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Article

Investigation on High-Temperature Effect of Recycled Concrete Aggregate on Mortars

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Abstract: In this study, the use of Recycled Concrete Aggregate (RCA) in mortar samples and their effects on mortars under high temperature were investigated. Mortar samples were produced in the dimensions of 40x40x160 mm. GDA, which has been converted into fine aggregate, has been replaced with 25%, 50% 75% and 100% of the sand used in mortar production. Mortar samples were exposed to 200, 400, 600, and 800 ºC after 28 days of standard curing. After the applied temperature, ultrasound transition speed, weight losses, flexural and compressive strengths were determined. With the increase of RCA, there was a decrease in the physical and mechanical properties of the mortars. Along with the increase in temperature, ultrasonic pulse velocity, compressive, and bending strengths were also decreased.

Keywords: Mortar; High temperature; Recycled Concrete Aggregate; Sustainability.

1. Introduction

The inclusion of by-products used in place of natural aggregates in concrete is a valid strategy to minimize impacts in different industrial processes due to increased waste generation [1]. Replacing aggregates with various recycled materials has led to significant advances in the construction industry, reducing the need for new natural aggregates. Materials used as an alternative to natural aggregate include recycled concrete, recycled glass, scrap tires, plastics, and by-products of other industries [2-3]. Construction wastes, which is called as rubble, can occur with intentional destruction for reasons such as remodeling and repair, as well as destruction as a result of earthquake-like natural disasters [4]. When concrete structures are demolished or renewed, recycling of concrete is an increasingly common method of disposing rubble [5-6]. Recycling of these wastes has become a more attractive option with the recycling process due to the increase of environmental awareness because of the insufficiency in the landfills and destruction of fertile fields, which were previously carried to waste storage areas [7]. In order to produce recycled aggregates instead of natural aggregates, it is a practical solution that mechanically crush of concrete and reduce it to aggregate sizes [8-9]. A

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number of recommendations have been given to regulate the design, manufacture, and construction of recycled concrete aggregate for use in structural carriers in many countries [10-11]. In this area, much scientific researches have been conducted to encourage the recycling of waste concrete and aim to reduce solid waste emissions. The evaluation of recycled concrete aggregates as an environmentally friendly material is still under investigation.

Although the cementitious mortar is an inorganic material, due to crack growth and chemical composition of the morphological structure under physiological effects, such as after exposure to extremely high temperatures caused by fire, vary significantly [12]. When cement-based mortars are exposed to high temperatures, three main mechanisms occur, namely pore pressure, thermal mismatches, and decomposition of hydration products [13]. The first two mechanisms are related to incompatibility between aggregates and cement paste [14]. Therefore, changing the type of aggregate in concrete can have a significant impact on these two mechanisms. Concrete made with regular Portland cement starts to change as of 150 ⁰C. The water in the capillaries and then in the gel cavities evaporates and shrinks. With the appearance of cracks, the tensile strength decreases, and the pressure resistance begins to decrease as of 300 ⁰C, since dehydration has started in alumina and iron oxide components. At 400 ⁰C, $Ca(OH)_2$ turns into CaO with the effect of 2 temperature, its volume shrinks in the order of 30%. The water sprayed during quenching converts CaO back to $Ca(OH)_2$, this time, the volume expands, and damage occurs. When 400 ⁰C is exceeded, silica gels begin to crumble. When 600-800 ⁰C is exceeded, all items are destroyed. At these temperatures, concrete elements also lose about 70% of their strength [15-16]. Component materials used in concrete also greatly affect the strength of concrete under the influence of high temperatures. The aim of this study is to investigate the effect of recycled concrete aggregate (RCA) in mortar samples on some characteristic properties of mortars under high temperatures. For this purpose, RCA has been used with the crushed sand used in the production of RCA mortar, which has been brought to a size of 0-4 mm, by displacing at the rates of 25%, 50% 75% and 100%. Mortar samples were exposed to 200, 400, 600, and 800 ⁰C after 28 days of curing. After the applied temperature, the physical and mechanical properties of the mortars were determined.

