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# Effect of Wastewater Curing and Elevated Temperature on Recycled Concrete Aggregates from Construction and Demolition Wastes

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*A B S T R A C T*

In this study, natural coarse aggregates were replaced with coarse recycled concrete aggregate (RCA) in 0 %, 50 %, and 100 % extracted from construction and demolition wastes. Their recycling could lead to a greener resolution for preserving the environment and paving the way for sustainability through solid waste management. The compressive strength of 0 %, 50 % and 100 % RCA at 365 days was reduced by 3.97 %, 4.88 %, 6.81 %, respectively, compared to the compressive strength at 28 days. Tensile strength at 365 days was reduced by 4.31 %, 6.50 % and 9.83 % compared to tensile strength at 28 days. There was no discernible effect of water type on the strength properties of concrete. Compared to other combinations, 100 % RCA concrete experiences a greater percentage of weight loss owing to evaporation of free water. When temperature was elevated, the concrete matrix expands and deep cracks were observed on the concrete surface. The overall performance of recycled aggregate concrete was not much influenced by the use of such aggregates, so these findings will add a new achievement to a sustainable construction through solid waste management.

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## INTRODUCTION

The World Business Council for Sustainable Development [1] states that changes in demand and infrastructure development lead to the production of construction and demolition (C&D) waste. This causes significant issues for solid waste management in terms of disposal space, unauthorized dumps, mixing with biodegradable trash, etc. The C&D waste disposal and remediation are both expensive and hazardous to the environment. The C&D waste is the one source of recycled concrete aggregates (RCA) [2] as a substitute for natural coarse aggregates (NCA) and has become an advanced solution to the non-availability of natural aggregates to prepare the concrete. The C&D waste recycling could result in a more environment friendly solution, paving the way for sustainability and solid waste management. Recycling on a broad scale can minimize natural aggregate consumption [3-5] and contribute to environmental preservation [6]. Different types of waste material, like rice husk ash, quarry dust, macro fly ash, guinea corn husk ash, and oak bark ash [7-9], are used to manufacture concrete for pavement and structural applications [10-12]. It is capable of resolving not just the environmental protection issue, but also the requirement for a sustainable society through solid waste management. As a material, RCA is becoming more appealing to the building sector because of its availability.

The concept of using recycled aggregate concrete (RAC) for structural purposes is now gaining scalability, and research in this area is also progressing. Around 1.8 million tons per year of RCA are available in India [13]. The use of RCA up to 20% in reinforced concrete is permitted by BIS IS: 383 [14] for fine and coarse aggregates. The experimental results agree with the empirical expression for RAC [15], and as the RCA ratio improved, the toughness and ductility of RAC decreased [16]. Most of the mechanical properties of the recycled aggregates are the same as those of the reference concrete [17]. RCA improves concrete's tensile strength with time [18]. It is stated that the use of RCA as a structural material in civil engineering construction is safe and practicable based on its mechanical and structural properties [19]. RAC beams have better performance than

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NAC beams, and they can be used as structural concrete [20]. The utilization of RAC in structural applications has become an essential aspect in recent studies [21]. The experimental examination of RAC beams demonstrated that altering the amount of RCA in RAC had no effect on structural behavior [22, 23]. The globe moves toward sustainable sources, and the research toward innovation with new technologies should be transparent as well as acceptable at large [24, 25]. The wastewater treatment plant and sewer structures, such as domestic sewage, industrial sewage, or storm water carrying concrete structures, are exposed to wastewater, and the industrial structures near to boilers in the textile industry as well as nuclear power plants are exposed to heat. The durability of such structures may be affected by wastewater and heat in the field. Problems with the water quality in tropical areas make this problem in concrete structures worse, especially in lean mixes. According to the authors' awareness, this is the only work that has compared the mechanical characteristics of RAC when it is heated and subjected to wastewater curing. This work also investigates the impact of the percentage of RCA in RAC.

This paper will address the paucity of previously published research on this subject in order to provide new facts on the reliable behavior of RCA concrete specimens under long term wastewater curing and elevated temperatures. By conducting laboratory investigations, this limited research study sought to investigate the possibility of using wastewater for curing as an alternative to potable water, as well as the effect of elevated temperature on the properties of RCA concrete. These findings will be specified that more large-scale studies are needed to reach a consensus on performance of RCA concrete and improve the structural database.

## MATERIAL AND METHODS

This experiment employed freshly packed 53-grade OPC compliant with IS: 12269-2013 [26]. According to IS 383:2016 [14], crushed NCA with a maximum nominal size of 20 mm and fine aggregates (FA) of zone II were used to cast the concrete. Figure 1 depicts the RCA obtained from the demolished structural element of a building.

With the help of a mechanical breaker and a jaw crusher, the old concrete structure piece was broken down into a required size and shape that could be used as coarse aggregate. The RCA was sieved via a 20 mm sieve and kept on a 4.75 mm screen per IS 383:2016, which was reaffirmed in 2016[14]. Table 1 shows the characteristics of NCA, RCA, and FA.

