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AN EXPERIMENTAL STUDY ON THE BEHAVIOR OF CRUMB RUBBER IN THE CONCRETE MIXTURE

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ABSTRACT

The study of tire recycling is one of the core environmental aspects, as tires waste is a complicated substance and cannot be rid-of easily. For that reason, this paper concentrates on tires recycling principle and takes the tires substances of a specific size that is called (crumb rubber). The paper studies the advantages of using tires waste into concrete mixture and aims to address how tires waste can strengthen the characteristics of concrete such as improving its thermal conductivity and sound insulation priorities. The results of the study reached to a point that tires waste can work as a good thermal and sound insulator in concrete that will help in reducing the consumption of resources as fine aggregate.

KEYWORDS: Concrete, crumb rubber, waste, sound, thermal conductivity, compressive strength

1. INTRODUCTION

One of the main factors affecting the provision of good-quality housing in Iraq is the rising high cost of building construction materials. Low-cost building supplies include recycled rubber automobile tires or other materials with similar qualities. This study looked into the properties of concretes made with locally accessible used rubber vehicle tires as fine particles. Also, tires waste treatment is now a global threat as Waste tire dumping, disposal of these materials or burning these tires cause serious environmental and health problems.

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As the thermal conductivity of the concrete can be reduced when rubber particles are added to concrete. The rubberized concrete can be used efficiently in a variety of applications that require insolation. It was agreed that using tires waste in concrete will lead to reduce the need for electricity, and reduces the expenditure and consumption of electrical energy. Hence, this will meet the requirements of reducing public fuel expenditure, and also lead to a significant reduction in greenhouse gas emissions.

Basically, recycling tires is an innovative idea or method in this case for preventing the environmental problem from worsening, Tire recycling is a method through which automobiles are recycled. Tires that have worn out or have irreparable damage and can no longer be used on vehicles (such as punctures).

In light of rising human population and rapid industrial development in the auto industry sector, the global car population is estimated to be between 1.5 and 1.6 billion cars (Ghandi & S. paltsev, 2020).

According to a survey by the Central Statistical Organization (Iraqi central statistical organization, 2020). Iraq has over six million automobiles. As a result, there is a great number of worn tires produced each year. For example, in the United States, waste tires were consumed at a rate of 275 million per year, while in the European Union, it was nearly 180 million per year (Issa, C.A. and G. Salem, 2013)., and Iraq imports more than 10 million per year, implying that there is a similar amount of worn tires and scrap in streets and highways squares. Because of the challenges in managing waste tires, which are now buried in the soil or dumped in the sea, environmental and public health problems will persist even after long periods of landfill treatment (Siddika, A., et al., 2019). None of these, however, is a long-term answer.

The practice of collecting tires with these massive amounts of scrap tires has resulted in a slew of issues, the most serious of which are stated below:

1. The waste management process has issues with significant amounts of worn tires accumulating, making it difficult to dispose them in a sanitary manner (Iraqi, C., 2020).
2. The location where spent tires are collected is thought to be a good environment for rodents and the proliferation of mosquitoes that transmit dengue fever and yellow fever, as the circular frame's impermeability allows water to be retained for a long time, allowing mosquito larvae to grow and transmit dengue fever (Williams, V.J. and G.A.2013).
3. The fire quickly engulfs vast mounds of discarded tires, making it difficult to extinguish. Large stacks of discarded tires can burn for months, emitting emissions that can be seen for miles, posing a threat to the environment. Traditional firefighting methods are difficult to deploy in these flames due to the degree of heat and smoke generated (Issa, C.A. and G. Salem, 2013).

4-Scrap tire fires released harmful gases such as polycyclic aromatic hydrocarbons and dioxins, as well as carbon monoxide, nitrogen oxides, and sulfur, all of which are compounds that have a direct and indirect effect on air, soil, water, and humans, causing allergies, asthma, cancer, and lung infections. Shortness of breath is caused by the creation of poisonous liquid chemicals such as cadmium, chromium, lead, selenium, and zinc, which leak into the groundwater and contaminate it with acid compounds, endangering the life of animals and plants. Pollution of the air and soil is also a problem, which is exacerbated when fires are put out with foam or water (Topçu, İ.B. and A. Unverdi, 2018).

