Noise Pollution Mitigation Study of Rice Husk-Ash Nanoparticle Reinforced Epoxy Resin Composites

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Abstract
The menace of noise pollution to human health, knowledge dissemination and tranquil environment continues to increase daily. This is not unconnected with industrialisation and multiplicity of human activities hence the need for the development of eco-friendly materials capable of drastically reducing noise pollution. In this study, epoxy resin composites were synthesised using rice husk ash nanoparticles (RHA_{NP}) as reinforcement varied from 5-25 wt. %. The composites were characterised for acoustic capabilities and the results show desirable sound absorption of up to 71.6% sound decibel mitigation at 5-15 wt. % RHA_{NP} addition. This was demonstrated by the Noise Reduction Coefficient (NRC) of the composites in the range of 0.654-0.805 at sound frequencies of 2-6 kHz. This compare well with most conventional acoustic panels installed on the ceiling of hospitals, conference centres and lecture theatres. The composites were also characterised for relevant handling mechanical properties required to guarantee damage-free installation. The outcomes indicate 35.8 MPa flexural strength, 4.3 J impact energy and hardness of 25.1 HV. These levels of mechanical properties are adjudged sufficient for safe handling and durability in service. The contributions of the study will significantly impart comfortability at facilities such as hospitals and libraries that are prone to noise pollution. Furthermore, the outcomes of the study have the potential to engender cleaner environment, value addition and a boost to the nation's Gross Domestic Product (GDP).

Keywords: Environmental pollution, epoxy-resin-composite, noise, rice-husk-ash nanoparticles

1.0 INTRODUCTION

Noise pollution emanating from different sources including the avalanche of human and heightened industrial activities remains a critical factor militating against comfortability in today's modern society. This underscores the need for an effective control of noise levels emanating from various sources through the development of eco-friendly materials capable of drastically reducing noise pollution. Generally, noise control entails sound emission reduction for reasons of personal comfort, environmental concern or legal compliance. The scientific approach in curtailing the menace of noise pollution has been the deployment of noise-isolating materials such as insulation, sound-absorbing tiles, or a muffler. It is established that natural and synthetic based composites are proven to be efficient in absorbing wide range of sound frequencies. However, for reasons of cost, bio-compatibility and environmental friendliness, natural fibres are most preferred to their synthetic counterparts (Kaila *et al*., 2009; Arenas *et al*., 2010; Nordin *et al*., 2016). In consideration of other types of materials morphology, the acoustic properties of non fibrous type materials were studied by the duo of Wang and Torng (2001) as well as Oldham *et al*. (2011). Thus, waste from straw and reeds were investigated by utilising their hollow structures to trap the sound wave. Quite promising results were obtained showing that these materials can absorb sound effectively from low to high frequency ranges at 500 Hz – 5 kHz.

Currently, large bodies of agricultural wastes are being processed for application as reinforcement in polymer matrix as acoustic materials. These processed wastes include rice

husk, coconut coir, sugarcane bagasse, kenaf, etc. Silica either in micro-meter or nano-meter is usually the active substance in most of the wastes (Yang *et al*., 2012; Lazaro *et al*., 2010; Rafiee *et al*., 2012; Rajappan *et al*., 2017; Zulkifli *et al*., 2010). Natural fillers appear to be preferred because they possess distinctive internal structures that influence sound absorption coefficients which are measured according to sound incident frequency. Furthermore, the intrinsic porousity inducement is an added advantage of natural fillers over synthetic ones. According to Seddeq (2009), this is the type of material often used in the fabrication of sound absorbers called resonators. Furthermore, it has been reported that the production of synthetic acoustic materials often give rise to the release of more carbon dioxide into the environment thereby compounding environmental pollution concern. Varieties of natural fibres including tealeaf (Ersoy and Kucuk, 2009); ramie as well as bamboo fibres (Koizumi *et al*., 2002), have been reported to exhibit absorbing coefficient ranging from 0.6-0.85 at frequencies 1-5 kHz.

