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Comprehensive review study for the effect of utilizing waste materials on the thermal conductivity of concretes

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ABSTRACT

. Since concrete is one of the most popularly utilized building mixtures in construction, a high demand of natural resources is significantly emerged. Therefore, a skyrocketed attention has been paid to create new opportunities for the use of recycle materials to develop a new construction substance with more satisfactory properties. The use of waste products in concrete is not only economical, but it helps in solid waste management as well. Among various properties of concrete, thermal conductivity is a crucial factor that plays an important role in in building insulation by evaluating a material's capacity to transfer heat. This paper aims to review the potential application of waste materials in concrete as additive ingredients and investigate the effect of this waste material on thermal conductivity of concrete. The review of literature revealed that the application of most of the waste materials exhibited an obvious potential as thermal insulator. However, further investigated work is needed to highlight the advantages of utilizing waste materials in concrete containing various type of waste materials

1. Introduction

Concrete is a mixture of cement, fine and coarse aggregate that obtained mainly from nature. It is attracting a great attention worldwide due to its high usage in nearly all construction activities like buildings, roads, dams, bridges, canals etc. It is regarded as the most extensively used material on earth after water. Expanding populations, increasing urbanization, increasing lifestyle due to technological innovations have demanded a huge amount of natural resources in the construction industry, which has resulted in scarcity of resources in the construction sector, resulting in a lack of assets Prusty et al. [1].

It is well known that a large amount of wastes has been generated from several sources which is genuinely prompting disposal issues. Reuse of such wastes as feasible development materials deal with the issue of defilement, just as the issue of zone filling and the cost of building materials [2]. Concrete is the most expense and vitality concentrated substituent of concrete. The issue of the could be solved by the replacement of cement with fly ash. According to previous studies, the usage of waste, as a waste material, is new research area that developed this usage on financial grounds as pozzolana for partial replacement of cement in concrete which improved workability, reduced bleeding, lowering advancement of heat and lowering water de-

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mand. The waste reinforcement concrete exhibited preferable mechanical and thermal properties compared to the plain concrete Huang et al. [3].

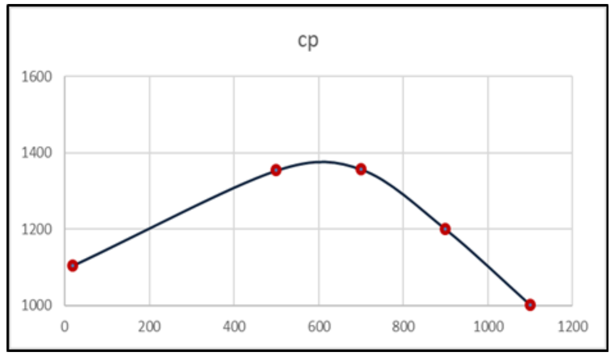
Since a great many people spend around 90% of their lives inside buildings, vitality protection and thermal comfort in structures are questionable themes. The energy required for building cooling and warming and thermal comfort rely enormously upon the thermo-physical properties of the development materials Asadi et al. .[4]. Concrete is well regarded as a strong substance that is heterogeneous and porous. At normal operating temperatures, the heat transfer in concrete material is primarily by conduction. The spatial dispersion and volume proportion of its elements, for example, complete, water concrete and voids, affect the properties of concrete. The voids within the concrete have a major effect on the concrete's mechanical and thermal properties. Changes in particular concrete properties cause various values in thermal conductivity Chung et al [5].

The use of waste in the cementitious materials to develop new products with enhanced thermal conductivity properties is new area of interest that have been studied by several researchers. Thus, the property requirements for these applications need to be understood to ensure that materials intended for recycling are able to meet relevant specifications, by using available technologies and facilities, at a reasonable cost. The aim of this paper is to review the literature and experimental studies on the effect of using waste materials for thermal conductivity in concrete.

