Evaluation and Optimization of Composite Thermal Insulators from Waste Materials

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Abstract- **The present work includes a study on the effect of loading rubber waste into cement mortar on the thermal and mechanical properties of a thermal insulator.The experimental work of the study included the preparation of ten models of 35 mm diameter and 5 mm thickness. Portland cement and natural sand were used as a matrix and rubber waste (extracted from the consumed tires) as a filler was added in weight percentages (5% ,10% ,15% ,20% ,25% ,30% ,35% ,40%,45% and 50%). Water was also used as a binder.Also, the experimental work included conducting a thermal conductivity test using Lee's Disk method, and a hardness test using the Shore scale. The theoretical side included extraction of empirical equations, depending on the experimental results. The thermal conductivity equation was for two variables, temperature and mass fraction. While the hardness equation was for one variable, mass fraction. Theoretically determined heat capacity was extracted using the equations of the composites. Based on the empirical equations of thermal conductivity and hardness and using the technique of multi-objectives genetic algorithm, the optimum values of temperature and mass fraction were extracted, which achieve the best thermal insulation of the mortar.**

The results showed a significant decrease in thermal conductivity. The reduction in thermal conductivity was (90.3%) at 5% and reduced to (95.73%) at 50%. The specific heat capacity was increasing as the percentage of rubber waste increase. The results also indicated a decrease in hardness. The optimal value of thermal insulation was (0.02658 W/m^2.°C) as a thermal conductivity and (58.07 N/m^2) as a hardness, at temperature (50°C) and mass fraction (27.764%) of rubber waste.

Index Terms— **rubber wastes ,empirical data , genetic algorithm.**

I. INTRODUCTION

Solid waste is one of the most dangerous pollutants to the environment, being difficult to decompose. Therefore, the reuse provides an optimal solution to this problem. On the one hand, these pollutants are disposed of in a healthy environment and provide an alternative source of energy.[1]

One such solid waste is tires, where a large proportion of these wastes are made up.In the construction sector, research is under way to find alternative materials used to provide environmentally friendly building structures(Green buildings).[1,2]

The annual global production of tires is about 1.4 billion tires, which corresponds to an estimated 17 million ton of used tires each year.The total worldwide production of waste tires represents 2% of total annual solid waste.[3]

One of the most important factors that focus on workers in the development of materials building structures, is the spread of the culture of thermal insulation of buildings. This reduces energy consumption and provides comfort at the same time.[2]

Composite materials are materials resulting from the fusion of two or more components. These components differ in either phase, or properties (physical or chemical) to obtain a new material with properties not available in the individual components.[4,5].

The use of composite products has been used to provide desirable properties not provided by raw materials in design. These materials provide several properties such as high loads and thermal insulation. [6,7]

The different characteristics of each component of the composite add special advantages to the resulting composite.[8]

One of the most important advantages in the use of composite in the construction sector (in addition to the above) is the high resistance to corrosion, high durability and flexibility in design.[9]

Solid industrial waste was used in the preparation of building materials in various forms and compounds, some used as a substitute for coarse aggregates in the preparation of concrete, others used as an alternative to fine aggregates. It was also used in the manufacture of building blocks, and the preparation of thermal insulators for walls.

Many of researchers have conducted studies on the manufacture of thermal insulators based on different methods where the researcher **N.M Fawzi et al (2010),** prepare a light weight concrete with low density from waste of building material (siporex and porcelinite and sawdust), to obtain on thermal insulation for buildings. Also the present work contains several test properties such as thermal conductivity ,density and compressive strength.[10] Also **Ms.R.Manju et al (2012),** investigated experimentally in replacing the fine aggregates of concrete (sand) partially by rubber waste using plastic bottles (PET). Cylindrical and cubed samples were made of fibers by rate 1%, 2%, 4%, and 6% from volume of fine aggregate in concrete. Several tests were conducted on them such as Compression test, splitting tensile test and flexural strength tests were done , the results shows that the increasing with loading in (PET),lead to increasing in compression and tensile strength.[11] The researcher **Christina J. Hopfe et al (2012),** studied empirical data on dry physical thermal properties and saturated state of stable concrete. Rubber is used for this purpose with different weights and different size (crude, coarse, mixed). The results showed that the addition of rubber crumbs to the concrete needed more time to wet during its integration. This leads to the entry of an intake of air into the mixture thus leading to reduced a thermal conductivity.[12] Also **Gargouri Ahmed et al (2014),** investigated the effect of adding rubber waste to self-consolidating concrete (SCC), four models were prepared rectangular shape and contrast ratio of rubber aggregates these percentages ranged from 0%, 10%, 20%, 30% of the volume of the gravel. Rubber waste was used from tires used for this purpose. Several properties were examined, including thermal conductivity and thermal diffusion. The results showed an improvement in the thermal performance of the resulting concrete.[13] and **S.M.Abdel.wehab et al (2015),** Prepar thermal insulation of the building from a compound(NR) and rubber waste, and then investigated the effect of adding rubber waste to a compound (NR) and its effect on mechanical and thermal properties. while the **Sanaa A.Hafed(2017),** prepared a hybrid mortar material consisting of cement and sawdust. Portland cement, natural sand, sawdust and water were used in the preparation of this compound. The effect of the addition of sawdust on the thermal, physical and mechanical properties was also studied on the resulting compound.[14]