Modern tires are built to last a long time and to survive tough surroundings and weather variations. Tires are made of rubber, steel wire and fiber, and other materials to deal with these conditions. However, environmentalists continue to be concerned about tire disposal. Cutting, shredding, or breaking down discarded tires into little pieces are all expensive and time-consuming processes. Dumping discarded tires in vacant ground has been a prevalent practice for many years. According to the Rubber Manufacturers Association (RMA), every year one tire is disposed per person. The U.S. stockpiled scrap tires have reduced tremendously from one billion scrap tires to 111.5 million scrap tires (approximately 89%) from 1990 to 2010. The main explanation for this significant reduction appears to be the increased usage of scrap tires in a variety of applications. This decline was partly influenced by state legislation and rules prohibiting the disposal of tires in landfills. The first scrap tire laws were enacted in 1985. Since then, the majority of states have enacted legislation and rules to manage and handle scrap 4 tires. Despite the fact that the quantity of scrap tire mounds has decreased, states must nevertheless accommodate the annual generation of tires and dispose of what is left in landfills. Municipal governments are in charge of policing unlawfully disposed tires, and they collaborate with inventors and investors to develop a market and practical solutions for old tires in their jurisdictions (RMA, 2012). 1990 to 2010. The main explanation for this significant reduction appears to be the increased usage of scrap tires in a variety of applications. This decline

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This study investigates the suitability of rubber tire use in the construction material as an instead for the use of fine aggregate. Tires waste is termed as crumb rubber that will be mixed together will other construction materials to study the effect of the thermal and sound insulation of concrete.

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2. STUDY OBJECTIVE

The contemporary faced challenge of this century is to find the most suitable solutions on how to minimize the consumption of the primary resources and how to provide the environmentally-safe waste disposal technologies. The use of rubber particles in concrete can be a cost-effective means of utilizing rubber, as well as providing superior environmental benefits. By partially replacing waste tire crumb rubber particle with fine aggregate in concrete, waste tire rubber offers a concrete with good engineering qualities to be used in many applications. The aim of this study is to:

Use of rubber particles in concrete can be a cost-effective means of utilizing rubber, as well as providing superior environmental benefits. This study aims at examining the possibility of partially replacing waste tire crumb rubber particle with fine aggregate in concrete through its thermal properties, sound insulation, and cost-effective techniques to be used in Duhok governorate.

3. MATERIALS AND METHODS

3.1 Experimental Work

In order to investigate the differences in concrete behavior while adding the crumb rubber. A total number of 18 concrete cubes of size (15*15* 15) cm were constructed in the laboratory of Duhok polytechnic University. The concrete cubes were prepared firstly without adding any percent of crumb rubber, and then the percent of crumb rubber has been increased gradually by a percentage of 5%, 10%, 15%, 20%, and 25%. After preparing the concrete cubes, a number of physical tests were done for the concrete to test how adding the crumb rubber is affecting on the behavior of concrete. Physical tests as testing thermal conductivity, and sound insulation were done at the concrete laboratories of Duhok University.

In the manufacture of structural concrete, the fine fractions of crumb rubber are employed as rubber aggregate. In Iraq, the only responsible factory for recycling the scrap tires is located in Diwaniyah that is called, ABRAJ AL KUT factory which is responsible for recycling the scrap tires where the tires are aggregated into different sizes and types.

Tires are recycled by a method called the mechanical strategy, which is one of the most extensively used, in which worn tires are chopped into various sizes using special equipment and machines, and this job is done at an ambient temperature or at a low temperature below (-280) Celsius (Ghandi, 2020).

After being frozen at a temperature of - 280°C, worn tires are shredded into smaller pieces. Where all the minerals and pollutants are disposed of utilizing sieves and magnets in this manner. In the first mechanical method, the scrap tires are divided into four groups based on the size of the rubber aggregate, each type has a different name see (figure 1):

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Type (A): this type is called the shredded aggregate or the coarse rubber that can be replaced with coarse aggregate; the size of these particles is between (13-76) mm.

Type (B): this type is called the crumb rubber that can be replaced with sand, the size particles of this material are varied between (0.425- 4.75 mm).

Type (C): this type is called the ground rubber that can be replaced with cement aggregates, the size of this material is almost less than 0.425mm.

Type (D): this type is called the fiber aggregate that is shaped in the form of short fiber where its length is ranged as 12.5 mm.

