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## Effect of crumb rubber aggregate on the performance of cementitious composites: A review

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# Effect of crumb rubber aggregate on the performance of cementitious composites: A review

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**Abstract.** The increasing use of cementitious composites for different infrastructure constructions has led to an increase in the consumption of raw materials such as aggregate which is a major component in cementitious components. In order to reduce the huge strain posed on the natural sources of aggregate, and continually meet the increasing demand of aggregates to produce cementitious composites; the use of recycled products such as crumb rubber as aggregate in these composites is a viable alternative. However, as the properties of crumb rubber differ from those of conventional aggregate, it is paramount to understand how the incorporation of crumb rubber affects the performance of the cementitious composites. Therefore, this paper presents an overview of how the use of crumb rubber as aggregate affects the performance of cementitious composites in terms of its mechanical, durability, thermal and insulation properties. Conclusions from this paper showed that crumb rubber content in cementitious composites can be optimized to achieve desired properties. Also, the use of crumb rubber as aggregates in cementitious composites reduce significantly the embodied carbon and cost of the composite.

## 1. Introduction

Cementitious composites have been the base construction material we use for various construction applications due to its numerous advantages. A cementitious composite is any composites that incorporate Portland cement as its main binder, and this composite can be in the form of concrete, mortar, grout, etc., depending on its composition. With the numerous advantages of cementitious composites also comes limitations of which sustainability is a major one. The increasing utilization of cementitious composites for different applications has resulted in the high consumption of raw materials and consequent degradation of the environment [1]. The evolution of cement science over the years has seen the replacement of a larger percentage of cement with alternative materials such as supplementary cementitious materials [2–5]. Consequently, Portland cement can be totally replaced with the use of alternative binders such as alkali-activated binders [5–8]. Nonetheless, there is a need to also pay huge effort into finding alternative waste materials such as recycled products that can be incorporated into cementitious composites as aggregate [9–12].



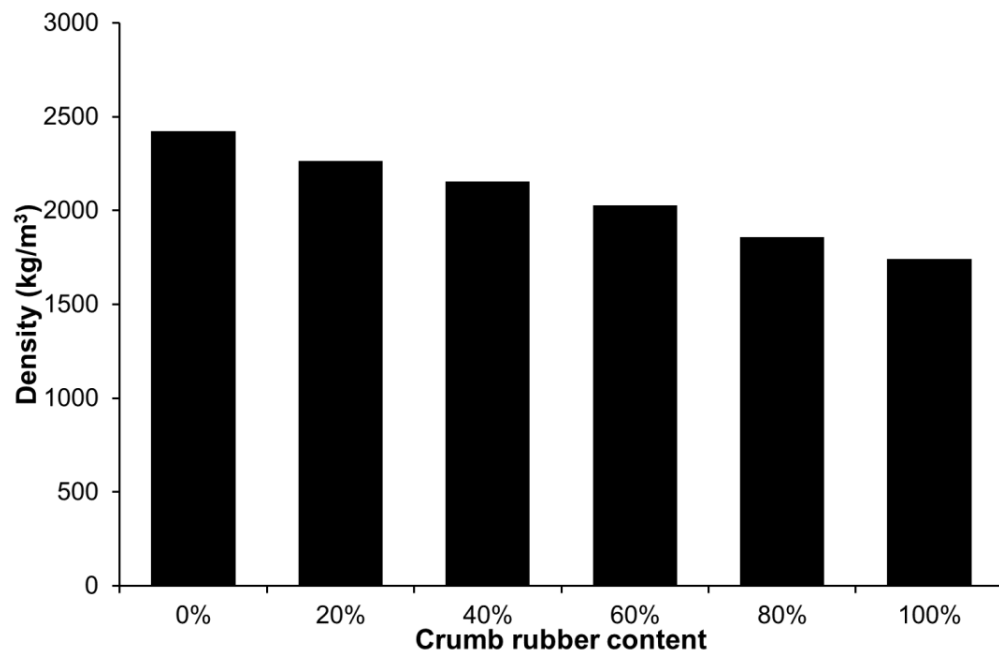
A promising future application is the use of crumb rubber as aggregates in cementitious composites. Crumb rubber aggregates are obtained from recycled scrap tyres. Scrap tyres are a huge menace to the environment as they pose both physical and health hazards when disposed of improperly in the environment [13,14]. The consequent increase in population coupled with the increasing number of car users has led to a corresponding increase in the waste tyres disposed into the environment. In the United States alone, about 250 million scrap tyres are generated annually and this quantity is expected to increase in the coming years [15]. Most of these scrap tyres are disposed of in open areas such as car lots, deserts, etc., making it a huge aesthetic and environmental menace. Therefore, finding a useful way to manage these scrap tyres by utilizing them as aggregates in cementitious composites will not only help to make our environment sustainable and beautiful but will also embody it with an economic value. The use of recycled tyre also referred here as crumb rubber has been extensively incorporated into materials such as asphalt mixtures. However, its use in cementitious composites has been limited. Nevertheless, there have been studies that have investigated the use of crumb rubber in cementitious composites. For example, Topcu [16] explored the effect of the content and crumb rubber size on the mechanical properties of concrete. Sodupe-Ortega incorporated crumb rubber as aggregate into concrete to produce light-weight composite [17]. The use of crumb rubber as aggregate have also been explored in the area of alkali-activated systems. Dehdezi *et al.* [18] and Wongsu *et al.* [19] utilized crumb rubber in alkali-activated fly ash, while Aly *et al.* [20] incorporated crumb rubber as aggregate in alkali-activated slag system. Zhong *et al.* [21] evaluated the effect of crumb rubbers combined with waste tyre steel fibres on the properties of a binary system of alkali-activated slag and fly ash.

