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RESEARCH ARTICLE

THERMAL AND ACOUSTIC INVESTIGATION OF ECO-FRIENDLY BULDING MATERIAL FROM NR/SBR BLEND LOADED WITH CEMENT KLIN DUST

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Abstract

In this paper the effect of cement klin dust loading on the thermal, swelling, mechanical and acoustic behavior of NR/SBR blend were investigated. The obtained results of eight different compositions for NR/SBR blend with (0, 20, 40, 60, 80, 100, 150 and 200) phr of cement kiln dust were compared. From the current investigation, it was found the incorporation of CKD waste into the NR/SBR blend increases the thermal conductivity and decreases the swelling parameters. It was also found that mechanical parameters such as tensile properties, hardness and compression set exhibited some extent of improvement with the addition of CKD.

INTRODUCTION

Blending two or more polymers produces new materials with mixed properties has been extensively developed in several industries [1, 2]. Natural rubber NR crystallizes under stretching, so that it resists deformation and enhances its strength while many synthetic rubbers such as styrene butadiene rubber SBR-1502 does not crystallize. Mixtures of NR and SBR are quite often used in order to get desired technological properties [3].

Large quantities of industrial by-products are produced every year by various industries. The main goals of environmental protection agencies and governments are to seek ways to minimize the dual problems of disposal and health hazards of these by-products(waste materials) such as fly ash, silica fume, slag and cement kiln dust (CKD). Efforts on a large scale have been made by the polymer industry to develop cost effective techniques to convert industrial waste into processable forms. Utilization of this waste material as building materials or Portland cement substitute appears to be a viable solution not only to such pollution problem, but also to the problem of economical design of buildings. The increase in the popularity of using environmentally friendly and low cost construction materials in building industry brings the need for searching more innovative, flexible and versatile composites**.** The waste material also used to as filler integrated with a rubber matrix to improve both the thermal and mechanical performances of new building products

The need to optimize the energy behavior of buildings' has been enforced by the scientific researchers because thermal insulation in buildings is an important factor to achieving thermal comfort for its occupants. As more energy efficient buildings could reduce the quantities of fossil fuels consumed and thereby reduce the amount of carbon dioxide and Sulfur dioxide emitted into the atmosphere. Insulation reduces unwanted heat loss or gain and can decrease the energy demands of heating and cooling systems. [4, 5]

Acoustical material plays a number of roles that are important in acoustic engineering such as the control of room acoustics, industrial noise control, studio acoustics and automotive acoustics. Sound absorptive materials are generally used to counteract the undesirable effects of sound reflection by hard, rigid and interior surfaces and thus help to reduce the reverberant noise levels [6, 7]. The aim of this paper is to determine the effect of CKD loading on the thermal, swelling, mechanical, and acoustic properties of NR/SBR blend matrix.

2. EXPERIMENTAL WORK

2.1. Materials

All materials used in this research come from Alexandria tire Manufacture factory, Egypt. The structure of these materials is as follows

- Natural Rubber (NR), with specific gravity 0.934 g/cm^3.
- Styrene-butadiene rubber (SBR) describes families of synthetic rubbers derived from styrene and butadiene [1]. These materials have good abrasion resistance and good aging stability when protected by additives with specific gravity 0.913 g/cm^3.
- Zinc oxide (ZnO) as activators with specific gravity at 15 ^{o}C is 5.55–5.61 g/cm^3
- Stearic acid: melting point 67–69 ^{o}C; specific gravity 0.838 g/cm^3
- Benzothiazyl Disulfide. (MBTs) as accelerator with specific gravity 1.29–1.31 g/cm^3, melting point 1485 ^{o}C and order less powder
- Antioxidant N-isopropyl N'-phenyl-1,4 phenylenediamine (IPPD): purple gray flakes have density 1.17 g/cm^3.
- Elemental sulfur (S) with fine pale yellow powder and specific gravity 2.04–2.06 g/cm^3.
- Naphthenic oil, with specific gravity 0.94–0.96 g/cm^3 at 15 ^{o}C, viscosity 80–90 poise at 100 ^{o}C and deep green viscous oil.
- Cement kiln dust, is the fine-grained, solid, highly alkaline waste removed from cement kiln exhaust gas by air pollution control devices.