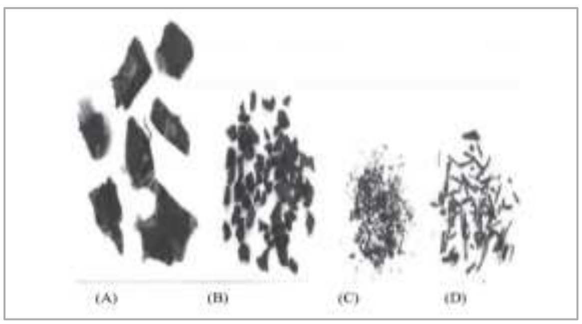

Figure 1. Size of Rubber Aggregate.
Source: (Ghandi,2020).

3.2 Preparation of Concrete Cubes

1. Before beginning the test, all components must be warmed to room temperature, preferably 27 ± 3 oC.
2. Each batch of concrete must have aggregate samples that are of the desired grading and have been air-dried. When arriving to the laboratory, the cement samples must be properly mixed dry, either by hand or in a suitable mixer, to provide the best possible blending and consistency in the material. Precautions are being taken to avoid the introduction of foreign substances.
3. The quantity of water, cement, and coarse aggregate must be similar for all the testing cubes.
4. The concrete must be mixed by hand, or preferably in a laboratory batch mixer, so that no water or other materials are lost. After molding the appropriate number of test specimens, each batch of concrete must be large enough to leave roughly 10% surplus.
5. Mixing process shall be not less than two minutes, till the concrete mixture is homogenously mixed.
6. Cement and fine aggregate should be mixed before adding any other material, cement and fine aggregate

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should be mixed in a homogenous way, after that, coarse aggregate has to be added to cement and fine aggregate,

7. After all the dry components are being mixed, water will be added gradually in a homogenous way to ensure a full mix of all the materials.

8. The dimensions of the test specimens must be 0.15 x 0.15 x 0.15 cm. If the aggregate's biggest nominal size does not exceed 2 cm, 10 cm cubes can be used instead. The length of cylindrical test specimens must be double the diameter. They must have a diameter of 15 cm and a length of 30 cm. smaller test specimens must have a diameter-to-maximum-size-of-aggregate ratio of not less than 3 to 1, except that the diameter of the specimen must be no less than 75 cm for mixtures having aggregate that is more than 5%.

9. The test specimens must be created as soon as possible after mixing, in such a way that the concrete is fully compacted with no segregation or excessive laitance. The concrete should be poured into the mold in five-centimeter-deep layers. To achieve a symmetrical distribution of the concrete within the mould, each scoopful of concrete should be moved along the top edge of the mould as the concrete slips from it. Each layer must be crushed by hand or through vibration.

10. All the surfaces of the testing cubes have to be clean without dust or sand to ensure a pure mixing of the concrete without any additional materials.

11. Testing machines have to be set in a stable place without vibration, in an environment that is relative moisture of at least 90 percentage humidity.

12. Testing cubes have to be rested in a dry place for 24 hours.

13. Concrete samples have to stay in water for 28 days.

Concrete cubes were constructed by mixing the (cement, sand, aggregate, crumb rubber, and water) together to build a mould. The percentage of crumb rubber was increasing from range of 0% to 25% to know how the increasing percentage of crumb rubber can affect on the physical properties of concrete; the percentage of the concrete ingredients is shown in (Table 1).

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Table 1: Mixing proportion of concrete cubes 15*15*15cm

Materials	*Cement (kg)*	*Sand (kg)*	*Aggregate (kg)*	*Crumb (kg)*
Control mix	1.370	2.055	4.110	0
5% crumb	1.370	1.952	4.110	0.103
10% crumb	1.370	1.757	4.110	0.195
15% crumb	1.370	1.493	4.110	0.246
20% crumb	1.370	1.194	4.110	0.299
25% crumb	1.370	0.896	4.110	0.298
Water	Drinkable water confirming to IS:10262	Drinkable water confirming to IS:10262	Drinkable water confirming to IS:10262	Drinkable water confirming to IS:10262

4. RESULTS AND DISCUSSION

4.1 Compressive Strength

The compressive strength was determined according to BS 1881: part 116, using 150 mm3. The compressive strength cubes were measured by using hydraulic self-indicating universal test machine of 2000 kn capacity and applied load rate according to ASTM C-39. For compression test, 15*15*15cm sizes of cubes were taken. All the cubes were tested after wiping out the surface moisture. Three cubes for each mix of crumb rubber replaced with fine aggregate were tested at the age of 28 days curing using universal testing machine, the testing of cube in compressive testing machine is shown in figure 2. This equipment is specialized for measuring the compressive strength of any concrete cube, the testing equipment might be of any type that is trustworthy and has enough capacity for the job. The machine is capable of applying the load at the specified rate, the mistake must not be more than 2% of the maximum load.