2. Concrete thermal conductivity studies

The study conducted by Shin et al. [6] aimed to investigate the thermos-physical properties of Korean concrete under high temperature conditions. The obtained findings demonstrated that the thermos-physical properties decreased with the increase of temperature. Compared with values at room temperature, the conductivity decreased by 50% at 900 °C. In addition, results showed that the specific heat raised to 500 °C, declined from 700 to 900 °C, and then raised again in temperatures above 900 °C. Figure. 1 (a, b) depicted specific heat at elevated temperature of concrete, and thermal conductivity variation of concrete as a function of temperature respectively.

Khan [7] studied the influence of several moisture contents on the thermal conductivity of mortar and concrete. Based on the findings of this investigation, and by using four different types of rocks at dry and fully saturated states, the relationship between concrete conductivity and aggregate conductivity was successfully developed. It was concluded that the thermal conductivity of rocks raised with the increase of the moisture content. On the other side, it was also found that thermal conductivity of concrete increased with the increase of moisture content. The pattern of the increase was more significant from the dry to 50% degree of saturation state.



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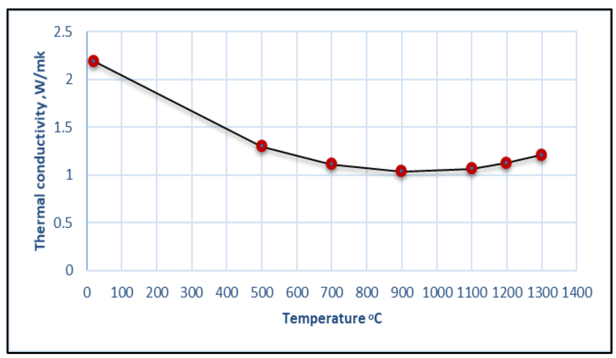


(b)

Figure 1. a) Specific heat at elevated temperature of concrete, b) Thermal conductivity variation of concrete as a function of temperature (Shin et al., 2002)

Kodur and Sultan [8] represented a useful finding which aimed to study the thermal properties of plain high-strength concrete (HSC) and steel fiber-reinforced HSC that was produced with siliceous and carbonate aggregate. The results were clearly indicated that the aggregate form has a great influence on the thermal properties of concrete under high temperatures. However, the thermal performance of steel fiber reinforced HSC was similar to that showed by the plain HSC. According to the findings of this study, the authors suggested the thermal characteristics relationships to be beneficial input data for the imitation the behavior of fire-exposed concrete structures.

In the study done by Wang and Tan [9], The objective of the authors was to measure the equivalent concrete thickness according to the particular geometric arrangement of concrete-encase steel I-sections using a design concept named the residual area process. They selected the EC 3 provisions to characterize the temperature field along the steel profile using a 1D heat transfer model. The methodology proposed applied for concrete I-sections exposed to external and parametric hydrocarbon fire curves. The results demonstrated that the remaining area approach is inherent, however not in heating conditions, to the geometrical arrangements (cross sections) of refined concrete I sections.

Demirboğa et al.[10] designed an experimental work to investigate the impact of high-volume class C fly ash, and blast furnace slag on the thermal conductivity and several mechanical properties of concrete. The finding obtained indicated that the thermal conductivity and compressive strength decreased with the increase of high-volume class C fly ash and blast furnace slag (Figure 2). Meanwhile, it was clearly shown that this depletion in compressive strength reduced with expanding the curing period

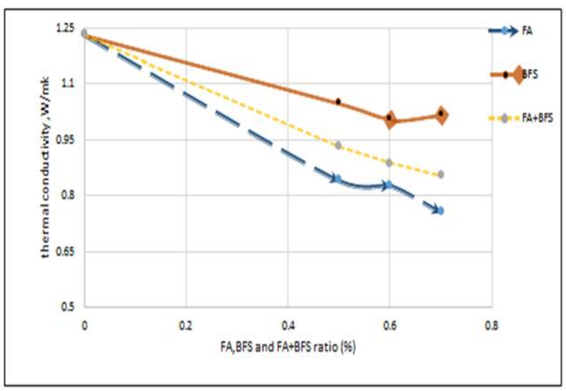


Figure 2. Relationship between mineral admixture and thermal conductivity (Demirboğa et al., 2007).