The use of crumb rubber in cementitious composites has been found to enhance the resistance of the composites to abrasion, alkali-silica reaction, freeze-thaw, etc. [8–10]. However, there is a consequential effect of the crumb rubber on the mechanical properties of the composite which becomes significant with increasing crumb rubber content regardless of the binder system utilized. Therefore, in order to propel more awareness and application of crumb rubber in cementitious composites, this review was undertaken to explore how the incorporation of crumb rubber affects the performance of cementitious composites. The properties of cementitious composites briefly discussed are the density, mechanical, durability, insulation and thermal properties. It is anticipated that this review will serve as a useful reference and resource for stakeholders in the construction, research and education community.

## **2. Cementitious composites incorporating crumb rubber**

### *2.1. Density*

When crumb rubber particles are incorporated into cementitious composite, the resulting density is lower when compared to those with conventional aggregate. The reduction in density with the incorporation of crumb rubber can be attributed to the lower density of the crumb rubber particles, coupled with the introduction of more air content into the composite [24]. Therefore, with proper optimization of crumb rubber to achieve desired mechanical properties, crumb rubber can be utilized to produce a lightweight cementitious composite. The effect of crumb rubber proportion on the density of concrete as observed by Medina *et al.* [25] is presented in figure 1. It will be observed from figure 1 that the density of the concrete mixtures reduces with the increasing proportion of crumb rubber content.



**Figure 1.** Effect of crumb rubber proportion on density (data from [15]).

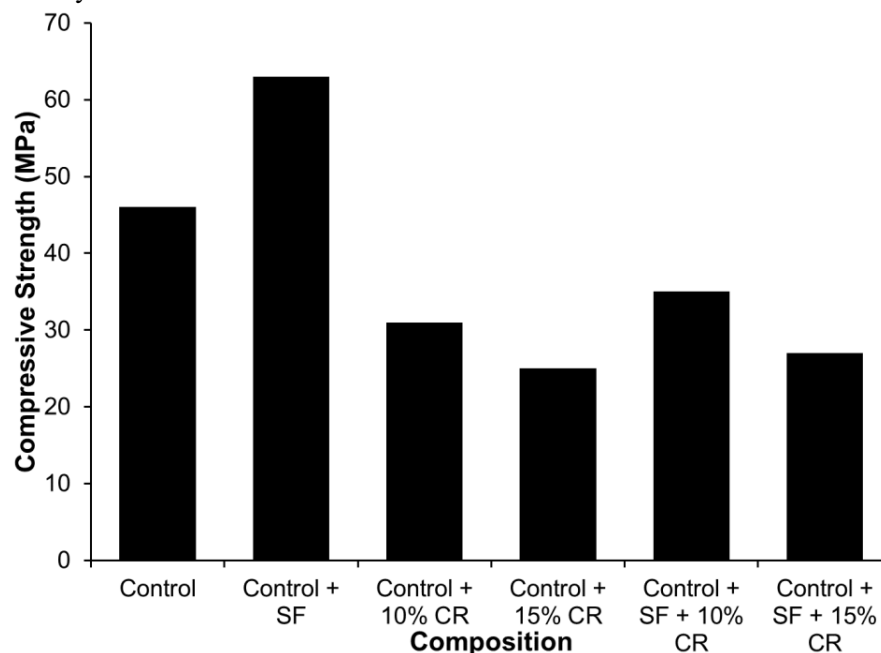
## 2.2. Mechanical Properties

An early study by Eldin and Senouci [26] showed that the incorporation of crumb rubber as aggregate in concrete mixtures resulted in lower compressive strength and split tensile strength. However, the fracture energy and toughness of the matrix was improved. This observation agrees with that of Topcu [16] and Khatib and Bayomy [27] where they also concluded that the use of crumb rubber in concrete mixes enhanced the plasticity of the matrix even though the compressive strength was lowered. The reduction in the compressive strength of mixtures incorporating crumb rubber can be attributed to the lower hardness of the crumb rubber and the reduced bond between the crumb rubber and the cementitious matrix. Najim and Hall [28] used crumb rubber as partial replacement of fine aggregate up to 15% in self-compacting concrete. Their results correspond to the observation made for conventional concrete as they observed a decreasing compressive, split tensile and flexural strength with increasing crumb rubber content.

