Their properties were tailored by hybridizing them with natural pine needles and agro waste mustard. A remarkable improvement in mechanical and wear properties was observed.

"Specifically rice husk has been used to develop hybrid bio-composites with Bauhinia-Vahlii-weight and Bauhinia-Vahlii-weight/sisal fibres" **[18].** "The mechanical properties like tensile strength and flexural strength improved significantly (34.42 and 33% respectively) and hardness by 7.1% due to hybridization. RH particulates with glass were also used for epoxy matrix" **[19].** The hardness, tensile modulus and impact energy improved while there was deterioration in tensile and flexural strength.

"Another method of improving mechanical properties of RH based composites is surface modifications. A lot of research has been focused on this area as well. to improve properties the interface between the matrix and the lignocellulosic material has to be improved. There are various methods for promoting interfacial adhesion in systems where lingo-cellulosic, treatment with silicon compounds, graft co-polymerization], use of compatibilizers, plasma treatment, and other chemicals. Some of the above mentioned methods have also been applied to RH" **[20-28**]. In all the studies a significant improvement in properties was reported due to improved adhesion between matrix and filler. Besides there have been number of studies which have explore the development of hybrid bio-composites and have conclusively proven that addition of second fibre can significantly improve the mechanical strength **[29-38]**.

2. METHODOLOGY

2.1 Materials

In the present investigation epoxy resin CY-230 purchased from M/s Excellence Resins Limited, India has been used as matrix material. Epoxy resins, also known as polyepoxides are a class of reactive prepolymers and polymers which contain epoxide groups. Araldite CY-230 is a liquid solvent free epoxy resin. Hardener (HY-951)has been used as curing agent which is a yellowish-green coloured liquid.

Rice husk ash is the product of thermal degradation of rice husk. When rice husk is incinerated, it generates between 17-20% ash, made up of about 87-93% opaline silica and other metallic oxide impurities [Turmanova*et al.*, 2012][29] depending on the source of the husk. When rice husk is incinerated, two types of products can result, white rice husk ash (WRHA) and carbonised rice husk (CRH). In either forms, rice husk has some applications.

Sodium hydroxide and Hydrochloric acid were provided by M/s Allied Business Limited, India. NaOH was used for treatment of rice husk fibres while HCl was used for treatment during the processing of rice husk ash. Different processes have been used by different researchers to obtain silica from rice husk. The process which has been utilised here as proposed by Ahmad *et al.*, 2013 [15] can be summarized in following steps:

Rice husk was washed with water to remove any foreign material. Thereafter Hydrochloric acid solution of 0.4 M was prepared and 100 g cleaned husk was mixed in 1 L of prepared acid solution and boiled at 100–105^{0}C for 30–45 min. After the reaction, the acid was completely removed from the husk by washing with tap water.It was then dried in an oven at 110^{0}C for 3–5 h in oven. The treated husk burned in an electric furnace at 600^{0}C for 6 h; silica was obtained as white ash. The shape of the silica is similar to the shape of the husk but smaller in size.

After the preparation of RHA various samples of RHA based composites were prepared. The weight proportions for silica were 0.5, 1 and 2% and were mixed in rice husk and epoxy which were in the proportion of 20:80. Tensile, flexural, impact and hardness were measured for various specimens and SEM was used to understand the failure mechanism.

2.2 Sample Preparation

For the optimization of rice husk different proportions of rice husk were added to the epoxy resin. The ratios taken were 10, 20, 30, 40 wt%. Depending upon the size of the mould 30*30*10 cm^3) rice husk, epoxy and hardener were taken in the desired proportion. Hardener and epoxy are taken in the ratio of 10:1 i.e. 10 parts epoxy and 1 parts hardener. Firstly rice husk and epoxy were mixed and heated at a temperature for 1 hour in an electric oven [5] and then allowed to cool down to 45^0C (to avoid bubble formation) after which hardener was added. The particulate matter before casting was treated with NaOH. The process of alkali treatment was optimized by treating the fibres in different amount of alkali solutions viz. 2, 4, 6, 8 and 10%. The rice husk flour was kept in these mixtures for approximately 5 hours and after that was washed with running water so as to remove the alkali and then was dried to remove moisture. Thereafter RH, RHA and epoxy were mixed in various proportions poured into the mould and various specimens were prepared.

2.3 Mechanical Testing

The tensile tests were conducted on 100 KN ADMET make servo controlled universal testing machine at 0.5 mm/min crosshead speed under displacement control mode. The specimens are made according to the ASTM D 3039 and ASTM D790-10 for tensile and flexure test respectively.