The undertaken study performed by Dweik et al [11]. highlighted the advantageous effect of the incorporation of ground melamine-formaldehyde in concrete. The results revealed that the thermal properties of concrete were grew along with the growth of ground melamine-formaldehyde from 0% to 60%. Unlike control specimens without ground melamine-formaldehyde, the 60% ground melamine-formaldehyde concrete mixes recorded a decline of up to 30% of temperature.

Zhang and Wachenfeldt [12] studied the of thermal transfer behavior and storage capacities of the air cavity concrete walls using finite element analysis which were done by applying COMSOL program. This study highlighted how the impact of concrete walls can be observed in single-layer and two-layer single-dimensional designs with similar thermal conductivity and mass density in building energy simulation with air cavities. The results revealed that one-layer model can be used to measure the heat storage potential by using an inflated mass density of the same magnitude as two times the mass density.

Vasilache et al. [13] aimed to suggest new constructive solutions for buildings thermal insulation which contributing likewise to protecting the environment and cost savings. For this aim, the authors used bulk materials including sawdust, hacked paper, crumbled expanded polystyrene, PVC recipients. Based on the results, these bulk materials exhibited a beneficial effect in lowering the thermal conductivity. Hence, it was concluded that these materials can be recommended as new affordable thermal insulation for buildings.

Topçu and Uygunoğlu [14] was one of the few studies that investigated the correlation between the aggregate type, and the physical and mechanical properties of hardened self- consolidating concrete which mixed with lightweight aggregate. The pumice, normal lime- stone, and volcanic tuff and diatomite were the three types that used in the experimental work. In general, the results clearly indicated that self-consolidating lightweight concrete with lightweight aggregates have lower mechanical and physical characteristics at a lower unit weight except for thermal properties where the self-consolidating lightweight concrete has higher thermal conductivity coefficient.

The paper reported by Lorente et al. [15] discussed the influence of sulfate ions on the properties of concrete. The study was according to the comparison of results of natural diffusion with the results of migration. At the point when combined with an electromagnetic method, magnesium sulfate prompts critical mechanical quality misfortunes following a 6-month test, while common dispersion attacks lead to a lot littler misfortune. In brucite formation kinetics, a potential clarification may be found. Additionally, it was indicated that utilizing an electrical field to improve the sulfate attack brings about a significant decrease in the time necessary to reduce the mechanical performance.

Othuman and Wang [16] performed a study in order to quantify the thermal properties of lightweight foamed concrete (LFC) under elevated temperatures. The work design was based on two approached in which the analytical solution and direct estimation utilizing the hot guarded plate test method were performed. In the analytical approach, it was concluded that the thermal conductivity of LFC is a function of its porosity and pore size which was due the consideration of LFC as a two-phase material with solid cement and air pores. Results of hot guarded plate test were in line with analytical prediction results. Further validation was conducted using specific heat tests in an electric furnace on LFC slabs. Furthermore, this study represents a demonstrative investigation of fire resistance of LFC which offers a plausible surrogate to gypsum as the development material for partition walls.

Corinaldesi et al.[17] detected the impact of using scraps that came from polyurethane waste particles (PU) and sole rubber (SR) on the properties of a lightened building material including thermal conductivity. The experimental work was carried out by using three ratios (0, 10, and 30%) of SR or PU as alternatives of quartz sand. The results showed that the expansion of SR diminished the material unit weight and also the thermal conductivity of the material. By the same token, mixtures with 30% by volume PU exhibited notable reduction in the unit weight and thermal conductivity of the material. The thermal insulating impact of PU demonstrates an interesting potential for future improvements. However, limestone powder lead to higher thermal conductivity and even higher mechanical properties.