2.2. Rubber preparation

The samples used to perform experimental tests were prepared according to [ASTM C11361; 99] with the recipe presented in Table 1. Mixing and mastication of all ingredients are conveniently done using two roll mills. The mixing operation was carried out in two stages. The first one called master batch consist of rubber, activators, antioxidant, antiozonants, reinforcing agent (CKD as filler) and the large amount of processed oil, 10phr to assimilate high filler content and have optimum dispersion and coupling with rubber. The second stage is called the final batch. It consists of the previous master batch, curing agent (Sulfur and accelerators). These materials are added at the end of the process to prevent pre-vulcanization which may occur due to the elevated temperatures, the test specimens were die cut from test slabs. Vulcanization of the rubber compounds was carried out in an electrically heated uniaxial press between stainless steel plates at 150 ^{o}C and pressure 150 bar for a dwell time of 45 min. Samples were prepared by different shapes of molding according to the measurement types.

2.3. Characterization

2.3.1. Thermal Conductivity Measurements

KD2 – Pro portable thermal conductivity meter was used to measure the thermal conductivity of investigated samples according to transient method techniques. This test is done on cubic samples of side length 5 cm at room temperature according to the standard [ASTM D 5334; 08].

2.3.2. Specific gravity

This test is carried out according to [ASTM D792-08]. Samples prepared with dimensions 2 x 2 x 0.2cm. In this test the specimens are weighted in air and then weighted suspended in water. The Specific gravity of material (ρ) is calculated using the following equation [8].

$$\rho = \frac{w_a}{w_a - w_s} x\ water\ specific\ gravity \qquad (1)$$

W_a is weight of sample in air, and W_s is weight of sample suspended in water.

3.3.3. Swelling Parameters

Samples were immersed in toluene at room temperature (25 ^{o}C) and wiped to remove surface water before weighing. The weights of the samples were recorded at different times. The reported results were averaged of three shapes for each sample. The swelling parameters of blends were calculated by the following swelling data.

1) The degree of swelling (Q%) for the samples(i.e. percentage of weight gain) was calculated as follows [9,10]:

$$Q(t)\% = \left(\frac{m_t - m_0}{m_0}\right) x100 \qquad (2)$$

Where m_t and m_o represent the sample weights at time t, and before swelling respectively.

2) **Swelling index**(S) (Volume swelling percentage) was calculated using the following equation [11].

$$S = \left[\left(\frac{m}{m_o}\right) - 1\right]\frac{\rho_c}{\rho_s} \times 100 \qquad (3)$$

m Is the sample mass after swelling for 24hr. ρ_c and ρ_s are the densities of the specimen and the solvent, respectively.

3) **Crosslink density**

From equilibrium swelling measurements, the formation of cross-linking is executed by determining its density via the average molecular weight of the polymer between cross-links (M_c) according to Flory–Rehner relation [12, 13]:

$$M_c = -\frac{\rho_p V_s V_r^{\frac{1}{3}}}{\ln(1 - V_r) + V_r + \chi V_r^2} \qquad (4)$$

Where ρ_p is the density of rubber; ρ_p (NR/SBR) = 0.913 g/cm^3, V_s is the molar volume of the solvent (toluene) = 89 cm^3/mole, χ is the interaction parameter of rubber blend, V_r is the volume fraction of swollen rubber and given by the following relation

$$V_r = \frac{1}{1+q} \qquad (5)$$

Where q is defined as grams of solvent per gram of rubber hydrocarbon and calculated by

$$q = (m - m_d)/\, m_d \qquad (6)$$

Where m_d is the deswollen weight of the sample. The crosslink density, υ_e, is defined for a perfect network as the number of elastically active network chains per unit volume and is given by [14]:

$$\upsilon_e = \rho_p N_A / M_c \qquad (7)$$

Where N_A is the Avogadro number.

2.3.4.Mechanical properties measurements

1) Stress-strain curves were carried out in a tensile testing machine (SHIMADZU AG-X) according to ASTM D 412-06 test method using dumb-bell shaped samples at a uniform speed 200 mm/min. Each sample was measured three times and the data was averaged.

From mechanical measurements, The crosslink densities υ were also determined from the elastic rubbery moduli of the samples according to the rubber elasticity theory modified by Nielsen[10]

$$\upsilon = \frac{E}{3RT} \qquad (8)$$

Where υ the number of moles of chains per cm^3 (by multiplying the cross link density by Avogadro's number, its unit becomes cm^{-3}), R is the gas constant, T is the temperature in Kelvin (300K) and E is the elastic modulus obtained from the stress-strain curves.