Previous research shows the importance of the use of solid waste as rubber waste in the development of the performance of building materials in a way that ensures a strong structure and comfortable.

The current work highlights the use of rubber waste as an additive to the base material (cement and sand matrix) and the manufacture of composite building material. The effect of the micro-size of the materials and its effect on the homogeneity between the materials and thus the thermal and mechanical properties was also studied.

II. MATERALS

a. Rubber Waste

Rubber waste used in this work was derived from tires waste. These wastes were obtained to give micro-rubber particles in the welding workshop of Engineering collage at the University of Basra. Rubber particles were used after screening with 500 micro or less.

Fig. 1 Rubber waste

b- Cement

A cement is a binder, a substance used for construction that sets, hardens, and adheres to other materials to bind them together. Cement is seldom used on its own, but rather to bind sand and gravel (aggregate) together. Cement mixed with fine aggregate produces mortar for masonry, or with sand and gravel, produces concrete.[15]

The cement that used in this work is Portland cement ,Also Natural siliceous sand was used to prepare a mortar and with the same size (500 micron and below).

III. PREPRATION OF COMPOSITES

These samples were prepared in the laboratory metallurgy in the Department of Materials Engineering / College of Engineering / University of Basra. Models were made in normal weather conditions of pressure and temperature. Composites shall be 35 mm in diameter and thickness (5 mm) (depending on subsequent tests).these samples sand was added to cement and the weight ratio was (3: 1) to be used as a mortar for construction. According to the Iraqi Labor Code[16]. The samples were prepared as follows:

1 - Mix the amount of sand and cement according to mixing ratios mortar and mix well.

2 - The amount of the mixture above and the amount of rubber is calculated by weight fraction (5%, 10% ,15% ,20% ,25%,30%,35%,40%,45% and 50%) .

3 - Put both articles in the above paragraph in the vessel and add water gradually until a homogeneous mix. (it was difficult to determine the amount of water needed due to the different moisture content of the material)

4 - pour samples into molds and leave to dry.

5 - The samples are extracted and the surface is softened with a softening device and then ready for tests.

Fig. 2 Sample of (R-Ce) represent it's Diameter and Thickness.

IV. THERMAL AND MECHANICAL TESTS

a. Thermal Conductivity

Thermal conductivity was measured using a **Lee'S Test** . Measurement was done at steady state.

The device used for this purpose consists of two copper disks, one of which is connected to a thermal source to generate a thermal gradient during the sample. The figure (3) show the structure of Lee's device. The sample is placed between the two copper disks and based on Fourier's thermal conductivity when equilibrium:[17,18]

$$K = \frac{Q.\Delta x}{A.\Delta T} \quad (1)$$

Where K is the thermal conductivity coefficient of the material of dimensions (w/ m.K), Q is the heat flow at steady state , *A* is the cross section area in (mm^2) ,x is the sample thickness in (mm) and $(\Delta T = T_1 - T_2)$ is the temperature gradient at the thickness of the sample.

Temperatures is recorded when T_2 is constant for more than ten minutes.

To calculate the amount of heat transferred during the sample, the heat source is stopped and the disk cooling rate is recorded until the difference of temperature is ten degrees (T_1-10 °C).

Depending on the equation.

$$Q = mc_p \frac{dT}{dt} \qquad (2)$$

Where:

M is the mass of brass plate

c_p is the specific heat capacity of brass (0.38)$\frac{kJ}{kg.K}$

When the cooling curve for the brass plate as in Fig (4), determine the slope $\left[\frac{dT}{dt} = \frac{\Delta T}{\Delta t}\right]$ at the temperature T_C.