Rice husk is one of the most widely available agricultural wastes in many rice producing countries around the world. Globally, approximately 600 million tons of rice paddies are produced annually (Kumar *et al*., 2013). Out of this quantity, about 20% of rice paddy is husk giving rise to an annual total production of 120 million tons of rice husk. However, the safe disposal of rice husk has been plagued by challenges ranging from ground water contamination to greenhouse gas emissions (Tarique *et al*., 2017). Thus, the feasibility of its conversion to useful product on large scale is a boost to the nation Gross Domestic Product (GDP) and a cleaner environment. Thus, the aim of the study is to synthesised rice husk ash reinforced polymer composite with a view of evaluating the acoustic properties.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials used for the study include epoxy resin and hardener sourced commercially while rice husk was obtained from an integrated rice farm in Ikorodu, Lagos, Nigeria. Major tools employed during the study include among others; pulveriser, ball mill, XRF, FTIR, optical microscope, impedance tube, Instron mechanical tester and Brinell hardness tester.

2.2 Experimental Procedure

The rice husk was oven dried at 120^{o}C for 5 hours and afterward fed into a pulveriser to grind into micro particles. The pulverised rice husk was then subjected to ball milling for further reduction in particle size. In order to achieve nanoparticles, the ball milling exercise lasted 60 hours. It is established that ball milling of carbonised organic particles for 50 hours and above produces nanoparticles (Zhang et al., 2008; Rizlan and Mamat, 2014; Subramani et al., 2016). This was followed by carbonisation in the absence of air (under argon controlled environment) for 40 hours. The input materials including epoxy resin and carbonized rice husk nanoparticles (RH_{NP}) were blended according to the mixing ratio shown in Table 1. Each of the sample formulated weighs 60 g as the reinforcement varied from 5-25 wt. %. The thoroughly blended mixture was then poured into cavities of a wooden mould coated with paper tape which served as mould releasing agent. The cast was allowed to cure at room temperature. All the samples were stripped from the mould after 24 hours of curing. The dimensions and shapes of the cavities were made according to the size and shape of standard test samples according to ASTM D638-03.

Table 1. Materials formulation

Sample	Reinforcement, wt. %	Matrix, wt. %	
	RH_{NP}	Epoxy resin	Hardener
Cs	0	66	34
A	5	63	32
B	10	60	30
C	15	57	28
D	20	54	26
E	25	51	24

2.3 Characterisations

Fourier transform infrared (FTIR) spectroscopy test was carried out to confirm if the resin used is actually epoxy. The FTIR analysis uses infrared light to scan test samples and observe chemical properties by sending infrared radiation of about 10,000 to 100 cm^{-1} through the sample. While some of the radiations are absorbed, the rest are transmitted. Usually, the absorbed radiation is converted into rotational and/or vibrational energy by the sample molecules. The resulting signal at the detector presents as a spectrum, typically from 4000 cm^{-1} to 400 cm^{-1}representing a molecular fingerprint of the sample. Each molecule or chemical structure will produce a unique spectral fingerprint, making FTIR analysis a critical validating tool for chemical identification. Determination of the rice husk ash (RHA) elemental composition was carried out on X-ray fluorescence (XRF) analyser. Each of the elements present in the RHA sample produces a set of characteristics fluorescent X-rays and the result is presented in Table 2.

The sound absorption tests were carried out according to ASTM E1050 at an incremental sound frequency of 1000 Hz. Equipment configuration for the exercise include an impedance tube, two microphone and a digital frequency analyser (Figures 1 and 2).

Figure 1: Impedance Tube

Figure 2: Frequency Analyser

The experimental procedure involves five (5) successive steps namely; (i) the test sample was fitted to the sample holder and into the impedance tube while the signal generator was adjusted to give a frequency of 1000Hz sound wave.