2) Hardness measurements

The hardness was determined using Shore A durometer according to ASTM D 2240-07

3) Compression measurements

Compression set test (ASTM D395) was performed on the standard test specimen of cylindrical shape of 25 ± 0.1 mm diameter and 12 ± 0.5 mm thickness vulcanized by compression molding method. The test specimen shall be placed between the plates of the compression device with the spacers on each side of it, allowing sufficient clearance for bulging of the rubber when compressed. The percentage of the compression employed shall be25% of the original thickness for 24hr. After the compression was released the sample left for 30 min, after this reset time the final thickness was measured by an electronic digital caliber of 0.01 mm accuracy. The compression set % is defined as:

$$C\% = \frac{t_0 - t_1}{t_0 - t_s} x\ 100 \qquad (9)$$

Where $t_\circ$ is the original thickness of the sample, t_1 is the thickness of the sample after removing compression.

2.4. Acoustic Measurements (*Sound Absorption Coefficient)*

The sound absorption coefficient is measured using the two-microphone method where a sample of the material to be tested is placed in a sample holder and mounted to one end of a straight tube. A rigid plunger with an adjustable depth is placed behind the sample to provide a reflecting surface. A sound source, typically a high-output acoustic driver, is connected at the opposite end of the tube. A pair of microphones is mounted flush with the inner wall of the tube near the sample end of the tube. The sound absorption coefficient is measured according to ASTM E1050

3.Results and Discussion

3.1. Effect of CKD on the thermal properties of NR/SBR blend:

Figure 1 shows the variation of thermal conductivity with CKD loading NR/SBR blend. It is clear from the figure that thermal conductivity increases with the increase in concentration of CKD. It is observed that until the sample of 60 phr CKD with thermal conductivity (0.2 W/m.K), the composite lies in the range of thermal insulating materials according to the Egyptian code of thermal insulating materials. Even the highest value of the thermal conductivity 0.35 W/m.K for a sample of 200 phr CKD lies blew that of concrete and Brick materials.

Table (1) Composition of NR/SBR blend loaded with different concentration of CKD

Ingridents(phr*)	samples							
NR	50	50	50	50	50	50	50	50
SBR	50	50	50	50	50	50	50	50
Cement by-pass	0	20	40	60	80	100	150	200
Stearic acid	2	2	2	2	2	2	2	2
Zinc oxide	5	5	5	5	5	5	5	5
Processing Oil	10	10	10	10	10	10	10	10
MBTs	2	2	2	2	2	2	2	2
IPPD(4020)	1	1	1	1	1	1	1	1
Sulphur	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

* Part per hundred parts of rubber by weight.

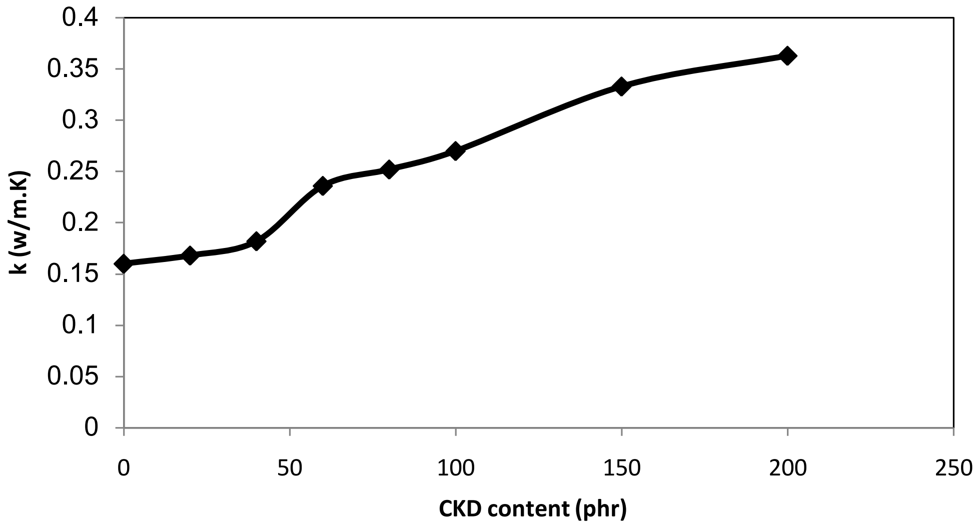

Fig. 1. The variation of thermal conductivity with CKD content loaded NR/SBR blend.