Tumadhir[18] studied the possibility of use chopped basalt fiber to improve the mechanical properties of glass aggregate concrete using a combined method of statistical analysis and tests. It was found that using basalt fiber improved all mixes with the presence of an optimal fiber content in each ratio of glass which gave more strength. 20% of glass was found to be the optimal ratio that exhibited a significant enhancement the compressive and the splitting tensile strength.

Turgut and Gumuscu[19] analyzed the possibility of producing artificial limestone brick using different ratios of sawdust waste (WSW) and limestone powder waste (LPW). A notable reduction of 38.9% was observed in the thermal conductivity at 30% WSW replacement compared to the control mix. On the other hand, the results revealed a potent relationship between the thermal conductivity, ultrasonic pulse velocity, and unit weight values of the specimens. This study presented WSW-LPW combinations as a potential byproduct that can be utilized in the production of a new lighter brick with improved thermo-elastic properties.

Tian et al. [20] presented the core temperature layer concept for the analysis of the thermal dynamic response behavior of the concrete radiant cooling sheet. Three sub-processes divide the process of thermal transfer process into the concrete slab, in addition to three models for thermal transfer which were developed by the reaction coefficients method. Moreover, Two-dimensional unstable heat transfer model of concrete cooling plate is eventually created. The findings obtained from this study indicated that the inconstant thermal transfer model showed better ability to describe the two-dimensional dynamic heat transfer process. On the other hand, results also revealed that the six different unsteady conditions exhibited relative error between calculation and experimental of 7%, while the four different steady conditions showed relative error of 1.5% between the calculation and experimental and less than 2% when compared the results with the referenced data.

Khamidi et al. [21] aimed to investigate the impact of silica aerogel on the thermal conductivity of cement paste used in the construction of concrete buildings. The experimental work carried out using free water ordinary portland cement mixed with different ratios of silica aerogel and subjected to several tests at 3, 7, and 28 days of curing. The sample mix contained 20 ml of silica aerogel recorded the lowest thermal conductivity with a value of 0.076 W/mK, which represents a reduction of 93.58% compared to the control mix. Therefore, silica aerogel suggested as beneficial cement paste filler which significantly enhance the thermal conductivity.

Price et al. [22]discussed the effect of replacing ordinary portland cement with Corncob Ash cement on the mechanical properties and the thermal conductivity. It was observed that Corncob Ash improved the mechanical properties of the mixtures. In addition, 10% Corncob Ash replacement found to be effective on reducing the thermal conductivity of the tested mixtures. Thus, Corncob Ash cement may be useful material that can enhance the insulation characteristics of the construction material.

Su et al. [23] discussed the thermal transfer and cooling features of the concrete ceiling radiant cold panel. By using the finite difference method, two-dimension mathematical models for steady state heat transfer were created. Numerically simulated heat transfer in the concrete panel. Indoor and concrete panel surface temperatures have been collected. The large thermal inertia in the concrete panel was the factor behind the slowly drop of panel and indoor air temperatures, nonetheless, it lowered the adverse impact of the water supply temperature.

Real et al. [24] designed an experiment to investigate the thermal conductivity of structural lightweight aggregate concrete which fabricated with various types of aggregate, binder, and different ratios of w/b. The thermal conductivity observed to be reduced with the increase of the w/b ratio or the volume and porosity of lightweight aggregate from one side, and with the reduction of the density, the sand portion or the water content of the concrete from another side. Moreover, thermal conductivity drops by approximately 0·6% in the samples with 1% increment in the LWA porosity. Eventually, a high exponentially correlation was noticed between the thermal conductivity and concrete density.

