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# Thermal conductivity of hybrid recycled aggregate – Rubberized concrete

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## HIGHLIGHTS

- Thermal conductivity of different types of recycled aggregates concrete mixes.
- Hybrid recycled concrete aggregate-rubberized concrete (RARC) properties.
- Viable application of RARC as a non-structural thermal insulating material.

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## ABSTRACT

The following laboratory study examined the validity of incorporating varying amounts of recycled concrete aggregate (RCA) and crumb rubber (RA) in order to create a hybrid recycled aggregate-rubberized concrete (RARC), which boasts both acceptable physical and mechanical properties while maintaining a relatively low thermal conductivity. Further, the combined use of RA and RCA ensures environmental sustainability that can be maintained through the reduction of raw materials required for new concrete while also reducing the dumping of scrap tires.

The experimental investigation noted that a 20% replacement of natural coarse aggregates with RCA by weight, along with a 10% replacement of sand with RA by volume to produce RARC reduces the thermal conductivity of RARC relative to that of conventional concretes. Thus, indicating the viable application of RARC as a non-structural thermal insulating material.



## 1. Introduction

The useful application of otherwise waste materials such as demolished concrete and scrap tires within the construction industry allows for their use as a resource material thus solving disposal problems [12]. The use of Recycled Concrete Aggregate (RCA) in concrete can be considered as an applicable solution to the ever expanding world-wide construction industry [25]. This has enabled the concrete construction industry to be a net consumer of waste, using 47 times more waste than it generates, knowing that concrete itself is 100% recyclable [29].

Many studies have been conducted on rubberized cement containing crumb rubber as a replacement to fine aggregate at different percentages. The findings of these studies indicated that although the compressive and flexural strength of the rubberized concrete decreased as the percentage of fine aggregate replacement increased; its unit weight decrease [4,22,2].

Aiello and Leuzzi [1] investigated the effect of the size of rubber particles on the properties of rubberized concrete mixes. He found that a larger reduction of mechanical properties occurs when replacing coarse aggregate rather than fine aggregate with rubber particles. Moreover, an overview study focusing on engineering properties of rubberized concrete mixtures was deeply investigated by Hooton et al. [14]. Mixing rubber with polyethylene (PET) bottle producing a hybrid rubberized concrete has been studied by Yesilata et al. [32], revealing that: proper addition of selected waste materials into concrete can significantly reduce heat loss or improve thermal insulation performance.

The percentage of the waste materials to be used for the production of concrete mixs should not adversely affect its structural integrity. Researchers ascertained that, when RCA are used to replace up to 20–30% by weight of coarse Natural Aggregates (NA) in concrete, a slight effect to its properties is detected [25]. Based on such findings a conservative value for rubber replacement not exceeding 10% of fine aggregates combined with no more than 20% RCA replacing NA is used in this study to produce the hybrid Recycled concrete Aggregates-Rubberized Concrete (RARC).

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Extensive efforts have been taken on the mechanical properties and thermal conductivity of rubberized concrete [27,8], as well as on concrete incorporating RCA [26,4]. However, no previous work has reported on the thermal conductivity of RARC which incorporates a combination of scrap tire crumps and RCA. As thermal property is very important in many construction applications, this study aims to investigate the thermal conductivity of the hybrid concrete mix, focussing on its applicability to be used as an insulating material consequently conserving the environment and its natural resources.

Thermal conductivity (k) is the rate at which heat flows through material for a unit temperature difference and unit area, and is used to determine a materials steady state heat flow [31]. Thermal conductivity of concrete is sensitive to many factors, such as concrete density which is primarily related to the type and density of the incorporated aggregates in addition to some other properties as reported by Vangeem et al. [31] and furthermore to the aggregate volume fraction and moisture condition of specimen [16].

Studies on the thermal conductivity of cement paste to eliminate the effect of NA were conducted with an outcome that the maximum thermal conductivity of cement paste samples containing plain cement was 1.186 W/meter Kelvin (W/mK) [9]. Since aggregate comprise of 70% to 80% of the total solid volume of concrete [24], thermal conductivity of concrete may be significantly influenced by the type of aggregate because of the large differences in the thermal properties of various types of aggregates. The crumb rubber percentage is limited to 10% according to many studies that recommend this percentage for acceptable effect on compressive strength of concrete [20]. Sukontasukkul [27] reported that concrete with a 20% rubber replacement, decreased in strength to only 22–28% of that of conventional concrete. Recycled concrete aggregates mainly differ from natural aggregates in that they are composed of two different materials; natural aggregate and cement mortar attached to the surface of the NA. The attached mortar adversely affects the quality of RCA [15,21]. It lowers the compressive strength which limits its application in structural members. However, reduction in some properties like the density or the thermal conductivity may put it into perspective for some non-structural applications.