2.4Morphology

The scanning electron micrograph study generally performed by scanning electron microscope, which uses electron to form an image with high resolution or magnification. To obtain the scanning electrons micrographs square samples are cut from the cast material and are gold coated to avoid the artefacts associated with sample charging and then placed inside a chamber in which an electron beam fall on the material. The accelerated voltage was 10 kV. Different images are taken at various magnification ranges (1.000x-500.000x).

3. Results and Discussion

3.1 Tensile properties

Fig 1-4 shows the tensile behaviour of rice husk and rice husk ash reinforced bio-composite. In the literature it has been established that addition of second filler can be beneficial in terms of strength. The hybridisation can have a positive or negative hybrid effect. If a property improves it is known as positive hybridisation effect and if it decreases it is known as negative hybridisation effect.

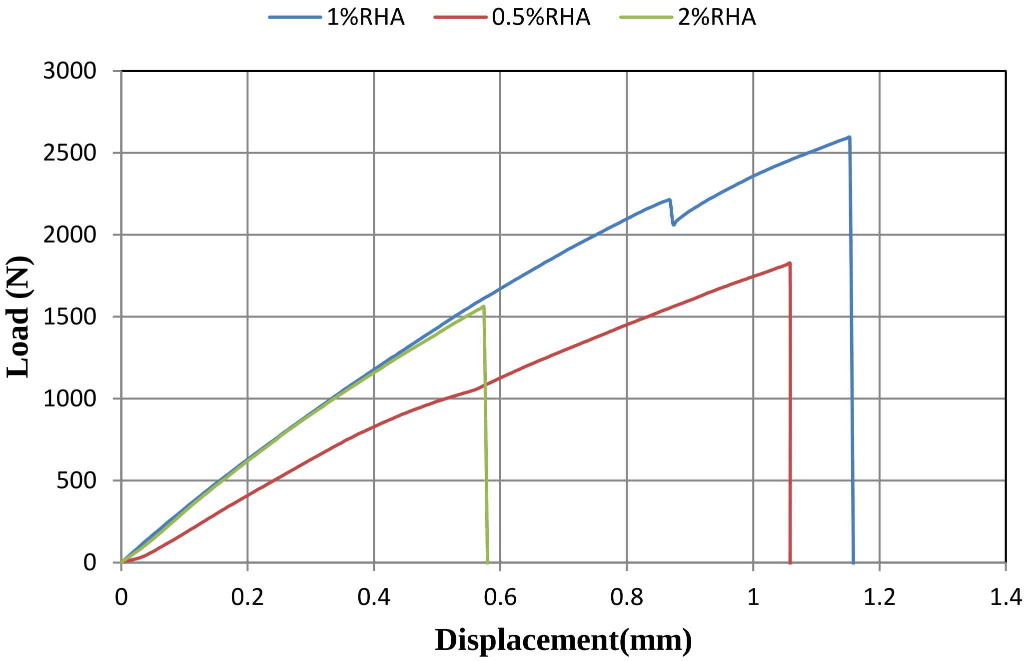

Fig 1: Load-deflection curve for different RHA reinforcement (wt %)

Fig 1 shows the tensile load-deflection curve for RHA reinforced epoxy bio-composite which also contain 20 wt% treated rice husk. From the stress-strain curve it can be seen that there is fibre breakage for 1% RHA which shows that there was maximum adhesion between fibre and matrix and as a result the mode of failure was fibre breakage thus imparting maximum strength to the bio-composite. Also it can be seen that the mode of failure in all the cases is brittle in nature. It can be seen that elongation was maximum for 1% followed by 0.5% and for 2% RHA it was lowest.

In Fig 2 comparative study of tensile strength for various amount of RHA has been done. The tensile strength obtained has been compared with that of 8% NaOH treated 20% RH reinforced bio-composite.