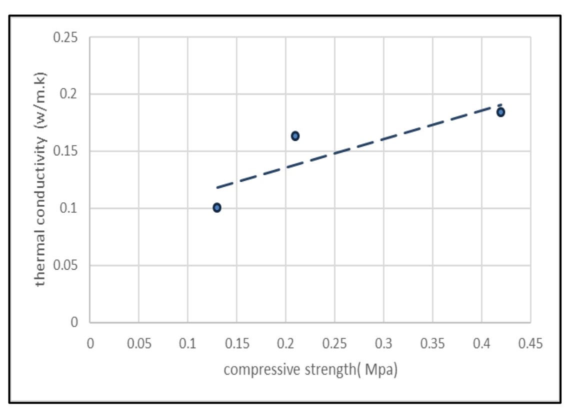
Benosman et al.[25] discussed in their research the influence of replacing cement with polyethylene terephthalate waste in cementitious matrix. The experimental research indicated that incorporation of polyethylene terephthalate particles decreased the ultrasonic pulse value and also improved the thermal conductivity and composite sportiveness. The decrease in the sorptivity of the composites value is therefore considered optimal for the durability of the mixes structures. The obtained polyethylene terephthalate -mortar composite materials tend to be low cost composites, helping to address some of the solid waste problems besides energy conservation.

Asadi et al.[4] reviewed the commonly used methods for calculating concrete thermal conductivity. Moreover, different factors that influencing the thermal conductivity of concrete were surveyed in the paper as well. The study disclosed that factors including, sort of aggregate, moisture content, sort of cementitious material, temperature, and density of concrete are thermal conductivity affecting components. It was found that transient methods are the mostly adopted methods by researches to define the k-value of cement-based materials. Moreover, k-value was found to be more prominent than that reported in dry conditions and showed a decreasing trend with temperatures elevating.

Aciu et al. [26] suggested to recycle plastic waste materials as an attempt to find proper solution to the major issues in the management of plastic waste. Results clearly showed that the thermal conductivity of mortar containing PVC recorded a reduction of an approximately 65% than the control formula. These encouraging findings motivated the use of PVC as a plaster mortar to enhance the physical-mechanical properties of construction materials, however, it is not advised to be used on inner surfaces as a result of its reaction to an open fire.

Balto et al. [27] evaluated the use of waste materials comprising eggshell (ES), fly ash (FA) and expanded polystyrene (EPS) with different ratios as complements for sand to fitting the thermal insulating properties of composite concrete mortar and their properties compared with normal cement mortar (NCM). The customized mortar with EPS and ES mixed with 25% volume sand replacement offers a substantial decrease of 40% and 16%, respectively in thermal conductivity with no any changes in its workability. While the FA-modified mortar was able to provide 17% higher compressive strength compared to NCM.

Leyton-Vergara et al. (2019)[28] clarified the effect of the granulometry of expanded perlite on the thermal conductivity and few selected mechanical properties of lightweight mortars. In this study, three initial gradations of perlite were acquired and three pairs of twin test mortars with these gradations were tested. The results demonstrated that pure granulometry manipulation can have a considerable and very positive effect on the properties of the mix., including thermal conductivity and water absorption. Figure 3 showing the effect compressive strength, water absorption on thermal conductivity.



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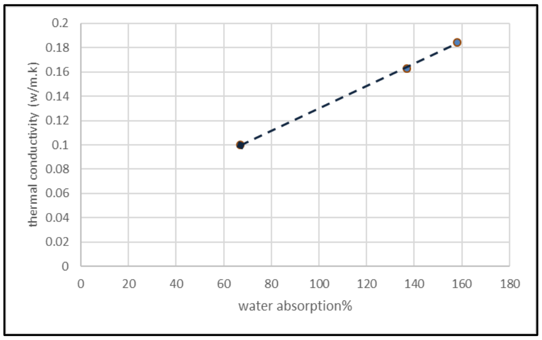

(b)

Figure 3. a): Relation between thermal conductivity and compressive strength, b): Relation between thermal conductivity and water absorption (Leyton-Vergara et al., 2019)

Contrafatto et al. [29] focused in this study on the evaluation of the mechanical, physical and thermal characteristics of lightweight insulating mortar reinforced by recycled Etna volcanic aggregates. According to the computational homogenization method at the mesoscale, the thermal properties of the mixture components influence the compound's resulting thermal conductivity. Moreover, it was stated that the mixtures ideal for lightweight and heat mortier are associated with mechanical and physical properties of composites such as thermal conductivity which were often within the range 0.154-0.266 W/mK.

