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Preparing Eco-friendly Composite from End-life Tires and Epoxy Resin and Examining Its Mechanical, and Acoustic Insulation Properties

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ABSTRACT

The recycling of the enormous number of used tires that are discarded annually after the end of their service is a high-priority issue in order to conserve the environment and reduce the raw material costs of products, particularly in cases where high strength requirements are not necessary. In this study, crumbed tire rubber (CTR) was used as a filler with different weight fractions (10%, 20%, 30%, and 40%) to prepare CTR/epoxy composites. Mechanical, thermal, and acoustic insulation properties were tested to gather sufficient data on the development of these properties with increasing CTR content. The results indicate a decline in mechanical properties with increasing CTR content. The composite with 40 wt. % CTR showed a decrease in hardness, tensile strength, and flexural strength compared to neat epoxy by 75%, 70%, and 75% respectively. Additionally, the thermal conductivity of this composite was 36.3% higher than that of epoxy. Finally, the acoustic insulation test for the composite with a 40% CTR weight fraction showed improved sound insulation over a wide range of applied frequencies (0-10000) Hz.

Keywords: *Crumbed rubber, Acoustic insulation, Eco-friendly materials, Tire recycling*

1. INTRODUCTION

Nearly 1 billion tires reach the end of their usable lives each year, and more than half of them are simply thrown away [1]. Tires are non-biodegradable products due to their complex physical and chemical composition, as well as their three-dimensional cross-linked structure that is formed during the irreversible vulcanization process. These waste products are classified as hazardous and dangerous materials, with toxic impacts on the environment, society, and the economy, as they do not decompose and are highly flammable. Moreover, the accumulation of tires in landfills provides an ideal breeding ground for mosquitoes and mice [2, 3]. Scrap tires are frequently consumed in energy recovery management techniques, it is a relatively safe practice to use as fuel in power plants, paper mills, and cement kilns. However, new solutions are still needed because of the high cost related to expensive furnaces, environmental concerns, and efficiency, so finding affordable techniques for recycling scrap tires must be a top priority [4]. One of the most commonly suggested solutions to deal with scrap tires is merging with concert, asphalt, polymers, and other products after downsizing to small-size particles. Downsizing tires is a technologically complex process using specialized machinery that is capable of shredding and granulating tires and removing textiles and steels by using pneumatic separators and electromagnets, where the final downsizing process could vary from 0.3 mm to 75 µm [4, 5]. Many previous studies have been conducted to evaluate the properties' development of concrete, cement mortar, and asphalt after adding grounded tires [6-9]. Blending grounded scrap tires with polymer matrices serves two purposes.

The first is associated with lowering material costs, which is very common in applications that are not necessitated to meet very high thermal or mechanical performance criteria. The second goal is to improve the specific properties, such as thermal, toughness, and acoustic absorption. etc. Composite materials of grounded tires and different types of thermoset polymers such as; polyurethanes, epoxy resins, polyester resin, and melamine urea formaldehyde plywood, also have been investigated by many researchers [10, 11]. However, previous studies have shown that mixing ground tires with virgin polymer can result in a decrease in the mechanical properties of the composite due to weak bonding between the tire rubber and polymers. Therefore, various physical and chemical treatments have been conducted to enhance the bonding strength between the two phases [12]. Despite the expected decline in mechanical properties of epoxy/crumb tire rubber (CTR) composites, there is a significant need to document the development of these properties and explore the thermal and acoustic properties of epoxy/CTR composites for potential future applications where high strength is not required and cost-effectiveness is a priority.

2. MATERIAL AND METHODS

2.1. Materials

The materials used for the planned work include a two-part epoxy resin made by SIKAAG Company Swiss, it is prepared by mixing two parts (A and B) in a ratio of 2:1. The resin is solvent-free, low viscosity, and has a density of approximately 1.06 Kg/L [13]. Crumbed tire rubber (CTR) with a particle size range of 0-1 mm and a density of (1.1 – 1.3) gram/cm^3 density. The CTR was produced by Abraj Alkut for Rubber Products, Iraq. The constituents of CTR, including the rubber matrix and additive elements, as well as their testing methods, are shown in Table 1.