Furthermore, the Cathode Ray Oscilloscope (CRO) was adjusted to show the function generator output; (ii) the signal generator output was moved to leave the CRO screen to clear the way for the microphone signal; (iii) the microphone was moved along the axis of the impedance tube until the amplitude of the trace on the CRO is at a minimum while the peak to peak height of the trace was recorded as V_2; (iv) the microphone was further moved until the amplitude of the trace was at a maximum and the peak to peak values recorded as V_1 and (v) the frequency was changed to 2 KHz, 3 KHz, 4 KHz, 5 KHz and 6 KHz respectively while procedures i-iv were repeated for each frequency. Furthermore, water absorption test was carried out using

samples' dimension of 4.4 x 4.4 x 0.5 cm for each of the composite formulation. Each of the samples was immersed in a beaker containing water and the increase in weight was obtained after 12 hours. The new weight of the sample was recorded while the percentage water absorption (%WA) was calculated using equation 1.

$$\%WA = \frac{W2-W1}{W1} \times 100 \quad (1)$$

Where,

W1 = initial weight of sample (g); W2 = final weight of sample (g)

The composites were also subjected to various mechanical tests including flexural, impact and hardness. Three-point flexural test was conducted on the composites samples of dimensions 12 x 5 x 0.5 cm at room temperature using an Instron Electromechanical Testing Machine according to ASTM D 7264 standard. The experiment was conducted under a cross-head speed of 30 mm/min maintained at a span of 100 mm. An Avery impact testing machine was used to evaluate the impact toughness of the samples dimensioned to 5 x 1.5 x 0.5 cm. The Vickers hardness values of the composites were obtained through a micro-hardness tester using 4.4 x 4.4 x 0.5 cm samples.

3.0 RESULTS AND DISCUSSION

3.1 Fourier Transform Infrared (FTIR) Spectroscopy

The FTIR result presented in Figure 3 shows a peak of the oxirane group at 913 cm^{-1} which confirms that the epoxy resin used is Diglycidylether of bisphenol A (DGEBA). Although, the spectra looks similar to its hydrogenated derivative (HDGEBA), but the differences become obvious from the difference in peak values coupled with the absence of aromatic rings in HDGEBA. These features usually influence epoxy resin functional properties such as the glass transition temperature, viscosity and reaction rate (Laskin *et al*., 2018).

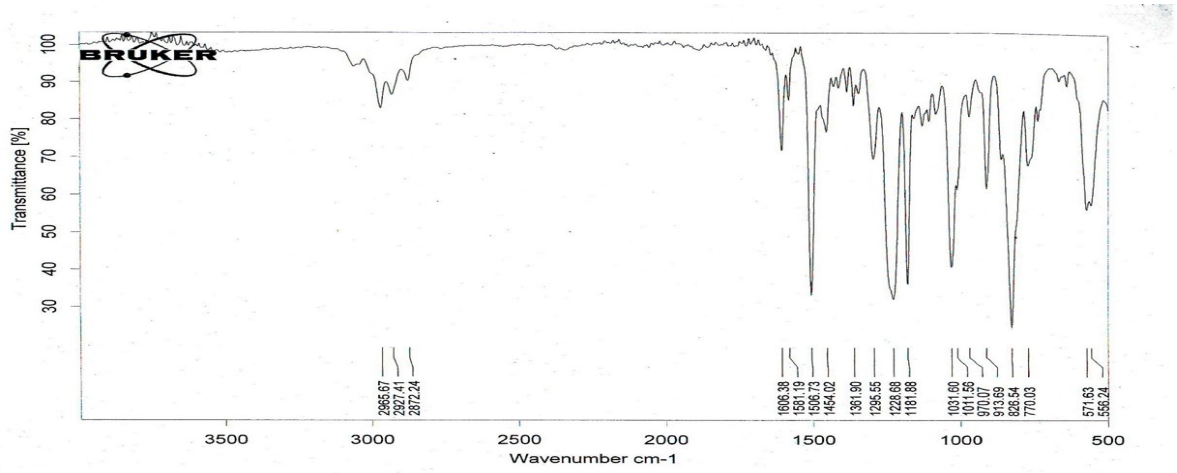


Figure 3. FTIR of the as-received epoxy resin

3.2 Chemical Composition of Rice Husk Ash (RHA)

The XRF analysis results carried out on the RHA is presented in Table 2.