2. Materials and Methods

Cement, which is one of the components of the mortar is used in the production of test samples, is CEM I 42,5 R type Portland cement produced in accordance with TS EN 197-1 (2012) [17]. The chemical analysis of the cement used was taken from the producer factory and is given in Table 1. In the experimental study, the city water of Osmaniye province, which complies with TS EN 1008 (2003), was used. In the mortar samples produced as part of the study, crushed sand and recycled concrete aggregate (RCA) were used as aggregates [18]. Concrete wastes obtained in the province of Osmaniye were brought to the size of 0-4 mm like crushed sand with the help of crushers.

The standard mixture was used in all samples produced in the experimental study; the binder and water content was kept constant. The reference sample aggregate consists entirely of crushed sand, a mixture of cement and water. In other samples, 25%, 50%, 75%, and 100% displacement of RCA by crushed sand was made. The amount of materials used in the production of mortars are given in Table 2.

Table 1. Chemical analysis of CEM I 42,5 R Portland cement.

Chemical analysis	CEM I 42,5 (%)
CaO	62,72
SiO_2	20,00
Al_2O_3	4,92
Fe_2O_3	3,76
MgO	1,84
SO_3	2,65
K_2O	0,73
Na_2O	0,26

After preparing the mortar mixture, it was poured into the molds of 40x40x160 mm in two stages on the cement shaking table and placed. The samples taken from the mold one day later were subjected to standard curing in water. In order to reveal the effect of RCA in case of exposure to high temperatures in mortar samples, certain degrees of high temperatures were applied to the mortars. The high-temperature application was required by exposing mortar samples to 200 ⁰C, 400 ⁰C, 600 ⁰C and 800 ⁰C temperatures at a temperature of 10 ° C / min in a laboratory-type oven with 1800 ⁰C and

60 minutes at all temperature values. They were kept in the oven. Then it was left to cool until it reached the temperature of the laboratory conditions. The bending strength determination of the mortar samples both in ambient condition and exposed to high temperature with the mid-point loading type in accordance with the TS EN 196-1 (2016) standard and the compressive strength in accordance with the TS EN 12390-4 (2002) standard were determined [19,20]. The ultrasound transition rate measurement of the samples was made according to TS EN 12504-4 (2004) [21]. The distance between the two surfaces of the samples was measured with the help of a caliper, and it was ensured to be smooth with ultrasound gel in order to avoid any air gap on the surfaces to be measured. A sample was placed between the probes (transmitter and receiver), aligned, and the device was operated. The transition time of the sound wave in the device is recorded. The intermediate distance value between the probes was proportional for the time read from the device, and ultrasound transition speed values were calculated. Specific properties of samples exposed to high temperatures and samples under ambient conditions were compared.

Table 2. Amounts of materials used in mortar production (kg/m3).

RCA ratio	Crushed Sand	RCA	Cement	Water
%0	1350	0	450	225
%25	1012,5	337,5	450	225
%50	675	675	450	225
%75	337,5	1012,5	450	225
%100	0	1350	450	225

3. Results and Discussion

The Ultrasonic pulse velocity (UPV) of the mortar samples is given in Figure 1. With the increase in the rate of RCA used in the fees, ultrasound transition speeds decrease. In the reference sample at ambient temperature, while the ultrasound transition speed is 3663 m / s, it has been observed that the rate of RCA decreases to 2717 m / s in case the rate of increase to 100%. Along with the increase in RCA ratio, there was a decrease in UGS. The main reason behind that is the sound passes longer due to the increase in RCA. In other words, it is understood that the ratio of space increases in the mortar depending on the rate of RCA. UGS values decreased significantly with the increase of the high-temperature effect.