Table 1 Crumbed tires rubber CTR constitutions

Content	Percentage	Test Specification
Ash	(5.0-15)	D297
Max. Fibers	0.5	D5603
Max. Steel Wires	1	D5603
Max. Heating Loss	1	D1509

2.2. Samples Preparation

Epoxy/ CTR composite with varying CTR weight fractions (10, 20, 30, 40) wt. %, in addition to planning epoxy specimens have been prepared by hand lay-up method by using a rubbery mold. The specimens were prepared to meet correlated testing standards requirements, meanwhile (240 mm x 240 mm x 6 mm) square dimensions specimens were prepared for performing acoustic insulation tests. The tests conducted included hardness tests, tensile tests, bending tests, impact tests, and thermal conductivity tests.

2.3. Testing Characterization

Fourier transform infrared spectroscopy FTIR inspection (ASTM E1252) has been performed for CTR over (400 - 3000) cm^{-1} wavenumber by using FTIR device type TENSOR-27, produced by Bruker Optics Company. Shore D hardness tests were performed according to (ASTM D2240), five reads have been taken to get the average value for each specimen. Tensile tests (ASTM-D638) were performed by 50 KN load capacity, computerized universal testing instrument, LARYEE, China, with 2 mm/min crosshead speed. Three tests have been performed for each CTR weight fraction. Three-point flexural tests (ASTM-D790) have been performed by the same universal testing instrument; three tests have been performed for each CTR weight fraction. Lee-Disc method has been used to determine thermal conductivity. Two tests have been performed for each CTR weight fraction. Finally, acoustic insulation tests were executed according to (ASTM - E336) by using a locally made device that is shown in Figure 1.

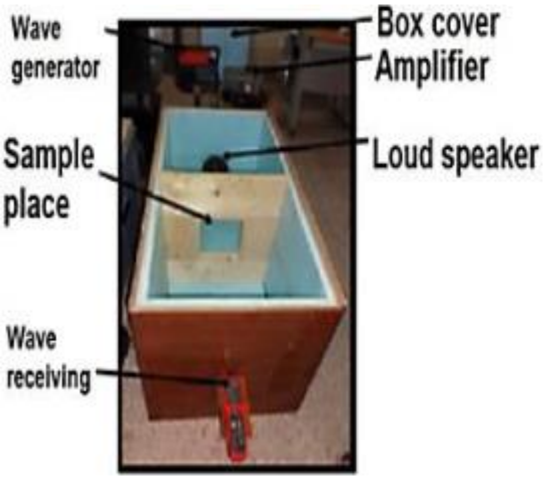

Figure 1 A) Acoustic insulation device, B) Universal testing instrument

3. RESULTS AND DISCUSSION

3.1. FTIR Inspection

In order to examine the chemical composition of CTR and ensure the absence of contaminants, an FTIR test was conducted on CTR powder. The results of the FTIR test can be discussed with reference to Figure 2.

The most significant peaks of FTIR transmittance spectroscopy for CTR were; 2960 cm^{-1}, 2869 cm^{-1} corresponding to C-H aliphatic groups, usually appears at range (3000 – 2800) cm^{-1}, 1606.66 cm^{-1} corresponding to C=C, usually appears at range (1680 - 1600) cm^{-1}, 1180.95 cm^{-1} corresponding to S-O-C, 1080 cm^{-1} corresponding to C-O-C, and the peak at 734.01 cm^{-1} corresponding to (C-S) bond that usually appears at range (775-570). These mentioned peaks are in agreement with similar reported FTIR spectra in previous studies [12,14].

3.2. Hardness

The development of structural hardness with increasing CTR weight fraction is shown in Figure 3. It can be noticed that there is a decrease in hardness with increasing rubber content weight fraction. This decline in hardness may be related to the lower hardness of crumbed rubber compared to the epoxy matrix. Additionally, the weak bonding between CTR and epoxy may be the reason behind the declining structural strength with increasing CTR. Furthermore, an increase in filler weight fraction is usually associated with an increase in voids and porosity, which have negative effects on the hardness [15].