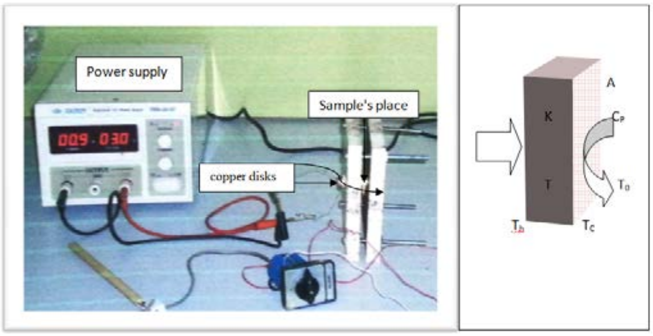

Fig. 3 Configuration of Lee's Test and The Temperature Gradient through The Sample.

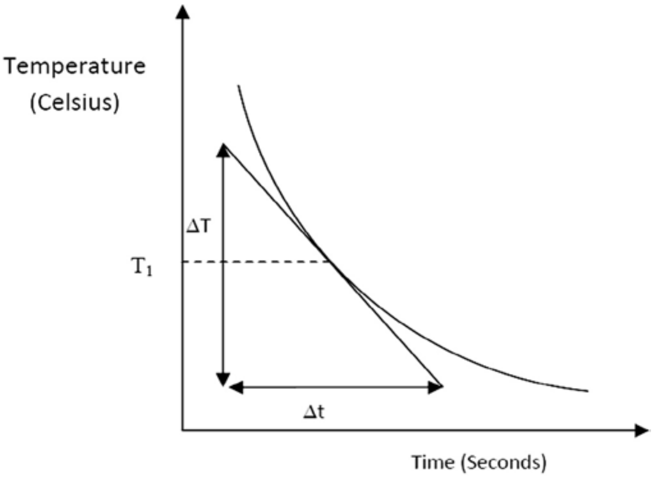

Fig.4 The Temperature–time Relation for Calculation of Q.[19]

b. The Mechanical Properties (Hardness)

The hardness test is the most widely used test for evaluating the mechanical properties of materials. The purpose of the hardness test is to determine the suitability of a material for a given application, conformance to a specification, standard, or particular treatment to which the material has been subjected (heat treatment, thermal process).[20]

The hardness of the samples was checked using a Shore scale type D.

V. THEORETICAL WORK

A. Regression Analysis

In most of engineering applications there is always need to model the relationship between variables in order to predict and study the behaviour of response variable (dependent) in terms of input variables (independent). Regression analysis is the method by it one can model a relationship between variables, if there is one independent variable it is called simple regression analysis and multiple regression analysis if there is more than one independent.[21]

1.Regression for Thermal conductivity (K)

Based on experimental data, the equation was derived based on two independent variables (temperature and weight fraction).

The empirical equation discovered using LAB Fit software.

$K_{(R\text{-}Ce)} = A * M_R\% \wedge (B * T_1) \qquad (3)$

Where K represent the thermal conductivity in W/m.˚C,T_1 represent the temperature of hot surface in ˚C.The values of equation constant and the regression correlation coefficient as follow:

- R=0.974
- R^2=0.950

2. Regression for Hardness

The experimental results of the hardness were based on one variable, the weight fraction. The equations derived from the empirical test and the convergence coefficients were as follows:

(R-Ce) composite:

$H = A * M_R\% + B \qquad (4)$

- R= 0.996
- R^2= 0.992

B. Specific heat capacity

The specific heat capacity of the composite can be optioned from its components. Suppose that the composite consists of two materials, the first material has mass fraction(M_f) and specific heat capacity(C_f),the second material the mass fraction(M_m) specific heat capacity(C_m). by consider m is total mass of composite material ,then the mass for first material (M_f m) and the mass for second material (M_m m). The heat absorbed per K rise in temperature is(C_f M_f m) for first material(filler), and is (C_m M_m m) for second material(matrix). The specific heat (C_c) of the composite is the total heat absorbed per °C rise in temperature divided by the total mass. The following equation show that:

$$C_c = (C_f\, M_f\, m + C_m\, M_m\, m)/m \qquad (5)$$

$$C_c = C_f\, M_f + C_m\, M_m \qquad (6)$$

And thus;

$$C_c = \sum_{i=1}^{n} Ci\, Mi \qquad (7)$$

The equation shows that the specific heat capacity of the compound depends on the weighted average of weight fractions of the components. This equation is a manifestation of the rule of mixtures. Note that the derivation of this equation does not require any particular distribution of the two components.[5]