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Figure 2: Testing the compressive strength of concrete cubes, Duhok Polytechnic University (2021).

As a result of the amounted replacement of fine aggregate by crumb rubber, compressive strength of the concrete cubes decrease as the amount of crumb rubber increases, at the percent of zero replacement, compressive strength is 27.15 MPa, while at 5% replacement of crumb rubber the percent decreases to 22.25 MPa, this percent continues to decrease where at the replacement of 10% compressive strength reaches 20.95 MPa. The highest different in the compressive strength has shown in the replacement of 15%, 20%, and 25% where the compressive strength drops to 17.99 MPa, 16.63 MPa, and 13.98 MPa.

Eldin, et al (1993) investigated the behavior of rubberized concrete's compressive and tensile strengths. He examines that rubberized concrete has different characteristics compared to normal concrete, Rubberized concrete had lower compressive and tensile strength than regular concrete, but unlike regular concrete, it could absorb a substantial amount of plastic energy under compressive and tensile stresses.

This decrease in compressive strength can be attributable to a number of factors. (1) Because of the hydrophobic character of a rubber surface, adhesion between rubber particles and cement paste is not as strong as it is for other mineral materials. (2) Because rubber is significantly softer than aggregate, substituting coarse aggregate for rubber reduces the amount of carry-load capacity material in the mix. (3) Rubber particles have a lower specific gravity than mineral materials, therefore they tend to rise. As a result, there is a predominance of softer materials that breakdown at lower loads (Zheng et al., 2008; Ganjian, Khorami & Maghsoudi, 2009).

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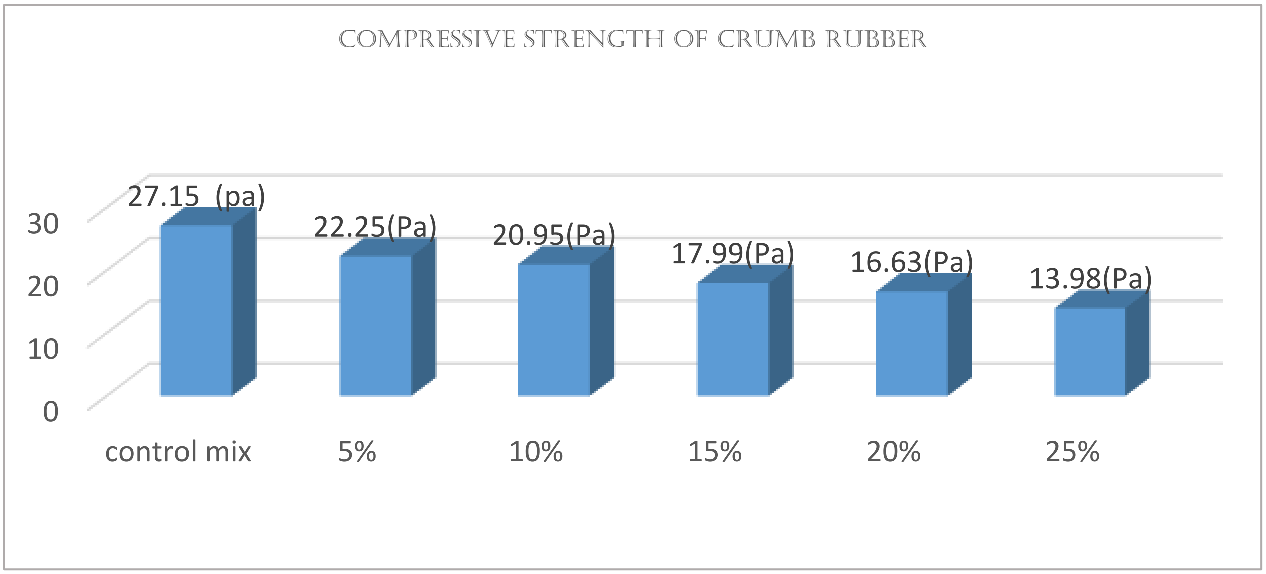

Figure 3: Variation of Compressive Strength (28 days) with addition of Rubber Aggregate. Made by the researcher.