In an attempt to enhance the performance of mortar incorporating crumb rubber, Onuaguluchi and Banthia [29] incorporated silica fume as a supplementary cementitious material. However, there was no significant increase in the compressive strength of mixtures incorporating crumb rubber and silica fume and those with only silica fume as presented in Figure 2. In contrast to most studies, Benazzouk *et al.* [30] and Topcu [16] observed an increase in flexural strength in the range of 15 – 35%. However, a reduction in the compressive strength of up to 50% was reported in their studies. Zhong *et al.* [21] incorporated crumb rubber as aggregate and recycled tyre steel fibre as reinforcement in an alkali-activated mortar; the flexural strength was enhanced significantly. However, a reduction in the compressive strength of the mixtures incorporating crumb rubber persists.

Generally, the reduction in compressive strength with the incorporation of crumb rubber can be attributed to the low toughness and introduction of voids into the composites. The poor interfacial bonding between the aggregates and the cementitious matrix can also be attributed to this lower

compressive strength. Nonetheless, crumb rubber can be incorporated into cementitious composites to enhance its ductility.



**Figure 2.** Effect of crumb rubber on compressive strength (data from [11]).

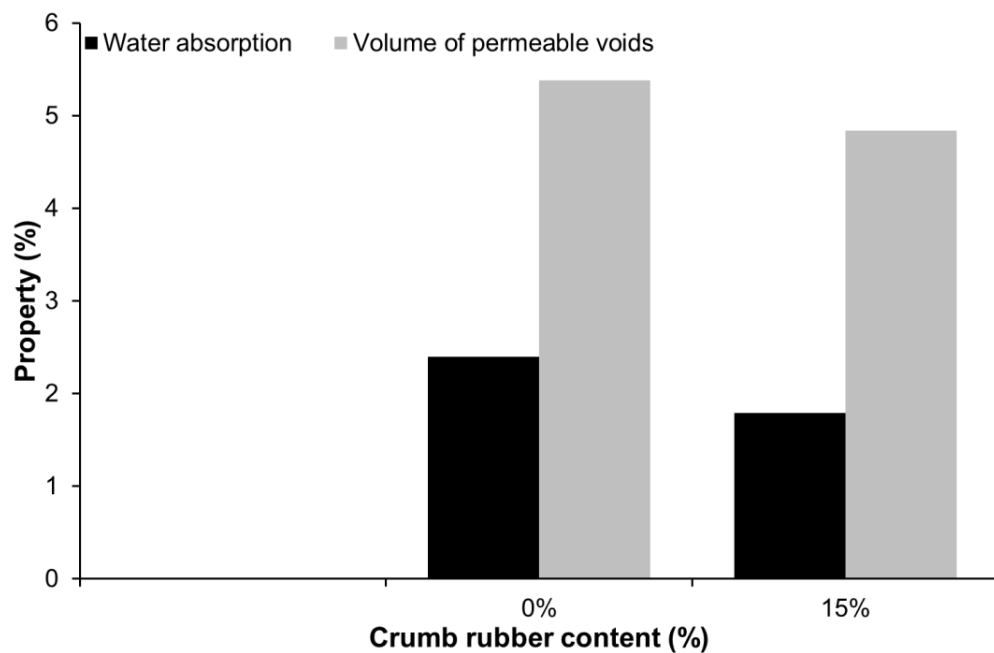
### 2.3. Durability Properties

In contrast to the mechanical properties of cementitious composites incorporating crumb rubber, there is a limited number of studies on the durability properties. The durability properties of a composite indicate its resistance to the various deleterious forces in the environment to which it is subjected. Sorptivity which is one of the permeability properties of cementitious composites that can be used to assess the durability properties of the composite has been found to reduce with the incorporation of crumb rubber as aggregate into cementitious composites [11–13]. However, the absorption and porosity of cementitious composites incorporating crumb rubber have been found to significantly increase [24,25]. This detrimental effect can be attributed to the poor interfacial bonding between the crumb rubber particles and the binder system. The effect of the incorporation of crumb rubber on the water absorption and volume of permeable voids concrete mixtures is presented in Figure 3. It will be observed from Figure 3 that the water absorption of concrete reduced with the incorporation of crumb rubber. This can be attributed to the reduction of the volume of permeable voids resulting from the discontinuity of the voids path when crumb rubber was introduced into the mixture.