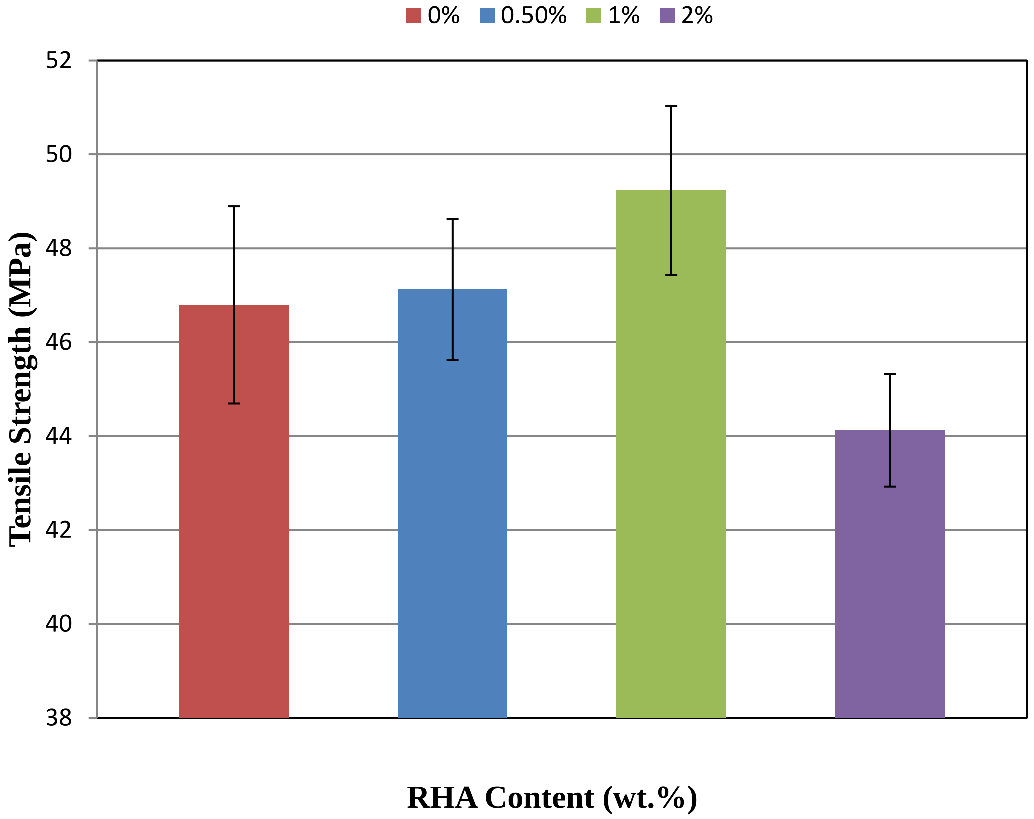

Fig.2. Tensile strength for treated fibres for different level of RHA addition

From the Fig 2 it can be seen that addition of RHA has a positive hybridisation effect on tensile properties. Increase in tensile strength can be observed due to RHA addition initially but addition of 2% RHA results in decrease in strength, the strength becomes even less than composite for composite without RHA. Addition of 0.5% RHA increases the tensile strength only marginally by 0.705%, it can be said that addition of 0.5% RHA has limited hybridisation effect. For 1% RHA the improvement in tensile strength was 5%. However beyond 1% there was a decrease in tensile strength. For addition of 2% RHA the decrease in tensile strength was 5.7% which negates the benefit of hybridisation and even the pre-treatment effect. The increase in tensile strength initially can be attributed to the fact that RHA has high aspect ratio d so therefore there is better stress transfer from matrix to RHA thereby increasing tensile strength. However at higher filler loading the RHA nano particles are not able to disperse well and so therefore there is reduction in tensile strength.

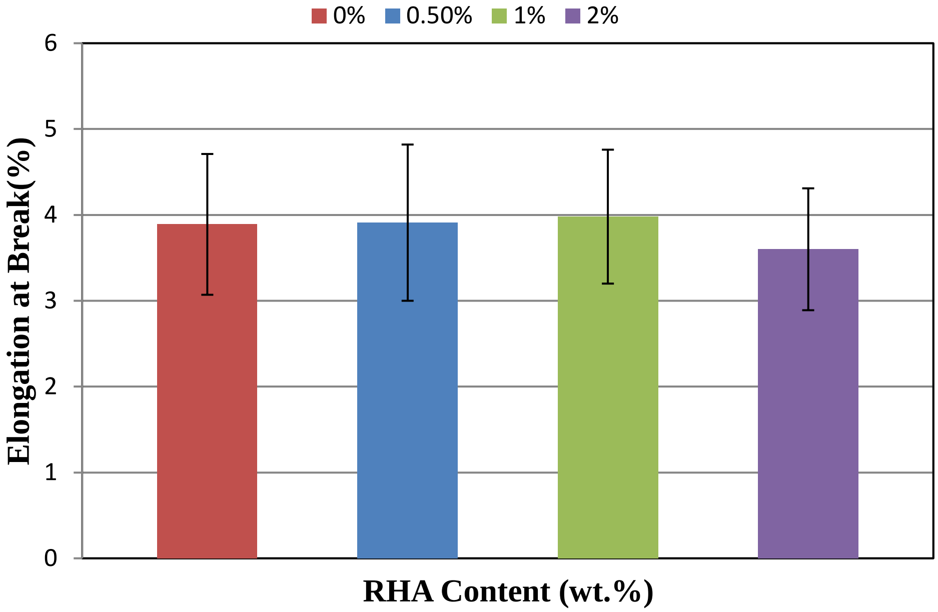

Fig.3. Elongation at break for treated fibres for different level of RHA addition