Table 2. Composition of RHA

Composition	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	MgO	P_2O_5	Na_2O	SO_3	*L.O.I
Wt. %	79.72	5.12	2.11	1.54	1.29	1.88	3.72	0.39	0.21	4.02

*Loss on Ignition

Table 2 shows that RHA consist of relatively high silicate glass known as cenospheres followed by Al_2O_3, Fe_2O_3, K_2O, CaO, MgO, P_2O_5, Na_2O, SO_3. According to Elena et al., (2012), cenospheres consist of silicate glass in which the silica content is higher than the calcium content. The main application of cenospheres is as inert fillers, in which they often provide up to four times the bulk filler capacity. Furthermore, being inert, they are resistant to most acids and high temperature conditions.

3.3 Water Absorption Coefficient

Result of the water absorption test carried out on the composites is presented in Table 3 where clear influence of the rice husk ash nanoparticles has been demonstrated. According to Anovitz and Cole (2015), there is a correlation between absorption and porosity which often impacts various transport phenomena in such medium. However, the most significant effect is usually conferred by the connectivity of the pores. The composites behaviour at varied absorption coefficient in relation to acoustic capability is illustrated in Figure 4.

Table 3. Water Absorption, %

Samples	Cs	A	B	C	D	E
Absorption coefficient	0.03	0.08	0.21	0.38	0.23	0.18

3.4 Sound Absorption Coefficient

The sound absorption coefficient data generated during the experiment are presented in Table 4.

Table 4. Sound Absorption Coefficient (SAC)

Frequency	Sound absorption coefficient, α					
kHz	Cs	A	B	C	D	E
1	0.438	0.738	0.278	0.283	0.491	0.503
2	0.556	0.918	0.624	0.757	0.874	0.276
3	0.883	0.568	0.857	0.315	0.395	0.889
4	0.247	0.437	0.752	0.395	0.387	0.735
5	0.284	0.639	0.853	0.495	0.964	0.647
6	0.641	0.516	0.615	0.594	0.653	0.629

The procedure for determining sound absorption capability of materials through direct usage of SAC data is rather complex. Hence, for application purposes, Noise Reduction Coefficient (*NRC*) which is computed using equation 2 is usually adopted.

$$NRC = (\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6)\ \text{kHz} \,/\, 6 \quad (2)$$

Where α_n = Sound absorption coefficients at 1kHz, 2kHz, 3kHz, 4kHz, 5kHz, and 6kHz

Substituting SAC values in equation 2 for each sample formulation yields the *NRC* values of 0.509, 0.654, 0.805, 0.673, 0.581 and 0.492 respectively for Cs, A, B, C, D and E samples. The

sound mitigation capacity of the composites as illustrated in Figure 4 correlates both the water absorption coefficient performance of the composites and their microstructural features in terms of the nature and dispersion of pores formed. Pores in this case serve as sound sink where sound in the form of vibration incident on the composites is significantly absorbed. Sound absorption coefficient of 0.65-0.81 at 2-6 kHz obtained in this study is comparable with commercial synthetic glass wool sound absorption coefficient in the range of 0.5-0.8 at 1-2.5 kHz (Putra *et al*., 2013).