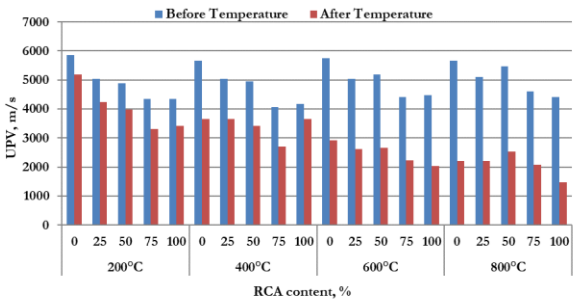

Figure 1. Ultrasonic pulse velocity (UPV) of RCA containing mortars.

After applying high temperature, weight losses of the samples are given in Figure 2. It was observed that weight losses increased with increasing temperature. In the reference sample, 1.69% weight loss occurs at 200 ^{0}C while the weight loss increased to 5.06% when the temperature increased to 800 ^{0}C. With the use of RCA, a decrease of 25% was observed in weight losses; it was observed that weight loss increased with the increase of RCA ratio. When the temperature was 200 ^{0}C, while the weight loss in the non-RCA grout sample was 1.69%, while 25% used RCA mortar sample decreased to 1.60%. Weight loses increased to 2.0%, 2.39% and 2.68%, respectively, in case of using 50%, 75% and 100%. When the temperature was 800 ^{0}C, while the weight loss in the non-RCA grout sample was 5.06%, while 25% used RCA mortar sample decreased to 4.84%. Weight losses increased to 5.36%, 26.119%, and 7.56%, respectively, in case of using 50%, 75%, and 100%.

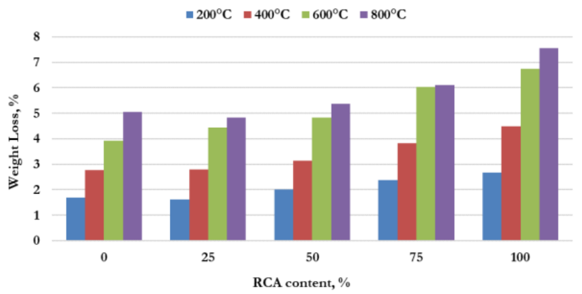

Figure 2. Weight loss of mortar samples after temperature.

Compressive strengths of mortar samples before and after temperature are given in Figure 3, and bending strengths are given in Figure 4. When the pre-temperature values are examined, the compressive strength of mortar samples without RCA is 44.5 MPa, while the compressive strengths are determined as 42.30 MPa, 30.11 MPa, 25.63 MP and 25.23 MPa, respectively, in the case of using 25%, 50%, 75% and 100% of RCA. Therefore, the compressive strength of mortars tended to decrease with the use of RCA. This is because the weakening of the matrix phase on the surfaces of the RCA during the breaking of the RCA and by the relatively easy breaking of these regions in the new pulp, it reduces the adherence resistance and, consequently, the pressure resistance of the composite [22]. As a result of applying high temperatures to the mortars, a significant reduction in compressive strength was observed. However, with increasing the temperature to 200 °C, the pressure resistance of mortars increased. Then, with increasing the temperature, pressure values tended to decrease. This situation occurs due to the shrinkage of the cement paste around 200 °C and, accordingly, it provides some increase in strength [23]. As the temperature increases more, the shrinkage that will occur with the loss of this water increases the strength of the concrete, and the vapor pressure that appears in the concrete may cause the concrete cover to crack and break off. Another component in the cement paste next to C-S-H is $Ca(OH)_2$ (calcium hydroxide). The chemical water and gel water of C-S-H start to disappear from 300 °C and turn into CaO by losing $Ca(OH)_2$ water around 530 °C [24]. Damages occurring at some temperatures cause the strength of concrete to decrease significantly [25]. The reference sample decreased by 7.33% at 400 °C, 40.61% at 600 °C, and 66.77% at 800 °C. Samples containing 25% RCA have decreased by 11.75% at 400 °C, 56.04% at 600 °C and 69.59% at 800 °C. Samples containing 50% RCA decreased 17.17% at 400 °C, 41.43% at 600 °C and 62.47% at 800 °C. Samples containing 75% RCA have decreased by 36.83% at 400 °C, 42.09% at 600 °C and 58.51% at 800 °C. Samples containing 100% RCA have decreased by 47.10% at 400 °C, 53.63% at 600 °C and 40.52% at 800 °C.