From Fig 3 it can be said that with addition of RHA the material becomes ductile. Similar to the tensile strength the increase in percentage elongation was not significant. However at 1% RHA the ductility improved significantly. At 2% RHA however the percentage elongation decreased significantly reducing from 4% for 1% RHA to around 3.6% for 2% RHA a decrease of around 10%. Compared to non-RHA composite the percentage elongation decreased by about 6.5%.

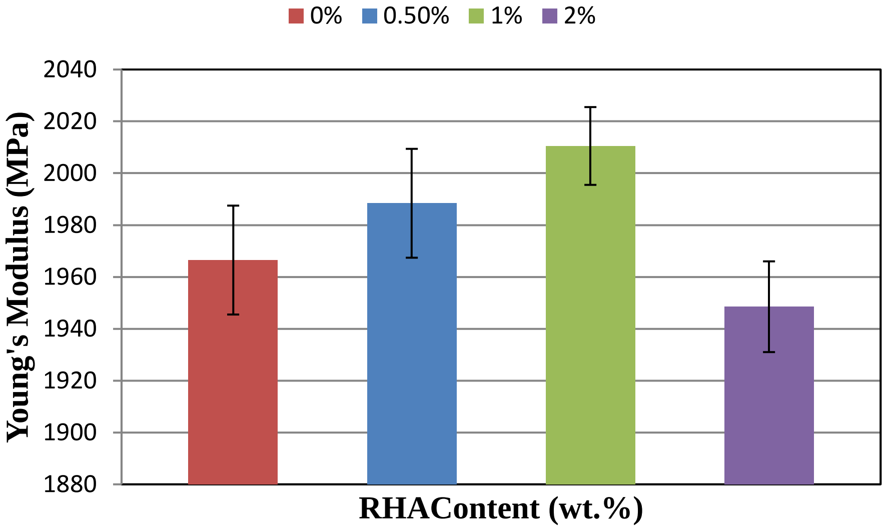

Fig.4. Young's modulus for treated fibres for different level of RHA addition

Fig. 4 shows the effect of RHA content on the stiffness of the composites. It is observed that the ductility initially improves due to the addition of RHA up to 1% loading but thereafter it decreases similar to the tensile strength.

3.2 Flexural properties

The flexural behaviour for different RHA reinforced composites has been done.