C. Optimization Methods

a) Optimization is defined as the process of selecting the best solution under the given conditions. Where work is done under these conditions to give the highest and lowest value which represent the optimal values of the solution.[22]
Optimization methods can be divided in to two categories: traditional and nontraditional methods. In response to solving complex optimization problems, traditional methods known as modern methods have been developed.[22]
The purpose of this study is to find the optimum values two objective functions (thermal conductivity and hardness) for thermal insulation of buildings, based on design variables that include both temperature and mass fraction.
From the above note we need to improve more than one objective, so multiple objectives optimization (MOO) method was used. Although multiple objectives optimization (MOO) are tough however they're realistic issues, wherever the objectives are usually conflicting preventing synchronal improvement of every objective. The Genetic Algorithm is thought of one amongst the foremost fashionable metaheuristic approaches that are like minded for resolution multi-objective improvement issues, because that multi-objective Genetic Algorithm (MOGA) doesn't need user to prioritise, scale, or weight objectives.[23]

b) Multi-Objective Optimization of the Present Study Using GA.
The extraction of the optimum values of thermal insulators manufactured in the current study depends on two objectives functions in terms of their design variables.
One of the most important thermal properties was chosen as the first objective which is the thermal conductivity. The second objective is the hardness, which is one of the important mechanical properties of thermal insulators.
The design variables are temperature and mass fraction of waste material. The optimization process has been performed by multi-objective optimizer(gamultiobj) in MATLAB R2014 a software that optimizes the two objectives simultaneously.
The options in multi-objective optimizer (gamultiobj) in MATLAB were specified as following:

1. Population Size=100.
2. Population Initial Range=[25 5 ; 50 50].
3. Lower Bound =[25;5], Upper Bound =[600; 50], which were considered as constraints for the objectives.
4. Creation Function =Feasible population.
5. Selection Function = Tournament,Tournament size=10.
6. Crossover Function = Two point crossover,Crossover Fraction=0.8.
7. Mutation Function = Adaptive feasible.
8. Pareto Fraction=0.7.
9. Plot Function= Pareto front.

VI. RESULTS AND DISCUSSION

A. Thermal conductivity

Figure (5) explains the variation of thermal conductivity with loading of rubber waste. The figure reveals that the drop in thermal conductivity of mortar with increase in mass fraction of rubber This can be explained as follows:
Rubber is an insulator material in itself, so adding it to the mortar reduces its thermal conductivity. also the size of the rubber particles that used has helped to reduce thermal conductivity because it has separated the contact points in the cement matrix and thus reduced thermal conductivity.[13]

Also, this figure show the effect of temperature on the thermal conductivity of the resulting compound when the ratio of the addition is confirmed.
Actually there is a clear drop in thermal conductivity with increasing temperature. This can be explained by the presence of pores in the composition of the termination material and the introduction of small rubber particles between these pores works to dissipate the electron and restrict its movement as well as reduce the vibration resulting in reduced thermal conductivity. [5,13,24]

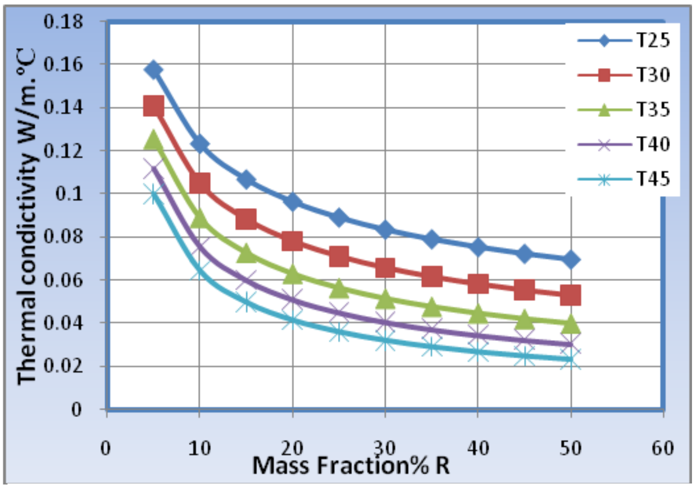

Fig. 5 The Effect of Mass Fraction and Temperature on Thermal Conductivity(R-Ce) Composites.