## 2. Materials and methods

An experimental program was developed to investigate key properties from a variety of different rubberized concrete mixtures incorporating recycled aggregates. The tests are limited to include; slump test, density, compressive strength, water absorption and thermal conductivity of a RARC concrete which is prepared with the addition of different RCA percentages to a 10% rubberized concrete. The results were compared to a control concrete mixture incorporating NA along with the other mixtures using the different percentages of RCA.

### *2.1. Materials*

Four types of aggregates were prepared to be used in this study:

1. Natural coarse aggregates, specifically crushed limestone, was locally sourced to obtain the control concrete mix. Gradation of the NA aggregates was shown in Fig. 1 within the standard limits. Any material passing a 5 mm sieve was discarded.
2. RCA was obtained by crushing previously tested concrete samples with a compressive strength equal to 27 MPa. The obtained particles were then washed, dried and sieved using standard course aggregate sieves. The gradation curve is shown in Fig. 1. The graduation of both natural and RCA aggregates is within BS 882 for grading requirements for coarse aggregate with a nominal maximum size of 20 mm to 5 mm. Any material passing a 5 mm sieve was discarded. The RCA was used to replace (5–20%) of NA.
3. Fine aggregate is natural silica sand with gradation as shown in Fig. 2 within the British standard limits.
4. Crumb rubber was obtained from a local industrial unit in Jordan. The crumb rubber was of a nominal size between 4.75 mm and 0.075 mm [23]. It will be used to replace (0–20%) fine aggregates by volume. The gradation curves for fine aggregates and crumb rubber are shown in Fig. 2 lying within the British standard limits. Crump rubber particles size compared to sand size is shown in Fig. 3.
5. The cement used in all mixes is ordinary Portland cement conforming to ASTM C 150-92 – Type I specifications.

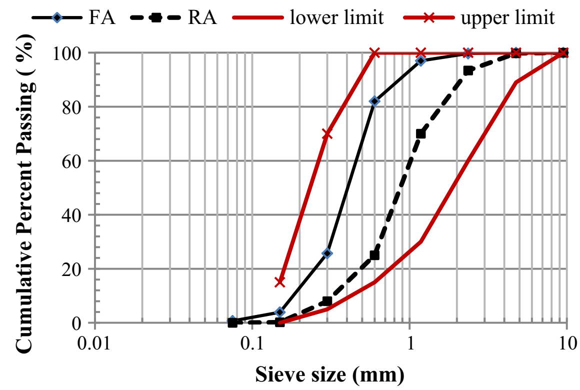


**Fig. 1.** Gradation curves for crumb rubber and sand within the British standard limits.

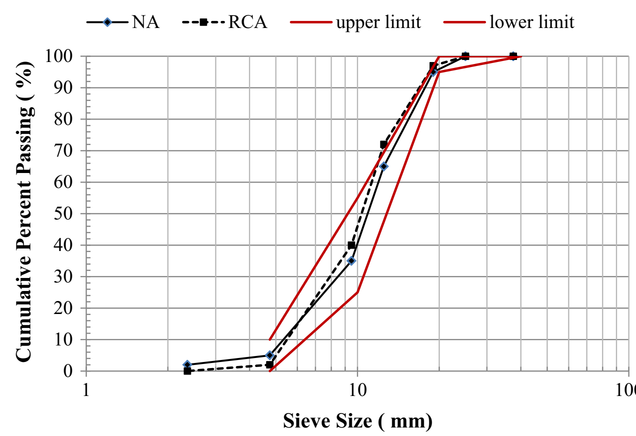


**Fig. 2.** Gradation of NA and RCA within the British standard limits.

The Specific gravity and absorption of the aggregates was measured using ASTM C127 and ASTM C128. The average of three values was calculated and presented in Table 1. The hardness of the aggregates using Los Angeles Abrasion (LA) was obtained using ASTM C131 for both NA and RCA and tabulated in Table 1.

Using the prepared materials, the following concrete mixes were prepared according to the type and percentage of recycled aggregates used:

a. Conventional concrete mix of water/cement ratio (w/c) of 0.56 was designed in the laboratory.
b. Concrete mixes containing RCA were prepared using different RCA percentages as a replacement to NA, while all other