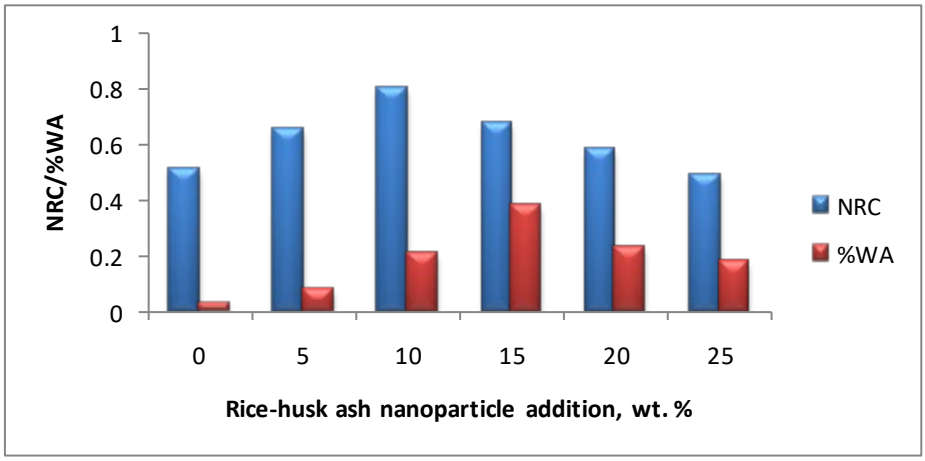
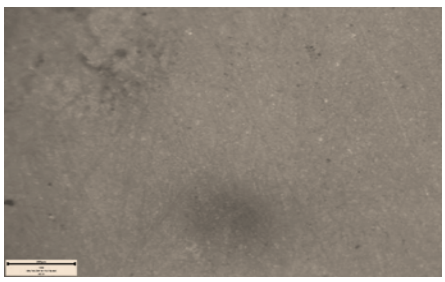


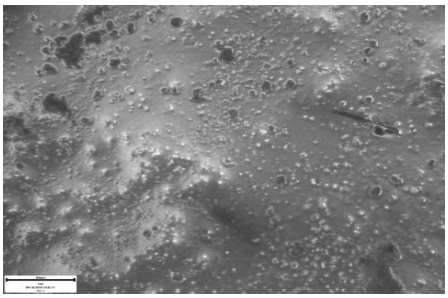
Figure 4. Combined influence of rice-husk ash addition and %water absorption on acoustic behaviour of epoxy resin composite

3.5 Microstructure

The microstructures that evolved at varied filler addition are presented in Figure 5 showing basically two main features with regard to the nature and fractions of pores induced in the matrices. The control sample's micrograph without filler is bereft of pores (Figure 5Cs). However, at 5-15 wt. % RHA_{NP} addition, varied fractions and interconnected pores are seen dispersed homogeneously within the matrices (Figure 5A-c). The pores in Figure 5A appear isolated while the pores in Figure 5B and 5C appear in a network fashion as RHA_{NP} addition increased from 10 wt. % to 15 wt. %. Further increase in RHA_{NP} addition from 20-25 wt. %, gave rise to a complete saturation of the matrices by the filler. Formation of pores may have stemmed from the combination of vacuum created during cross-linking and condensed moisture due to the hydrophobic nature of epoxy resin.