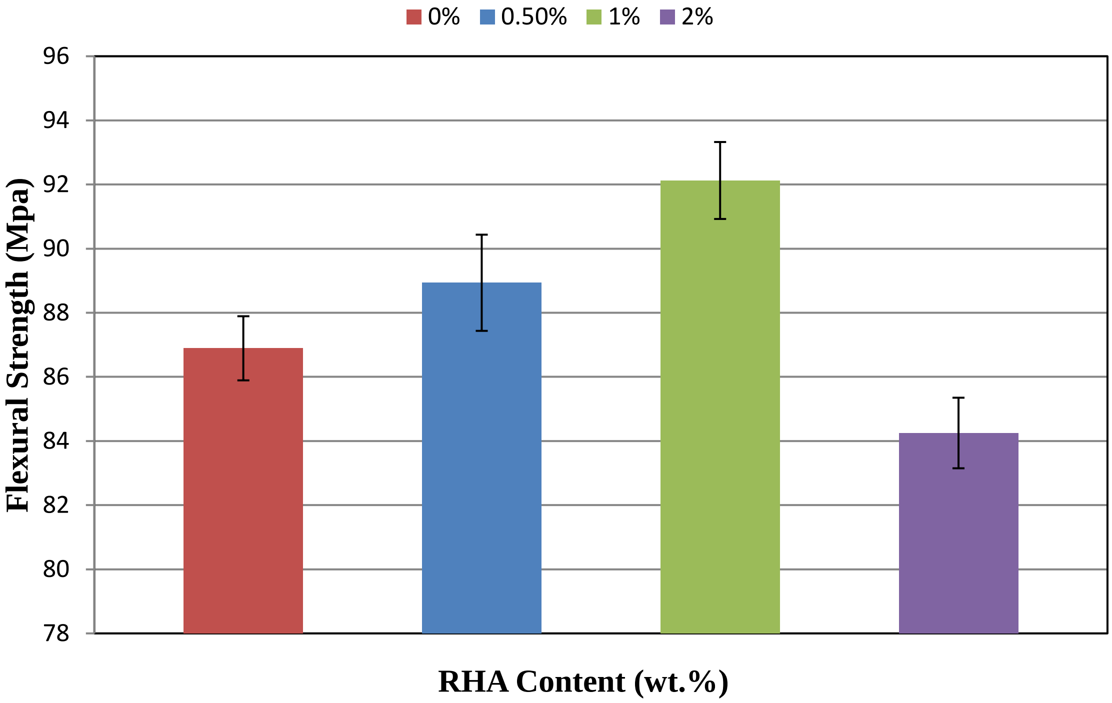

Fig 5: Flexural strength for treated fibres for different level of RHA addition

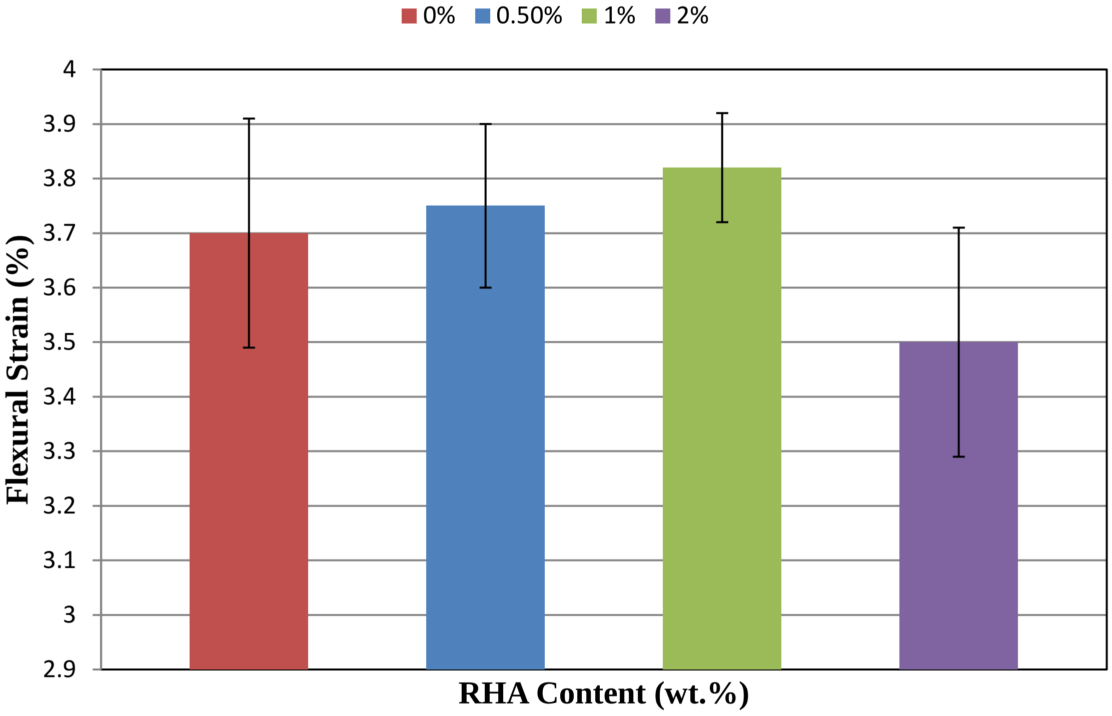

Fig 6: Flexural strain for treated fibres for different level of RHA addition

From Fig 5 which shows the effect of RHA addition on flexural strength shows that with RHA addition there is an increase in strength of 2.35% and 6.02% corresponding to 0.5% and 1% RHA. For further addition of 2% RHA the strength reduced by about 3.04% compared to composite without RHA and reduction of 8.54% compared to 1% RHA reinforcement. The trend is similar to that for tensile strength.