3.2. Effect of CKD on the density of NR/SBR blend:

The dependence of density on CKD content for NR/SBR blend is presented in Figure 2. It is obvious that the density has the same trend as thermal conductivity. The highest density is also below that of brick and concrete.

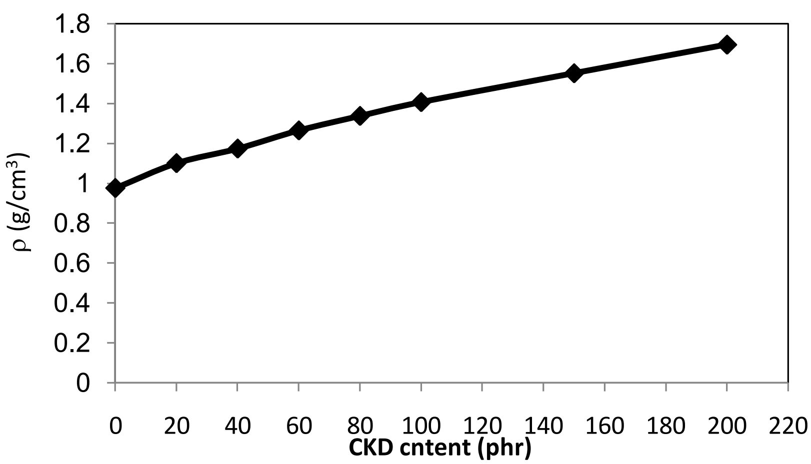

Fig.2. Variation of density with CKD content loaded NR/SBR blend.

3.3. Swelling properties

1) Sorption process and swelling parameters

Diffusion mechanism in rubber is basically related to the ability of the rubber to provide pathways for the solvent to progress in the form of randomly generated voids [10]. Figure 3 shows the plot of the degree of swelling Q% against swelling time (t). In this figure, all the sorption curves for all samples are similar in nature, and have sigmoidal-shaped profiles (i.e. Q% increases with time until a certain point, after which maximum value of swelling Q_m was obtained). It is clearly manifested, that the unfilled NR/SBR blend exhibits the highest solvent uptake which decreases as the filler increases. This is due to the void formation decreases with filler addition [15].

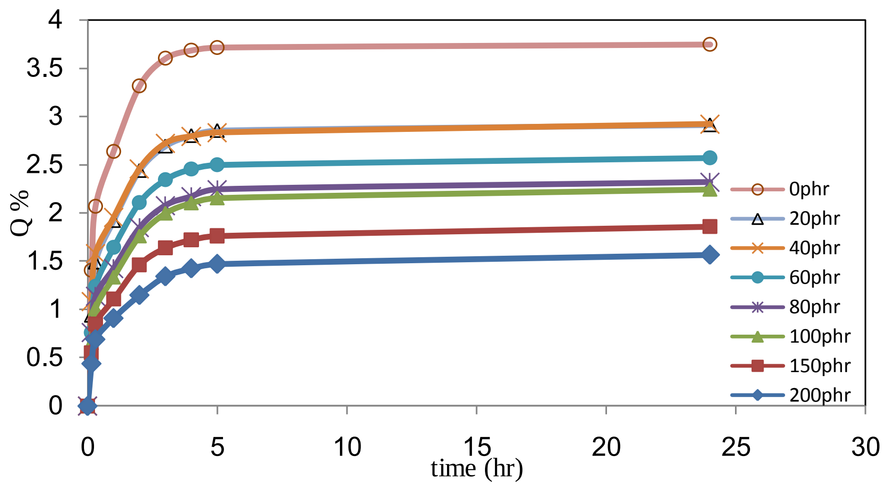

Fig. 3. Sorption curves for NR/SBR blend loaded with different CKD concentration.

2) Determination of swelling index and crosslink density

Figure 4and 5 shows the dependence of the crosslink density and swelling index on variation CKD content for NR/SBR blend. From this figure, one can observe that the swelling index and cross linking density has the opposite trend (i.e. The higher the Crosslink density of the rubber the lower the swelling). This means that the formation of more cross-links due to the increase in CKD leads to the low solvent uptake [16, 17]. This measurement emphasizes the interaction between this filler and rubber blends. So, the addition of CKD filler to rubber blend has the significant improvement in organic resistance.