Cs (0 wt. % RHA_{NP}**)**



A (5 wt. % RHA_{NP}**)**

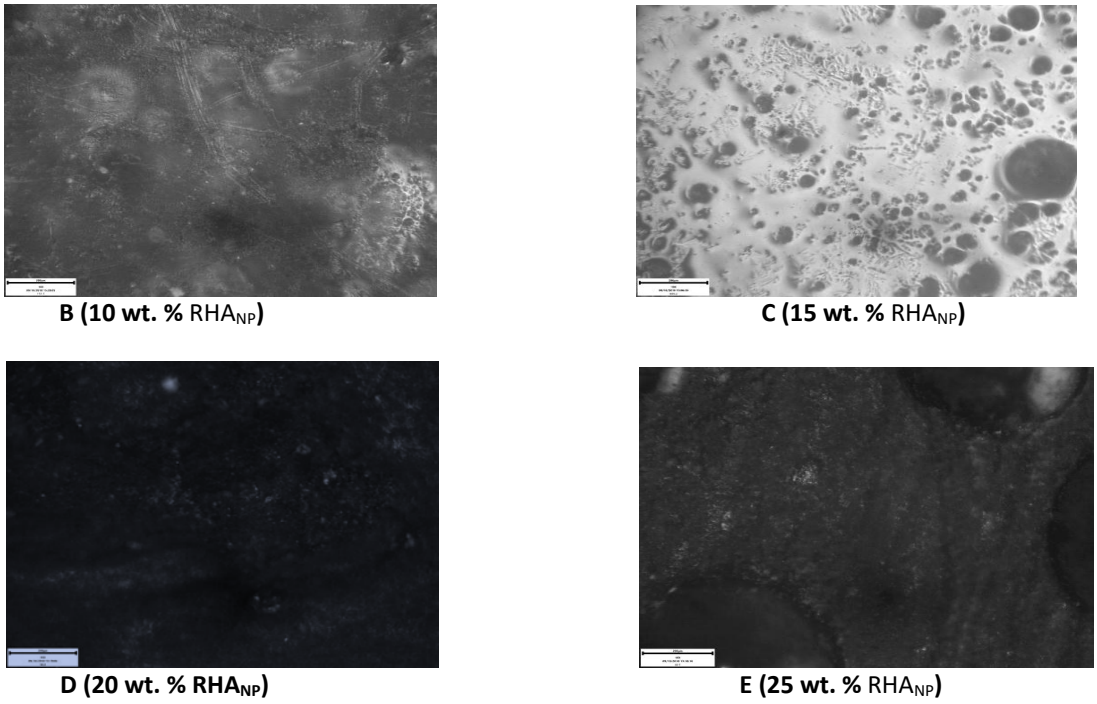


Figure 5. Optical micrographs of epoxy resin at varied rice-husk ash nanoparticle addition

3.6 Mechanical properties

As shown in Figures 6, 7 and 8, the flexural strength, hardness and impact energy of the composites were evaluated for the purpose of determining their damage free handling status. The composites ability to withstand bending forces without permanent warpage as in the case during installation is depicted in Figure 6. The control sample demonstrated the highest flexural strength of 52.1 MPa. This level of performance diminishes as rice-husk ash nanoparticles increase from 5-25 wt. % corresponding to 27.6-19.7 MPa. It appears discontinuity occasioned by pores within the matrices is responsible for the poor load transfer regime (Limi et al., 2012). In comparison with Ali et al., (2013 and Yan et al., (2017), the range of flexural strength demonstrated by the composites is adjudged adequate for safe handling during installation and durability in service.

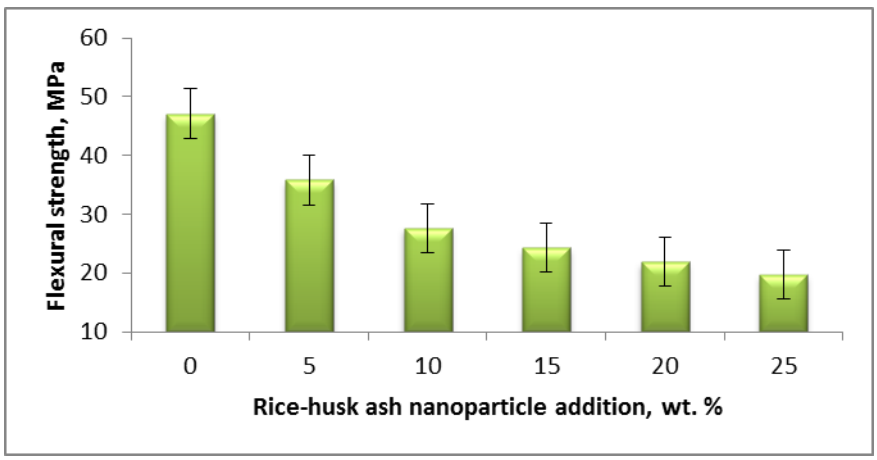


Figure 6. Influence of rice-husk ash nanoparticle addition on flexural strength

The hardness induced in the composites at varied rice-husk ash nanoparticle addition was evaluated through Vickers hardness technique and the result is illustrated in Figure 7. A modest level of hardness in the range of 25.1-18.5 HV was exhibited by the composites at 5-15 wt. %. However, significant decrease in hardness was observed at 20-25 wt. % filler addition corresponding to 15.1-13.4 HV. This can be attributed to weakening of cross-linking strength due high volume fraction of the filler within the matrix.