4.2 Sound Insulation Test

According to ASTM C 597-09, an ultrasonic pulse velocity testing device was used to test the sound insulation that passes through the cubes, this instrument is a non-destructive test that employs sound waves to detect flaws and cracks in materials and components. For conducting the sound insulation test, Sound level meter peaktech device 8005: used for measuring the intensity of sound of concrete without adding crumb rubber and with crumb rubber. Slabs of size 15 cm*15cm* 15 cm were prepared. The slabs were dried at an electronic oven of 105 Celsius to ensure a dry and constant slabs. The noise insulation test was recorded using Sound Level Meter device that is specialized to record the sound measurements corresponding a specific sound source. To test the sound insulation for the concrete cubes & concrete cubes + Crumb rubber, the slabs were put in a fully packed box that is surrounded by an insulating package, then this package was connected to a noise source, the insulating package was provided with the Sound Level Meter device to ensure the full measurement of recordings, (see figure 4) that shows the process of measuring the sound passing through concrete cubes at the laboratory of Duhok Polytechnic University.

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Figure 4: Testing the sound waves passing through concrete.
Taken by the researcher 2021.

The noise insulation test was recorded using Sound Level Meter device that is specialized to record the sound measurements corresponding a specific sound source. Table (2) illustrates the maximum and minimum sound average for each concrete cube, the results show that the average of sound passing through the cubes is decreasing as the amount of crumb rubber increases, the Results indicated that the crumb rubber works as an insulator for sound absorption in the concrete.

Table 2: Maximum & minimum sound average passing through different percentages of crumb rubber in (dB).

Concrete Slab	*Maximum average sound (dB)*	*Minimum average sound (dB)*
Without slab	64.3	57.3
Control sample	62	55
5 % crumb rubber	61.8	53.8
10 % crumb rubber	56	51.2
15%	54	49.4
20%	53	47.5
25 %	51	45.2

Based on table (2), it is found that most of the concrete cubes have a good sound absorption ability,

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Ranging from the control sample that has no rubber content, the maximum average sound recorded was 64.3 dB at 440 HZ. Then, this average seemed to decline as the percent of crumb rubber increases, the higher the crumb rubber percent, the more sound was absorbed. Generally, the coefficient of sound absorption in the concrete is relaying on several factors as; the density of the concrete, content of void, and the replacement of the crumb rubber content in the concrete. In this study, since the level of density is within the range of 2391 kg/m3 and 2188 kg/m3 this means that density is not contributing in the coefficient of sound insulation. The absorption of sound depends on the void content, the higher the void content, the more percent of sound absorbed into the concrete.

4.3 Thermal Conductivity Measurements

The thermal conductivity measurements were recorded using the (Quick Thermal Conductivity Meter), according to the standard [ASTM D 5334; 08]. The device that was obtained in the national center for constructional laboratories in Baghdad (figure 3). The thermal conductivity K, value was recorded for six concrete cubes that contained the following percentages; 0%, 5%, 10%, 15%,20%,25% ratios of crumb rubber. The test results shows the comparison between concrete that contains crumb rubber and concrete cubes which are without crumb rubber to value the effect of crumb rubber on the engineering properties of concrete. The measurement of thermal conductivity (k-value) was done with a specifically constructed equipment that is called Quick Thermal Conductivity Meter, this equipment exists in the central library of constructional tests in Baghdad city. The k-value was calculated by averaging the heat flux traveling through the specimen in steady state and the temperature difference across the specimen at the same time. These values were used to compute the k values using Fourier's law (equation 3.2). Equation 4.2 was used to modify the results, which was created by comparing the k values of known materials with k-values obtained for the same materials using the apparatus utilized in this study.

Figure 5: Heat conduction device for measuring the conductivity of concrete with and without crumb rubber.

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Thermal conductivity decreases as the amount of rubber rose, regardless of crumb rubber size, according to the findings of this study. Rubberized concrete had k-values ranging from 1.0261 W/ m K to 0.9811 W/ m K, where 1.0261W/mK represents crumb rubber of 0% and the 0.9811 W/mK represents the crumb rubber of 25% (see Table 3). The decrease in heat conductivity varied depending on the amount of rubber replacement and the size of rubber particles.

Table 3: Measurements of thermal conductivity passing through different sizes of rubber-aggregate.

Mixture	*K-value (W/mK)*	*S.D*
0%	1.3659	0.00259
10%	1.0261	0.02831
15%	0.9811	0.02041
20%	0.7870	0.00510
25%	0.7799	0.00192

The decrease in thermal conductivity of concrete containing rubber can be attributed to two factors: an increase in air content and rubber's lower thermal conductivity than paste.