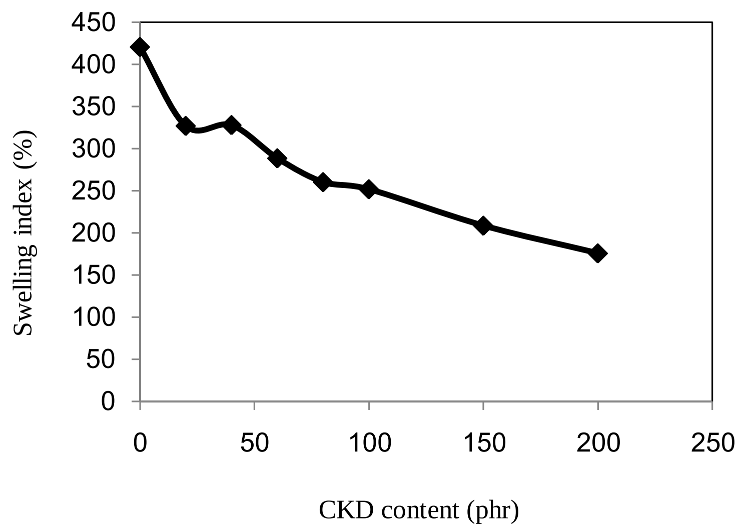

Fig. 4. The dependence of swelling index on variation of CKD content.

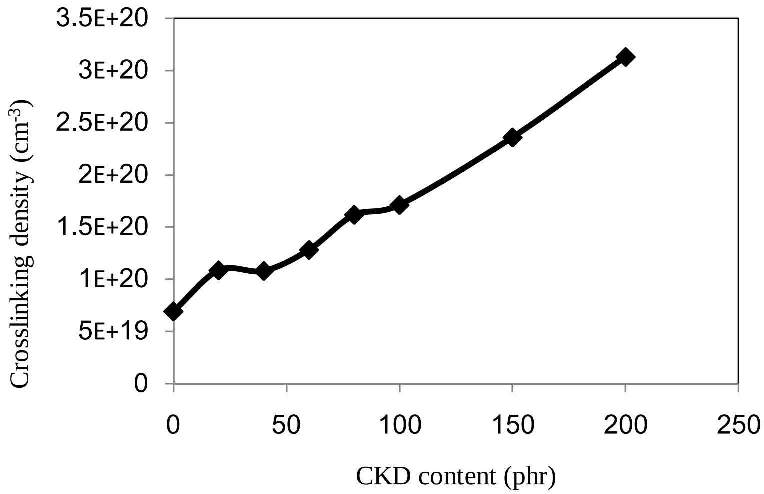

Fig. 5. The dependence of crosslinking density on variation of CKD content.

3.4. Mechanical properties.

1) Stress-strain behavior

The stress-strain relationships for all investigated samples are shown in Figure 7. From the figure, one can obtain some mechanical parameters such as tensile modulus, tensile strength and elongation at break. Tensile modulus was determined from the linear portion of the stress-strain curve. From this figure, it is clear that the tensile strength of pure NR/SBR blend has the minimum value. It is also noticed that the addition of CKD results in the increase in tensile modulus, tensile strength and elongation at break as shown in the figure 7(a-c). So the mechanical properties were enhanced by the addition of CKD. This is attributed to the improvement in the interfacial bonding between CKD and the matrix (NR/SBR) through the significant increase of crosslink density and physical interaction between them. The reinforcement of elastomers by particulate fillers has been studied in depth in numerous investigations [10, 11].