3.3. Tensile Tests

The stress-strain behaviour of epoxy and composites under tensile tests is demonstrated in Figures 4 and 5. Based on the figures, it can be observed that the mechanical properties, such as maximum tensile strength, modulus of elasticity, and elongation percentage, of epoxy, are significantly higher than those of epoxy/CTR composite materials. Furthermore, these mechanical

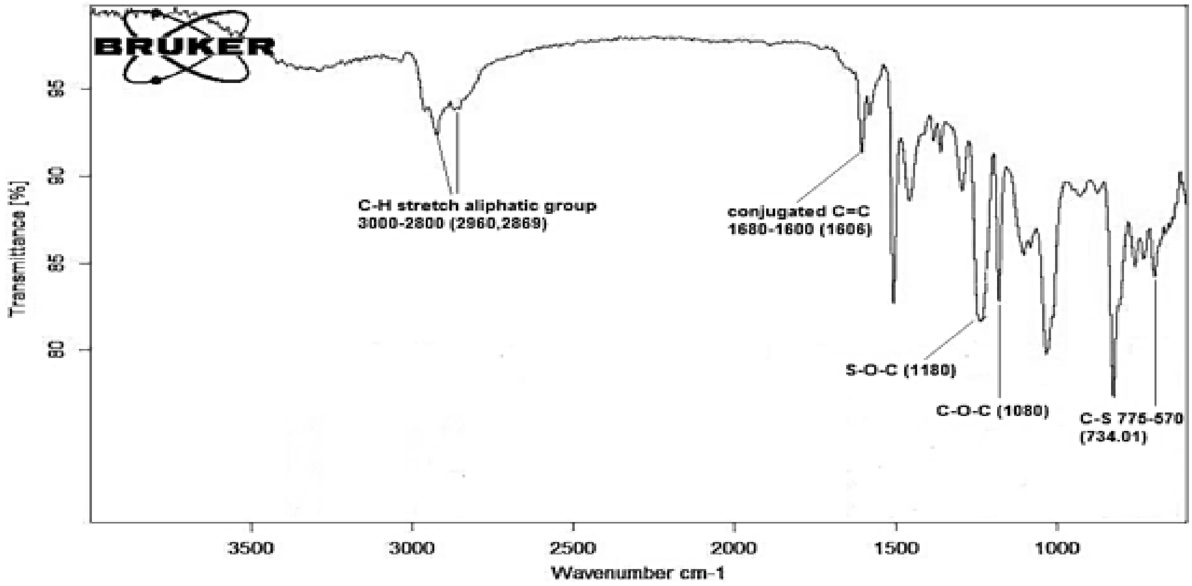

Figure 2 Shore D hardness VS. CTR weight fraction

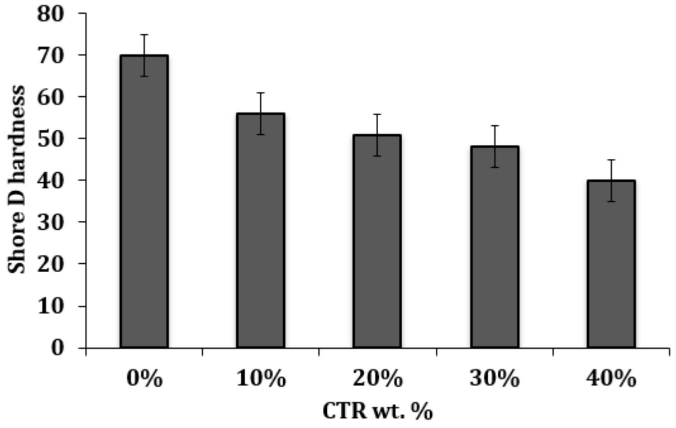

Figure 3 Shore D hardness VS. CTR weight fraction

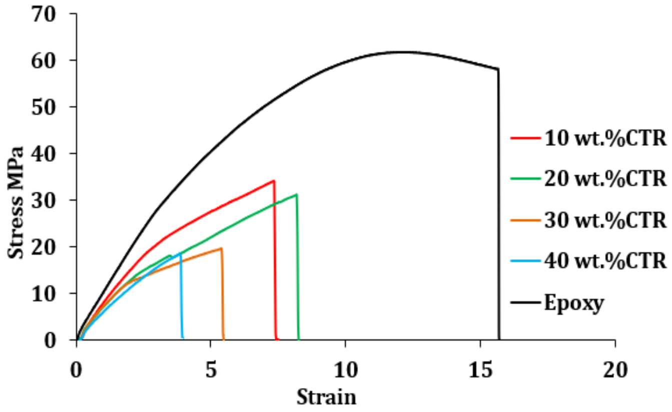

Figure 4 Strain of epoxy and epoxy/CTR composites

properties decline with increasing CTR weight fraction. The main possible reasons for this deterioration are the low mechanical properties of crumbed rubber compared to epoxy and the weak bonding strength between epoxy and the rubber surface. This means that the applied load is primarily supported by the epoxy, so with increasing CTR weight fraction within the specimen's cross-section, the applied load amplifies the stresses and accelerates failure.

Additionally, as mentioned earlier, increasing CTR weight fractions can lead to an increase in porosity, voids, and spots of CTR particle accumulations, resulting in a non-uniform structure. This non-uniformity may be attributed to non-regular mixing and pouring into the mold during specimen preparation [16].

3.4. Flexural Strength

A three-point loading style was used to evaluate the development in flexural strength of epoxy and epoxy/CTR composites. The results are shown in Figure 6.