Fig 6 represents the variation of flexural strain with RHA addition, it is clear that similar to the elongation at break for tensile test, the flexural strain is also maximum for 1% reinforced RHA. Compared to composite without epoxy there is an increase of 1.35% for 0.5% RHA and an increase of 3.24% for 1% RHA. For 2% RHA however there is a decrease in flexural strain. The decrease in quantitative terms was 5.45%. From Fig 7 it can be seen that there is an increase in modulus for 0.5% and 1% RHA. The modulus increased from 1657.1 MPa to 1660.32 MPa for 0.5% RHA and 1698.312 for 1% RHA corresponding to 0.18% which is insignificant and 1.8% also insignificant respectively. For further RHA addition there is a decrease in modulus from 1698.312 to 1650.122 MPa. So it can be said the effect of hybridization on flexural properties is positive to a certain level thereafter it becomes negative.

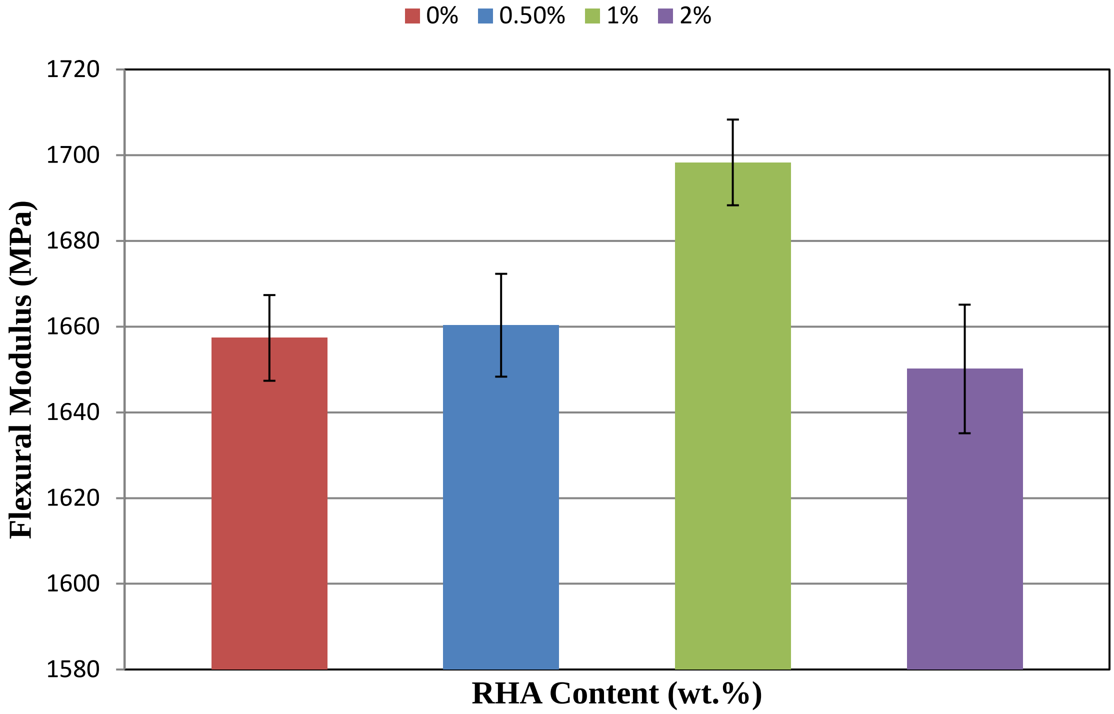

Fig 7: Flexural modulus for treated fibres for different level of RHA addition

3.3 Impact Strength

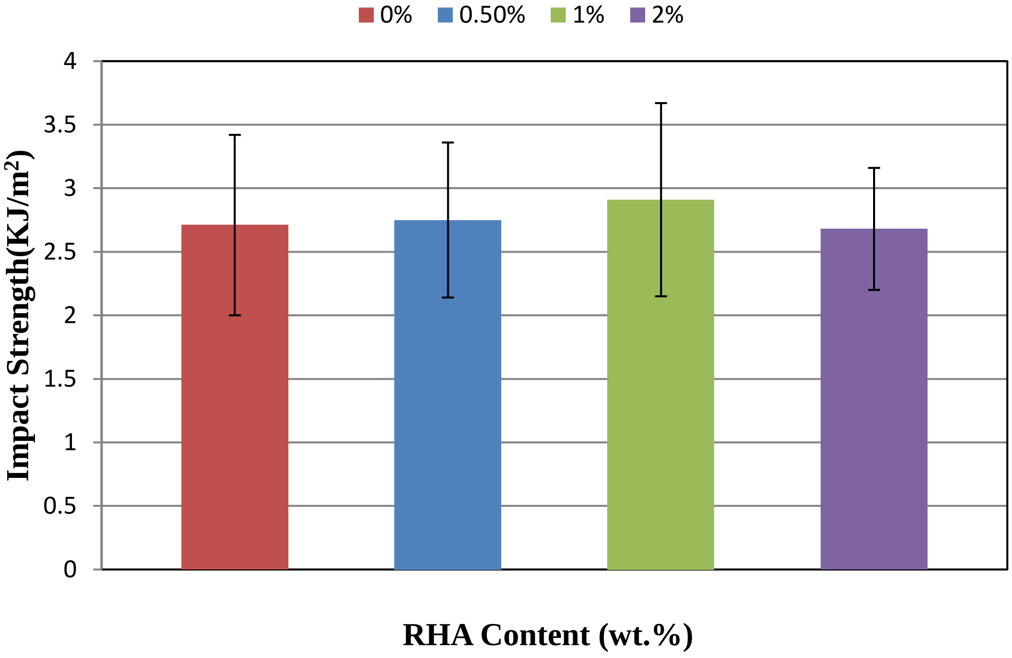

Fig 8: Impact strength for treated fibres for different level of RHA addition