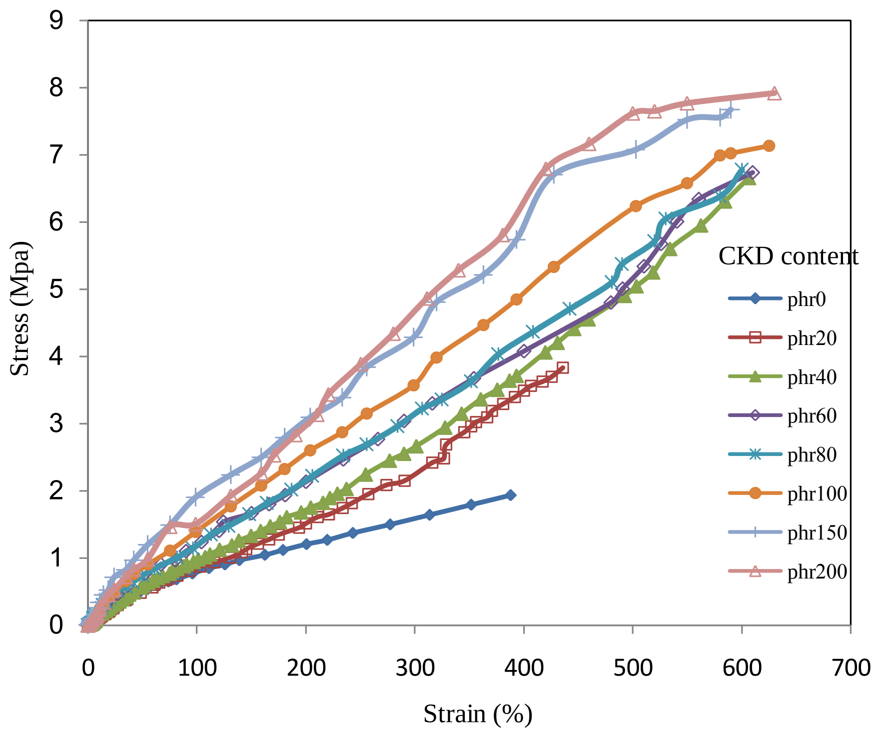

Fig. 6. Stress- Strain relation for CKD loaded NR /SBR blend.