B. Specific Heat Capacity(C_P).

Figure (6) presents the variation of specific heat capacity(C_P) with the loading waste rubber on cement matrix. the figure shows the increase in content increases, specific heat capacity is seen to progressively increase because of the specific heat capacity of waste rubber (2.01 KJ/Kg.°C) is greater than specific heat capacity of cement (0.96 KJ/Kg.°C). the waste rubber loading in the cement

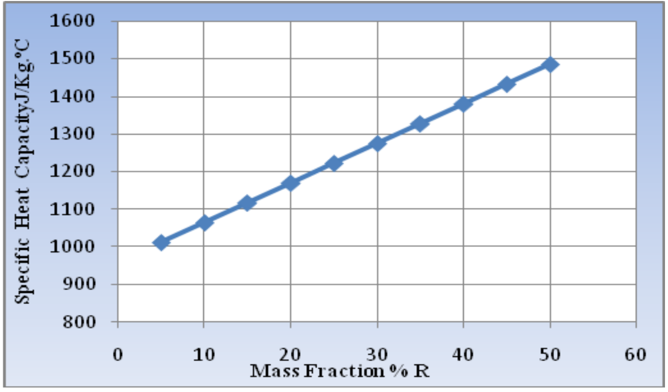

Fig. 6 The Effect of Mass Fraction and Temperature on Specific Heat Capacity of (R-Ce) Composites.

matrix resulted in composites becoming more specific heat capacity.[5]

C. *Hardness*

Figure (7) shows the effect of rubber loading waste on hardness of (R-Ce) composite. The figure reveals that the drop in hardness from (106.88 N/m^2) that occurs at 5% to (10.4 N/m^2) at 50%. this behavior is due to that flipping the material into the air leads to the introduction of air and the formation of voids, which reduces the hardness of composites. [8]

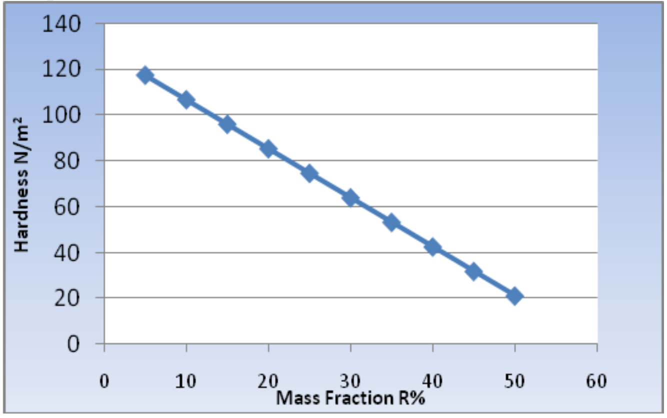

Fig. 7 The Effect of Mass Fraction of a Rubber Waste on Hardness (R- Ce) Composite.

D. *The Result of Optimization*

Figure (8) shows the result of optimization operation (Pareto optimal set) of composites. As well as the table I contains the optimum values of thermal conductivity and hardness and its variables.

Table I The Optimum Values of Design

composites	Thermal Conductivity (K) W/m. °C	Hardness N/m^2	T °C	Mass Fraction of Rubber waste%
R-Ce	0.02658	58.07	50	27.764

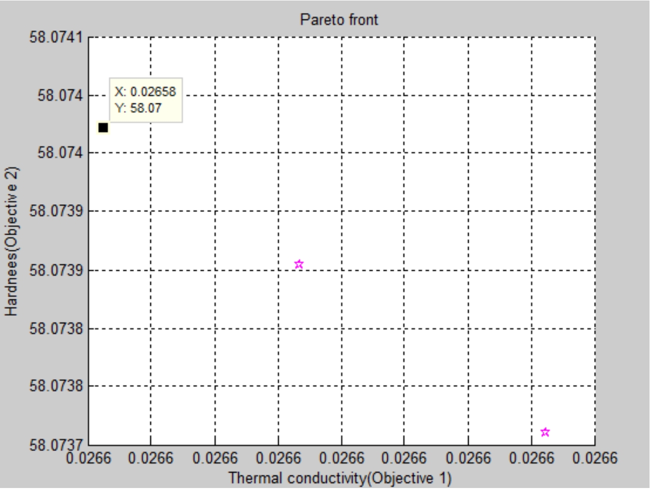

Fig. 8 Pareto Front Set (R-Ce) Composites

VII. CONCLUSION

- Adding rubber waste to the mortar reduces its thermal conductivity.
- The use of the micrometer size of the composite material molecules has greatly improved their homogeneity and improved thermal properties.
- Theoretically, the specific heat capacity increases with the increase in the proportion of rubber waste added.
- The hardness of the material decreases with the increased loading of rubber waste.

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