The effect of RHA addition on impact strength was also studied. The proportion of RHA was kept same at 0.5, 1 and 2%. From the Fig 8 corresponding to variation of impact strength with RHA proportion it is observed that initially there is an increase in impact strength from 2.71

for without RHA composites to 2.75 and 2.91 KJ/m for 0.5 and 1% RHA reinforced composite. However increase in RHA content further reduced the impact strength by around 8% compared to 1% RHA reinforced composite and it became even smaller than without RHA composite. The difference however was insignificant at a value of 1.1% compared to composite without RHA reinforcement.

3.4 Hardness

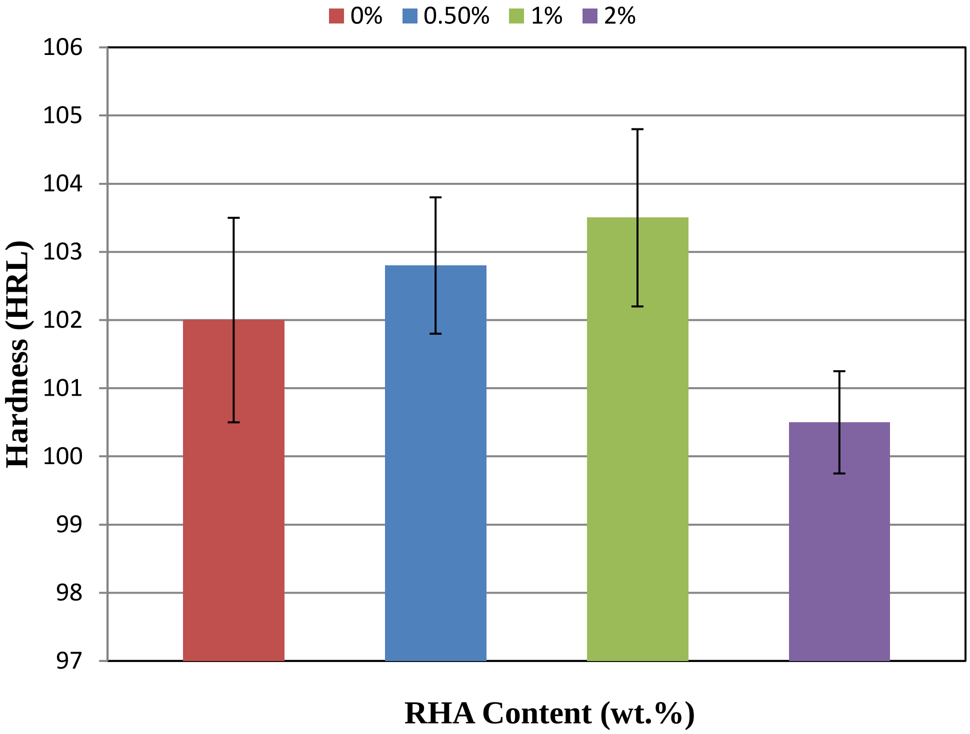

Fig 9: Hardness for treated fibres for different level of RHA addition

Effect of RHA addition on hardness is shown in the Fig 9. Hardness is seen to increase by a marginal amount of 0.5% and 1.4% for 0.5 and 1% RHA reinforced composites respectively so it can be said that RHA addition does not has any profound impact on the hardness. As the RHA content increases to about 2% the hardness drops abruptly from 103.5 to 100.5 a decrease of about 3% which can be attributed to the fact that RHA itself is a soft material and hence its reinforcement in larger amount results in decrease in hardness.