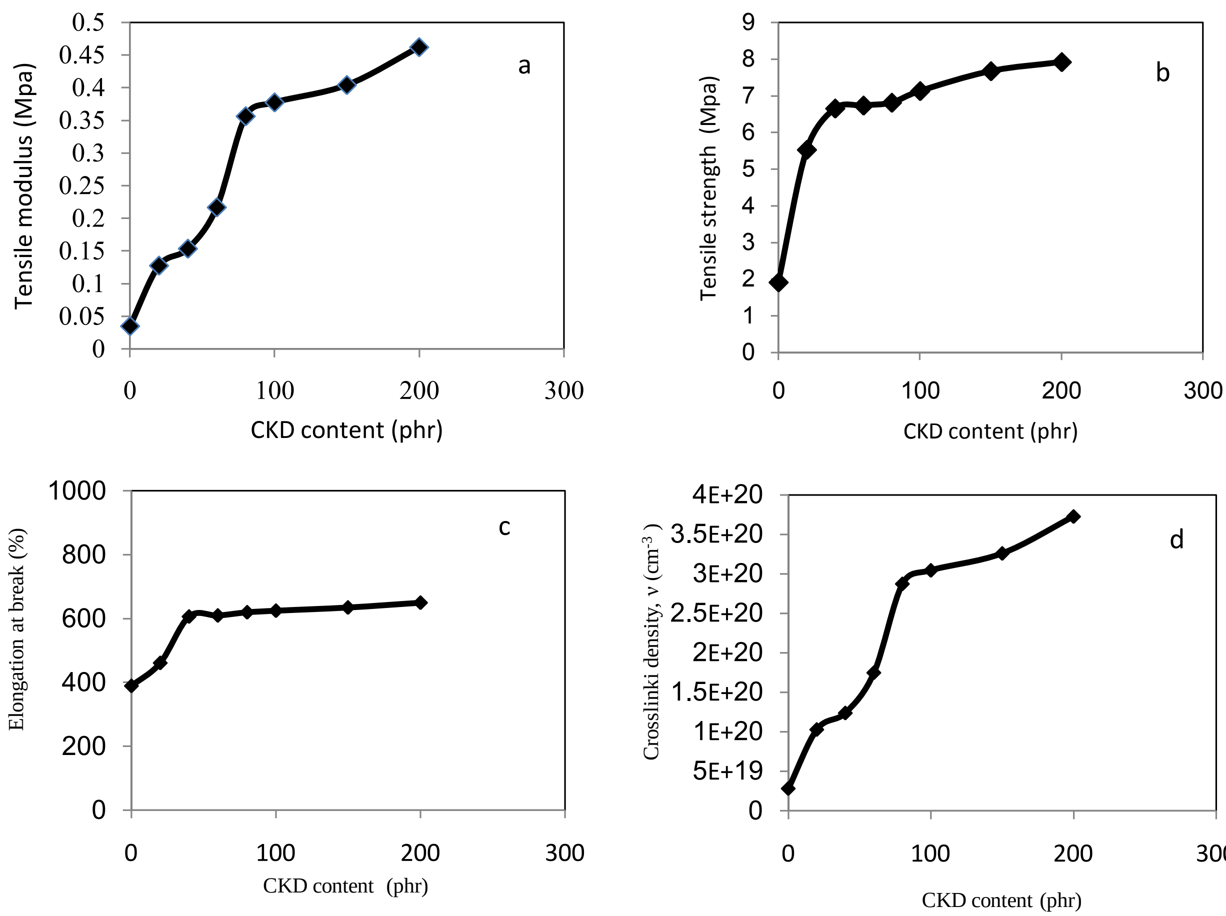

Fig. 7. The effect of CKD for NR/SBR blend on a) tensile modulus b) tensile strength c)Elongation at break d) Crosslink density

The calculated values of the crosslink densities from the elastic rubbery moduli of the samples are shown in figure 7d. It is found that the crosslink density gives the same trend and order of magnitude as that measured in the swelling measurement.

2) Hardness

The hardness of the unfilled and CKD-filled NR/SBR composites is presented in Figure 8. One can see that the hardness increases as CKD content increases which can be attributed to the increase in crosslink density as previous mentioned in swelling and mechanical measurements.

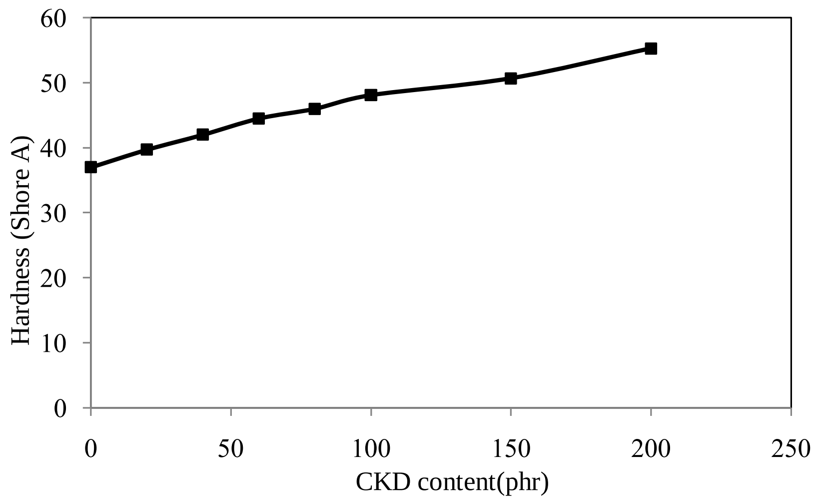

Fig.8. The variation of hardness with CKD loading.

3) Compression set measurement

The variation of the compression set percentage (C %) as a function of CKD loading for NR/SBR filled blend are presented in Figure 9. From this figure, it is clear that in the case of pure gum the compression set is low. While as CKD loading increases, the compression set increases. Because of increasing the crosslink density and decreasing the mobility of the rubber chains, consequently, induce stiffness in the filled compounds [18]. So, the specimen did not recovered to its original thickness and high percentage of compression set is obtained for high concentration of CKD. This results confirms the previous one