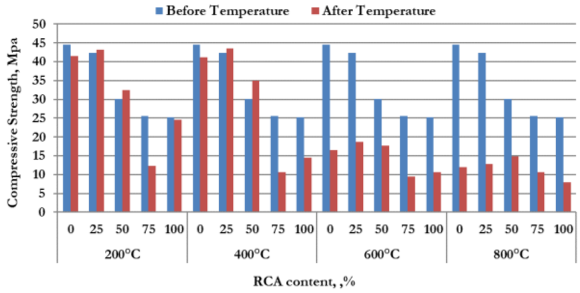

Figure 3. Compressive strength of mortar samples before and after temperature.

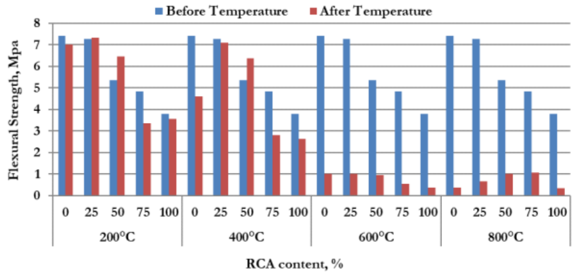

Figure 4. Flexural strength of mortar samples before and after temperature.

In mortar samples used in RCA, behavior similar to compressive strengths were observed in flexural strengths (Figure 4). While the bending strength before the temperature is 7.43 MPa, if 25%, 50%, 75%, and 100% of RCA is used, the compressive strengths are determined as 7.26 MPa, 5.35 MPa, 4.82 MPa, and 3.79 MPa, respectively. In the reference sample, bending strength increased at 200 °C, 4.64% at 400 °C, 40.64% at 600 °C, and 80.34% at 800 °C. In samples containing 25% RCA, there was an increase in flexural strength at 200 °C, 8.95% at 400 °C, 56.04% at 600 °C, and 83.47% at 800 °C. In samples containing 50% RCA, an increase in flexural strength occurred at 200 °C, 18.50% at 400 °C, 35.06% at 600 °C and 79.06% at 800 °C. Samples containing 75% RCA decreased 5.39% at 200 °C, 42.11% at 400 °C, 54.71% at 600 °C and 79.04% at 800 °C. Samples containing 100% RCA decreased 11.60% at 200 °C, 30.87% at 400 °C, 53.82% at 600 °C and 87.07% at 800 °C.

4. Conclusions

The findings obtained from the experiments and analyzes conducted throughout the study are presented below.

With the increase of RCA ratio, ultrasound transition speeds decrease. The increase in the void ratio, along with the RCA ratio, has caused a decrease in the speeds caused by the sound passing through the void longer. When compared with crushed sand, RCA has more space and decreases speed by increasing the sound transition time.

In the reference sample, 1.69% weight loss occurs at 200 ⁰C while the weight loss increased to 5.06% when the temperature increased to 800 ⁰C.

With the use of RCA, a decrease of 25% was observed in weight losses; it was observed that weight losses increased with the increase of RCA ratio.

While the pressure and flexural strengths were generally decreased with the increase in temperature, an increase of up to 400 ° C was observed with the use of RCA in 25% and 50% ratios. It is determined that if the ratio of RCA is 25% and 50%, they are resistant up to 400 ºC.

It has been observed that RCA can be used as aggregate in mortar. However, if the RCA ratio exceeds 25%, physical and mechanical properties are lost. In the case of high temperature, it is observed that the durability decreases if this rate exceeds 50%.

For the use of RCA in mortars, a 25% ratio is recommended considering both physical and mechanical properties and high temperature effects.

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Conflicts of Interest

The authors declare no conflict of interest.

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