Khalil and Mahdi [30] studied the impact of waste materials (irregular mix of plastic) on concrete characteristics and behavior. Three different ratios of coarse plastic aggregate (15, 25 and 45 %) were applied as substitutes to coarse natural aggregate by volume. The findings acquired recorded reduction in the compressive strength with slight rise in the workability. In addition, it was noticed that as the plastic waste aggregate increase, the dry density value of the concrete exhibited a notable decrease. However, a noteworthy enhancement was observed in the thermal conductivity of the mixtures containing plastic coarse aggregate compared to the plain mix. Eventually, it was assumed that concrete with 45% of plastic waste aggregate by volume was selected as structural lightweight concrete.

Rizvi et al.[31] used neural networks method to compute the effective thermal conductivity of two sands of different moisture content. The model anticipated experimental data was in line for the pure quartz sand, however, for quartz-feldspar the model over predicts the efficient thermal conductivity. The procedure was generally applicable for large geomaterials to effectively identify the parameters.

AlArab et al.[32] investigated the pozzolanic activity and thermal properties of concrete through assessment of synergistic action between ceramic waste powder (CWP) and blast furnace slag (BFS). In this study the testes and physicochemical characterizations were conducted using mixtures samples that produced either by incorporating separately 20% CWP, and 40% BFS, or a mix of 20% CWP and 30% BFS. Images of the electron microscopy scanning indicated that calcium hydroxide crystals are especially prominent in paste made only from cement, whereas for pastes containing CWP and BFS additions, these crystals have been reduced considerably. Frattini and strength activity index measurements validated these findings and indicating synergistic reactions that improved pozzolan reactions and contributed to higher calcium silicate hydrates.

Halim et al. [33] aimed to clarify the behavior of thermal properties in cement by adding polyethylene terephthalate waste to a concrete mixture. In total, four concrete mixes including 0%, 5%, 15% and 25% of polyethylene terephthalate were subjected to series of experimental analysis in order to calculate the thermal conductivity parameters of concrete blocks. The results were clearly highlighted the improvement of the mixes mechanical characteristics and the thermal performance which decrease heat gain and deliver better thermal insulation than the common a concrete mixture.

Cantero et al.[34] in their novel study they explored the thermal performance of concrete produced with cement replacements of 10 W/25% or 25 W/4% of ground recycled concrete (GRC) and of 25 W/50% or 50 W/60% mixed recycled aggregated aggregates (MRA) generated from construction and demolition waste. The thermal conductivity and several physic-mechanical characteristics of the concrete were measured using specific experimental software. The results revealed that 10% and 25% GRC in combination with 50% MRA decreased thermal conductivity from 7.9% to 11.8% and improved real thermal capacities by 6.0% to 9.1% compared to results showed by normal aggregate. In addition, the findings additionally support the claim that these new recycled concrete aggregate mixtures are more energy-intensive building materials than traditional concrete.

3. Conclusion

This review paper assessed the impact of utilizing several waste materials on the warm conductivity of concrete. The literature references cited in this paper showed that the waste materials utilized in all the experimental work exhibited significant effect in enhancing the thermal conductivity of concrete. Consequently, they were suggested as good thermal insulates. In most of the studies, the mixtures used showed a notable improvement in the mechanical properties as well. Furthermore, the modest expense of the waste materials utilized will motivate their incessant use. Based on all what mentioned above, further studies are needed to investigate the optimum use of these waste materials and also to increase their application in construction.

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