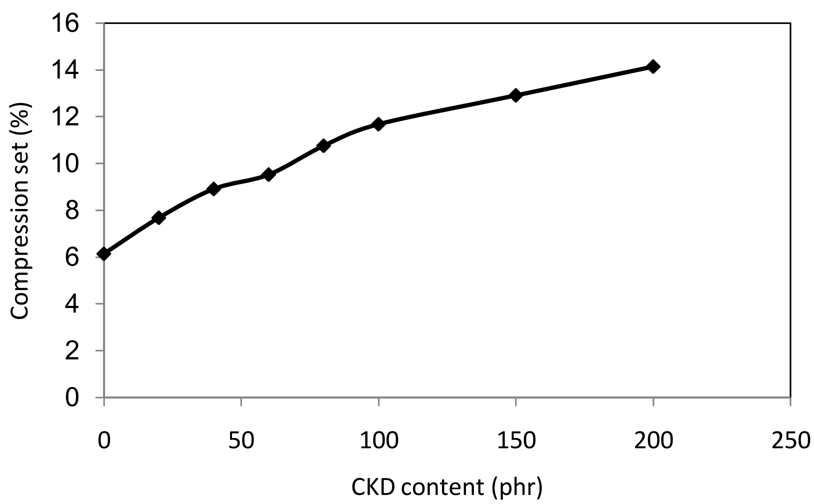

Fig. 9. The variation of compression set % with CKD loading.

2.4. Acoustic Measurements (*Sound Absorption Coefficient)*

The dependence of sound absorption on different frequency for NR/SBR blend loaded CKD is represented in Figure 10. The average sound absorption coefficients (α_{avg}) of all samples at low and high frequencies are listed in table (2).

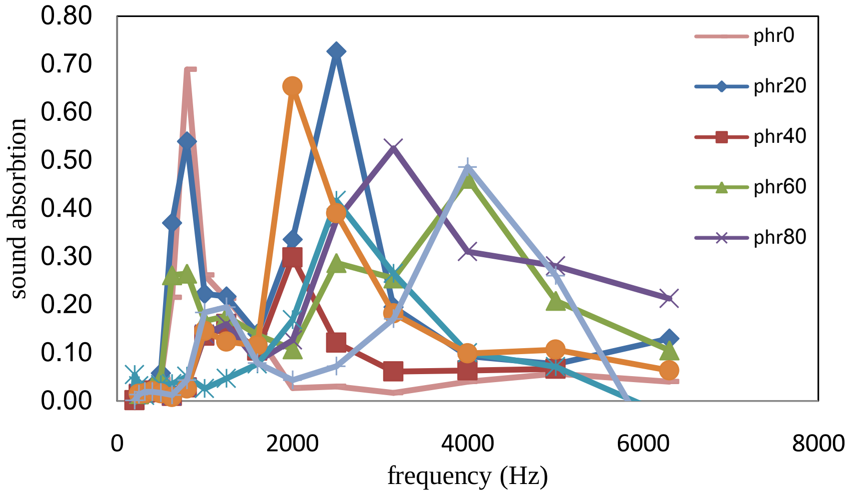

Fig. 10. The variation of sound absorption with different frequency for NR/SBR blend loaded CKD

From table 2, it can be noticed that sound absorption at low and high frequencies decreases than that of the reference (0 phr CKD) because of the decrease in sample voids due to the increase of the filler content. It is also notice that the sound absorption coefficient at high frequency is better than that at low frequency for all samples.

Table (2) the average sound absorption coefficients (α_{avg}) at low and high frequencies

CKD content (phr)	α_{avg} (Hz)	
	Low frequency	High frequency
0	0.12	0.3
20	0.13	0.24
40	0.04	0.09
60	0.09	0.22
80	0.04	0.2
100	0.03	0.2
150	0.04	0.17
200	0.05	0.14

Conclusion

The purpose of the investigated study is to achieve the possibility of using CKD (waste material) as an alternative filler for rubber blend. The present work confirms the successful synthesis NR/SBR blend loaded with different concentration of this filler. It was found that the addition of CKD to (NR/SBR) blend has significant enhancement of mechanical properties as well as suitable thermal conductivity and density used in building materials. The following conclusions from the experimental results emphasized this improvement:

1. The incorporation of CKD waste into the NR/SBR blend increases the thermal. conductivity and density.
2. The maximum degree of swelling and swelling index decrease with increasing CKD loading for NR/SBR composite blend leading to improve organic solvent resistance of the blend.
3. Crosslink density calculations from both swelling and mechanical measurements have the same trend and order of magnitude.
4. Addition of CKD waste to rubber blend leads to a noticeable increase in hardness and compression set emphasizing the stiffness of the samples.
5. The best chosen sample for building materials is NR/SBR loaded with 60 phr CKD which have a reasonable value of thermal conductivity which lies in the range of insulating material and suitable mechanical properties and other concentrations with higher thermal conductivity can used in other applications.

6. The addition of CKD to the rubber blends leads to a decrease in sound absorption coefficient.

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