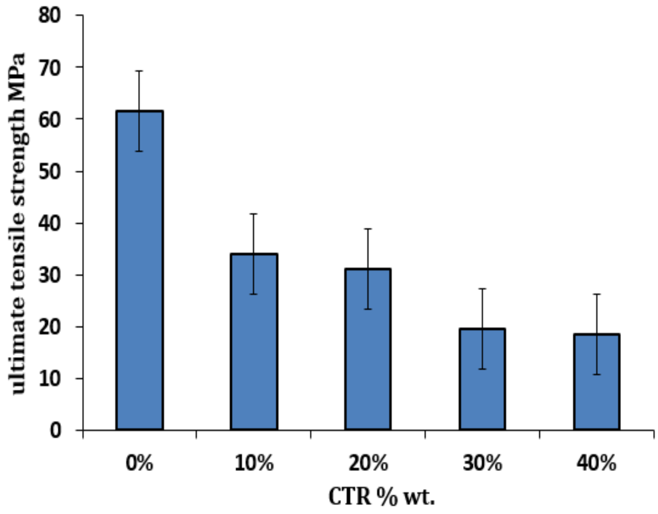

Figure 5 Ultimate tensile strength of epoxy and epoxy/CTR composites

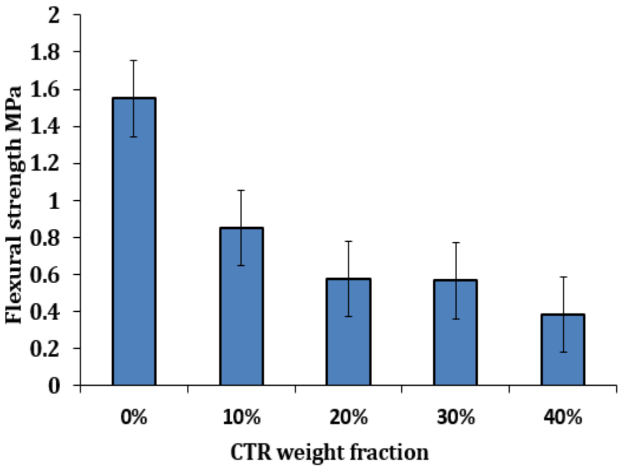

Figure 6 Flexural strength of epoxy and epoxy/CTR composite

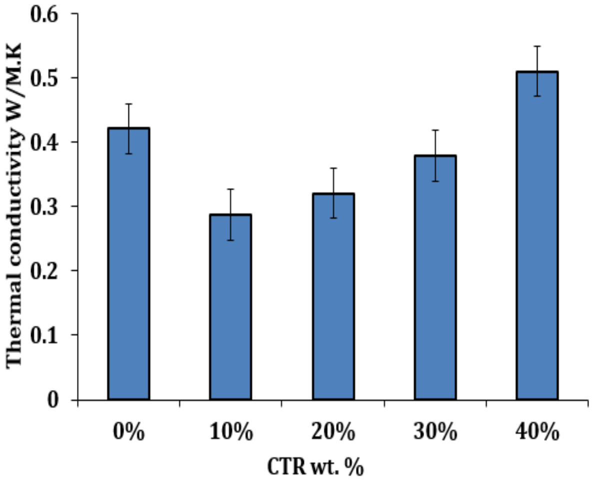

Figure 7 Thermal conductivity VS. CTR weight fraction

Maximum compression stresses are generated at the upper surface directly beneath the applied load point, while maximum tensile stresses develop at the opposite surface of the specimen directly under the loading point [17, 18]. The results demonstrate an expected inverse relationship between CTR weight fraction and flexural strength, and the explanation for this behaviour is related to the alterations in the microstructure, as mentioned in the tensile strength section.

3.5. Thermal Conductivity

The results of thermal conductivity tests for epoxy and epoxy/CTR composites are illustrated in Figure 7. The thermal conductivity of composite materials primarily depends on the thermal conductivity of their ingredients, following the rule of mixture.

Additionally, the presence of porosity and voids within the composite structure can also affect thermal conductivity. Based on the results chart, it can be observed that the composite with a 10% CTR weight fraction has lower thermal conductivity than pure epoxy. This may be attributed to the high porosity within the composite structure, which is typically associated with specimen preparation using the hand lay-up method. Furthermore, it can be noticed that the thermal conductivity of the composite increases with increasing CTR percentage. This can be explained by the higher thermal conductivity of CTR compared to pure epoxy. Although natural rubber has low thermal conductivity, other