Recently, Onuaguluchi and Banthia [29] evaluated the long-term performance of cementitious composites incorporating crumb rubber as aggregate. Their result showed that the possible introduction of air voids into the composite with the incorporation of crumb rubber resulted in lower degradation of the composite in the sulphate environment. They concluded that the use of crumb rubber as partial replacement of fine aggregate in the range of 10 to 15% of the conventional aggregate embodied it with higher resistance to sulphate attacks. This observation is similar to that of Yung *et al.* [36] where they observed concrete incorporating crumb rubber have a higher resistance to sulphate attack compared to concrete samples with the conventional fine aggregate. However, to achieve the use of crumb rubber in sizes ranging from 0.3 mm – 0.6 mm and as a replacement of fine aggregate in the range of 5 – 10% was

suggested. The higher resistance of cementitious mixtures incorporating crumb rubber can be attributed to the crumb rubber particles being “Sulphur bearing” Onuaguluchi and Banthia [37].

Regardless of some of the detrimental effects of crumb rubber, it can be incorporated as aggregate into high strength concrete to reduce the threat of spalling when the concrete is subjected to an elevated temperature such as a fire.



**Figure 3.** Effect of crumb rubber on the water absorption and volume of permeable voids (data from [13]).

#### 2.4. Thermal and Insulation Properties

The incorporation of crumb rubber into cementitious composites such as concrete has been found to result in higher thermal and insulation performance [28–30]. Sukontasukkul [41] was able to increase the noise reduction coefficient of concrete walls by 400% with the incorporation of crumb rubber additives in the concrete. Extensive research carried out by Herrero *et al.* [40] presented in Figure 4 showed that the thermal conductivity of concrete can be reduced significantly with the incorporation of crumb rubber as aggregate.

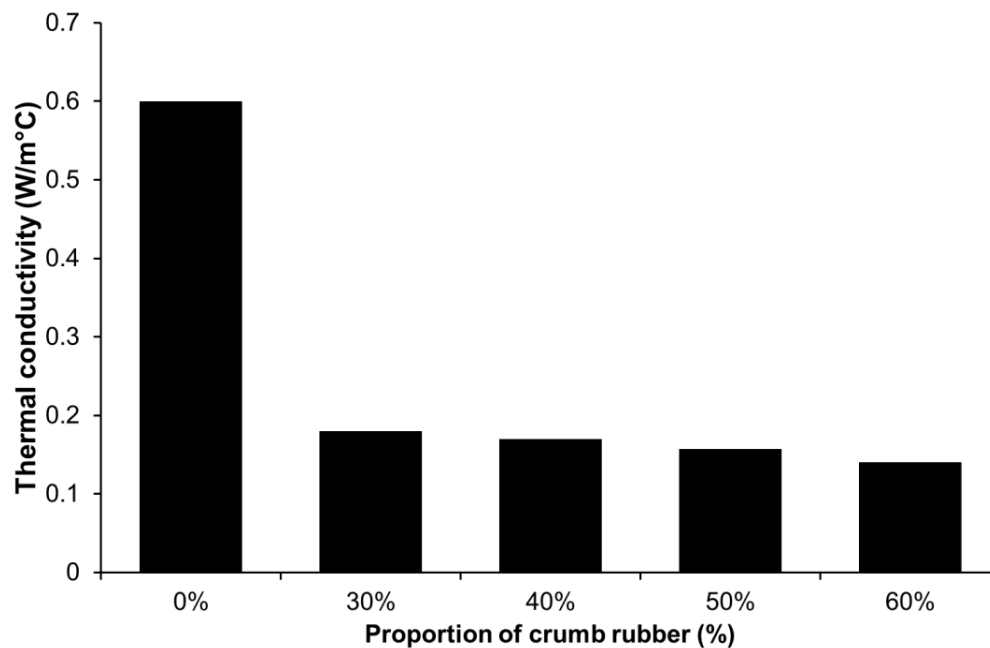


Figure 4: Effect of crumb rubber on the thermal conductivity (data from [31])

### 3. Conclusion

This paper has explored how the incorporation of crumb rubber as aggregate in cementitious composites affects its corresponding properties. Based on this review, the following conclusions can be drawn:

1. Utilization of crumb rubber as aggregate in a cementitious composite is a sustainable and economical way to manage the impending threat of waste tyre disposal in the environment
2. The low hardness of crumb rubber coupled with the introduction of additional voids into the composite when used as aggregate can lead to a reduction in the mechanical properties of the composite.
3. The use of crumb rubber to replace fine aggregate in cementitious composites in the range of 10 to 15% enhance its resistance to durability threats such as sulphate attack. However, the use of a higher proportion of crumb rubber is injurious to the overall integrity of the composite.
4. The different optimum content suggested for different properties of cementitious composite calls a need for the development of a design system to optimize the crumb rubber content for the overall performance.
5. More research is imminent on evaluating the durability properties of various cementitious composites incorporating crumb rubber.

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