Previous research has shown that the rubber present in cementitious mixtures increases the air content even without the use of an air-entraining additive. According to Benazzouk et al. (2007), when the amount of rubber was increased from 0 to 30%, the air content increased from 2% to 17%. The thermal conductivity of air is 0.026 W/ m K

(Bederina et al., 2007), which helped to increase the thermal insulation properties of the combination. The size of the rubber crumb employed in this experiment had an effect on the thermal conductivity of the combinations, according to the findings. When a mixture of crumb rubber sizes #30, mix, and # 10- 20 rubber was added at a 10% proportion, the thermal conductivity fell by 13.1 percent, 17.5 percent, and 18.2 percent, respectively, when compared to plain.

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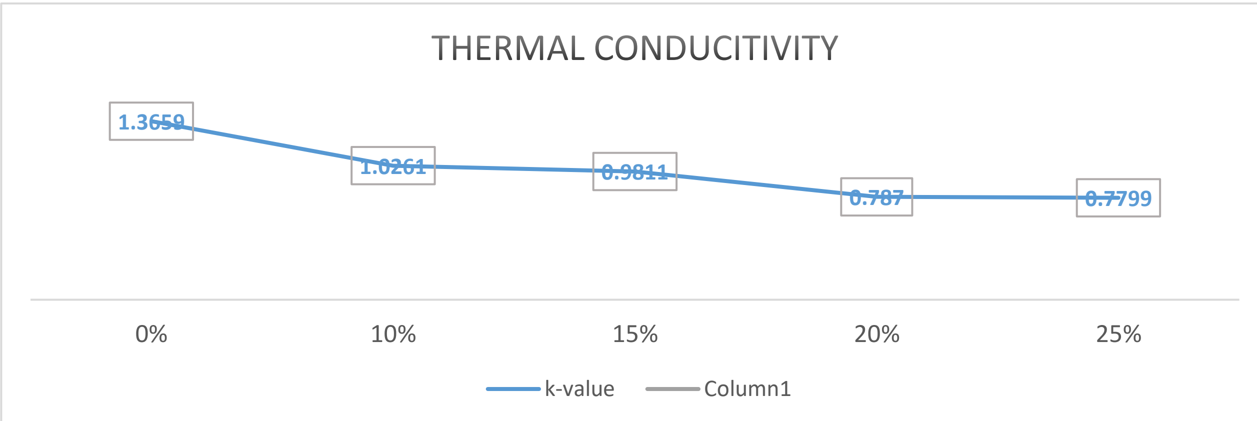

Figure 6: Thermal conductivity curve, K-value W/(m.K)

4.4 Density

Density of concrete cube decreases as the percent of crumb rubber increases, see table (4) that presents how density is decreasing as long as crumb rubber increases in the mixtures.

Table 4: Density of Concrete Cubes

Specimen	*Crumb rubber (%)*	*Age (days)*	*Volume (cm)*	*Average mass (Kg)*	*Average Density (kg/m3)*
0%	Control mix	28	0.15X0.15X0.15	8.01	2391.67
5%	5 %	28	0.15X0.15X0.15	7.93	2350
10%	10%	28	0.15X0.15X0.15	7.77	2303.17
15%	15%	28	0.15X0.15X0.15	7.66	2270.04
20%	20%	28	0.15X0.15X0.15	7.49	2219.8
25%	25%	28	0.15X0.15X0.15	7.386	2188.7

Density decreases constantly with the increase of waste aggregates. The density of rubberized mortar varied depending on the amount of rubber and the size of the rubber. When the amount of rubber used grew, the density decreased. According to Siddique & Naik (2004) and Ling (2011), the main reason for the decrease in density is due to an increase in air content due to the nature of rubber surfaces, which tend to entrap air. As the quantity of rubber increases, the air content increases, causing the density to drop. A similar observation was made by Sukontasukkul (2009). Rubber has a lower specific gravity than fine aggregate, which results in a lower unit weight. Because the specific gravity was the only variable, the difference in the unit weight of mixtures including varied crumb rubber sizes can likewise be linked to it.

CONCLUSION

The mechanical qualities of concrete, such as compressive strength, are observed to diminish when rubber is added, owing to a weak link between rubber particles and concrete compared to the bond when the concrete sample is without rubber, confirming prior research findings.

Because the thermal conductivity of the concrete is reduced by roughly 26.7 percent when rubber particles are added, the rubberized concrete can be used efficiently in a variety of applications that require isolation. Density results are seemed to be decreased as the percent of crumb rubber increases.

As long as crumb rubber percent increases, the noise insulation of the concrete cube increases too.

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