constituents of CTR, such as fibres and modification additives, particularly carbon black, can effectively enhance the thermal conductivity of CTR. This explanation is supported by previous research where a significant increase in the thermal conductivity of natural rubber was reported by adding carbon black, reaching as high as 0.42 W/m·K [19].

3.6. Acoustic Insulations

The acoustic absorption tests for epoxy and epoxy/40 wt. % CTR, conducted over a wide range of frequencies, are shown in Figure 8. It can be observed that the intensity of sound waves passing through the composite sheet is lower than that passing through pure epoxy across all frequencies (0-2000 Hz). This indicates that the composite has better sound insulation properties compared to pure epoxy. This improvement can be attributed to the rubber particles' ability to absorb a portion of the sound wave energy. The ability of a material to absorb sound is connected to its capacity to consume this energy within its structure by converting it into mechanical energy or heat energy, or as a result of friction between the constituents of the composite [20].

4. CONCLUSION

1. It is possible to prepare a low-cost, environmentally friendly composite with acceptable mechanical properties using used crumbed tire rubber (CTR).
2. Incorporating crumbed tire rubber (CTR) as filler material with the epoxy matrix can decrease mechanical strength, increase thermal conductivity, and improve the sound insulation of the composite.
3. Crumbed tire rubber (CTR) can be used in acoustic insulation applications.

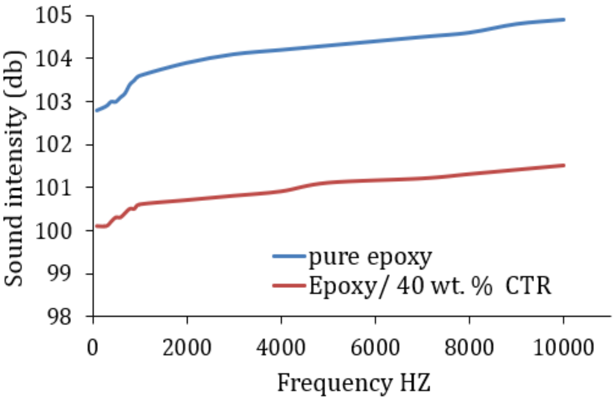

Figure 8 Acoustic attitude of epoxy and epoxy/ 40 wt. % CTR composite

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