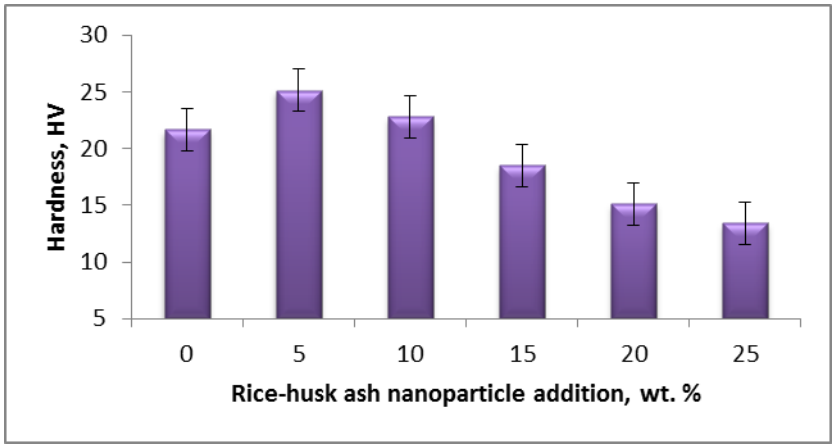


Figure 7. Hardness of rice-husk ash reinforced epoxy resin composites

Dynamic stability characteristics of the composites at varied rice-husk ash addition are shown in Figure 8. The impact energy performance reduces as the filler volume fraction increases corresponding to a range of 4.3-2.9 J. Progressive reduction in wettability between the matrix and reinforcement is assumed to be responsible for the behaviour. However, the impact energy demonstrated at 5-15 wt. % rice-husk ash addition is adjudged sufficient for a material intended for acoustic panel application.

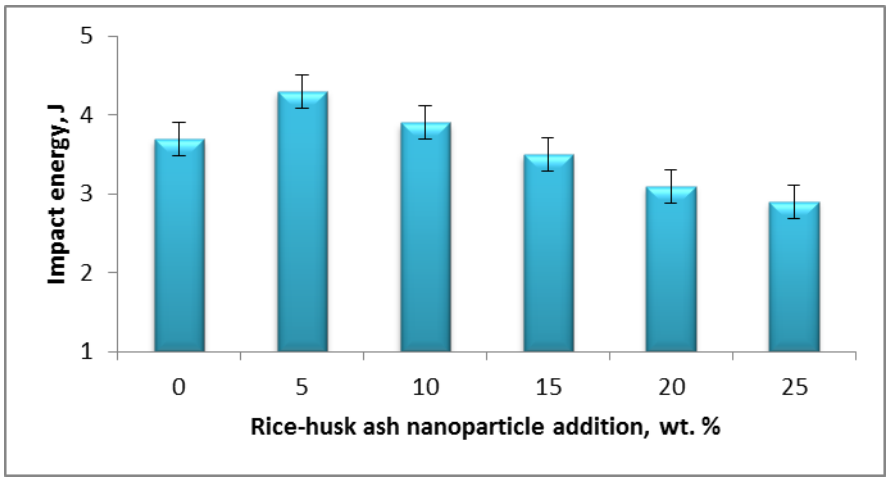


Figure 8. Toughness of rice-husk ash reinforced epoxy resin composites

4.0 CONCLUSION

Rice-husk ash nanoparticle (RHA_{NP}) reinforced composites were successfully synthesised and characterised for noise pollution mitigation application. The composites demonstrated adequate acoustic characteristics at 5-15 wt. % filler addition represented by the Noise

Reduction Coefficient (NRC) in the range of 0.654-0.805. This translates to 71.6% sound decibel mitigation capability of the composites. This is attributed to the volume of interconnected pores induced within the epoxy matrices by rice-husk ash nanoparticles. The composites also exhibited sufficient damage-free installation mechanical properties within 5-15 wt. % RHA_{NP} addition. Value-addition coupled with cleaner environment appears to be the major contributions of this study while the prospect for noise pollution mitigation is also significantly enhanced.

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