3.5 Morphology

The images are the scanned fracture surfaces of different proportions of RHA. As is evident from SEM images that at 1% RHA (Fig 12) the fractured surface is more even showing that there were no kind of voids present in the casting, however for 0.5% RHA (Fig 10) the surface is rougher due to the voids not being filled completely by the RHA. However at higher filling levels it can be seen that the mixing is improper since the liquid mixture becomes highly viscous and doesn’t cure properly as is evident from the cavity in the Fig 11.

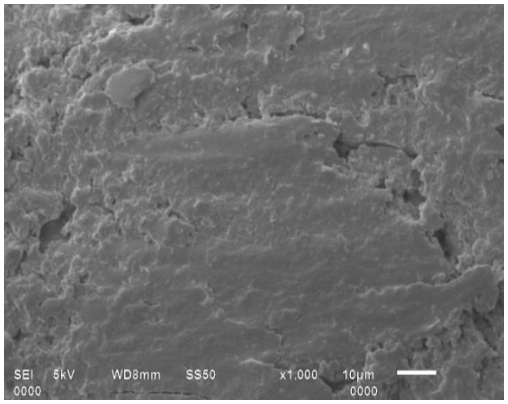

Fig.10 Scanning electron micrograph at x 1.000 for (CY-230 + 10 wt% HY-951+ 20 wt% treated Rice Husk (8% NaOH solution) +0.5% RHA)

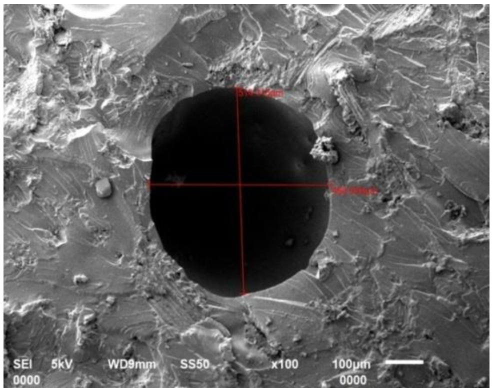

Fig.11Scanning electron micrograph at x100.000 for (CY-230 + 10 wt%HY-951+ 20 wt% treated Rice Husk (8% NaOH solution) +2% RHA)

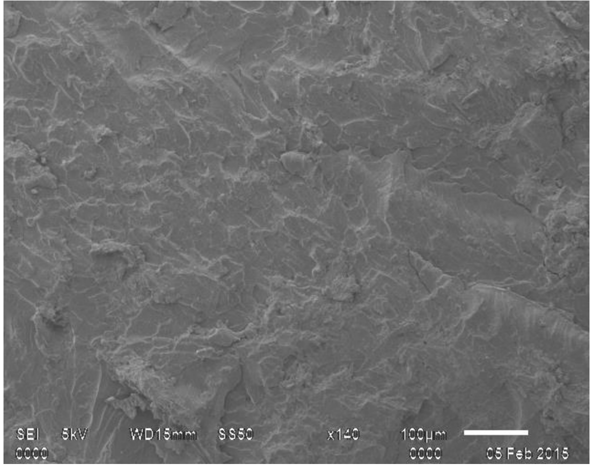

Fig.12 Scanning electron micrograph at x 140.00 for (CY-230 + 10 wt% HY-951+ 20 wt% treated Rice Husk (8% NaOH solution) +1% RHA)

4. Conclusions

Although naturally occurring lingo-cellulosic fibres can be advantageous in terms of being environmental friendly and cheaper, the opposing nature of the fibre and the polymer poses a problem with respect to the tensile strength. Modifying the surface by treatment with NaOH can be beneficial in this regard. Further properties can be improved by reinforcing the composite with RHA. The chemical composition of RHA is 92% silica which is known to be hard in nature. Further the small sixed silica particles are embedded in the RH epoxy composite, thereby increasing the tensile strength. The presence of RHA prevents or delays the fibre pull out, the main phenomenon behind the failure of composites. It is also seen that the hardness of the material improves thereby increasing its applicability because of lesser wear and tear. It was also observed that RHA makes the material more ductile and increases the modulus both in flexure and tension terms. The composite developed in this manner has higher strengths and modulus than pure epoxy and as such can be a substitute for epoxy which is otherwise environmentally eroding.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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