In the study, the polycarboxylic ether-based superplasticizer adhering to IS 9103:1999 [27] was utilized to produce the anticipated workability of the concrete. According to IS 456:2007 [28], concrete was mixed using potable tap water. For curing, the concrete specimens were immersed in two types of water: fresh treated tap water (changed every 28 days) and wastewater containing some impurities such as soil and other matters (not changed until 365 days). The wastewater samples were collected from a car washing station and allowed to settle solid particles for 48 hours before being used for curing purposes. The quality of water depends on the available physical, chemical, and biological contaminants in the water. The effects of this parameter may affect the RACs properties. The typical characteristics of fresh and wastewater are given in Table 2. As tap water and wastewater had BOD values of 4 mg/L and 45 mg/L, respectively, and COD levels of 10 mg/L and 180 mg/L, respectively. The presence of contaminants in wastewater may reduce the structural characteristics of RAC to a considerable extent, such as strength and durability, which are to be analyzed in this limited study.

In the lab, the concrete mix proportioning-guidelines IS10262-2009 [29] were used to make three sets of concrete mix $M_0$, $M_{50,}$ and $M_{100}$ of grade M30 that contain the 0 %, 50 %, and 100 % RCA. The water/cement ratio for all mixes, as shown in Table 3, was 0.40.

**Figure 1.** Recycled concrete aggregates from C & D waste

**Table 1.** Characteristics of NCA, RCA, and FA

| Type | Density (kg/m$^3$) | Water Absorption (%) | Fineness Modulus | Specific Gravity | Impact Test (%) |
|---|---|---|---|---|---|
| NCA | 1750 | 1.25 | 6.50 | 2.68 | 14.15 |
| RCA | 1650 | 3.85 | 6.75 | 2.42 | 20.10 |
| FA | 1600 | 3.50 | 2.72 | 2.64 | -- |

**Table 2.** Characteristics of fresh and wastewater

| Water Type | pH | Hardness (mg/L) | Carbonate Alkalinity | Electrical Conductivity (umho/cm) | TDS (mg/L) |
|---|---|---|---|---|---|
| Fresh | 8.03 | 96 | 10.90 | 1.03 | 719.13 |
| Waste | 7.25 | 154 | 8.10 | 1.09 | 807.77 |

**Table 3.** Concrete mix proportion

| Mixture | Cement (kg/m$^3$) | NCA (kg/m$^3$) | RCA (kg/m$^3$) | FA (kg/m$^3$) | Super Plasticizer (kg/m$^3$) |
|---|---|---|---|---|---|
| $M_{00}$ | 390 | 1140 | 0.00 | 675 | 5.2 |
| $M_{50}$ | 390 | 570 | 570 | 675 | 5.2 |
| $M_{100}$ | 390 | 0.00 | 1140 | 675 | 5.2 |

**Specimens and curing**

150 mm size concrete cubes were cast to test compressive strength, and 150 dia. x 300 mm size cylinder specimens were made to test splitting tensile strength. Metal molds were used to cast the specimens, which were then compacted using a vibrating table. Following remoulding, all samples were cured in a fresh water and wastewater tank for 28 and 365 days, as shown in Figure 2.

## RESULTS AND DISCUSSION

This section discusses the experimental program that was conducted on conventional concrete with partial and complete substitutions of NCA by RCA. During the development of a new generation product such as RAC, it is critical to investigate the fresh, hardened, and structural properties of concrete in order to promote and expand its use in the construction sector through solid waste management.

**Compressive strength of concrete**

The compressive strength of specimens was evaluated after 28 and 365 days of curing. The findings of the concrete's compressive strength are shown in Figure 3 and Table 4. IS 516-2004 [30] was used to assess the cube's strength. The strength of concrete has not been greatly influenced by either type of water. Table 4 illustrates that RCA reduces RAC's strength. Some of the cement paste could enter the RCA because of its porous nature. Over time, this strengthened the bond between the aggregates and the hydrated cementitious matrix. Because of the healing effect of cement paste after lengthy curing, cracks in RCAs were minimized in the presence of adhering mortar. The bond between the new cement paste and RCA has been improved. This suggests that the RCA content has an accumulative influence on the RAC.

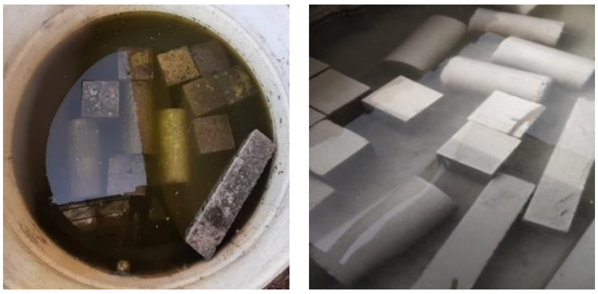

**Figure 2.** Curing of specimens in waste and fresh water

**Tensile strength of concrete**

The sample's splitting tensile strength was measured 28 and 365 days after it was taken out of fresh and wastewater. Table 4 and Figure 4 reveal the results of the tensile strength test on concrete. The tensile strength of concrete was evaluated following IS 5816-2004 [31]. It was clear that the RAC samples with 0 % and 50 % RCA concentrations had approximately identical tensile strengths. It was also noteworthy that the tensile strengths of the NACs were greater than those of the RACs. Table 4 further reveals that the use of RCA has a minor influence on the tensile strength of $M_{00}$ and $M_{50}$ concrete mixes. The tensile strength of the $M_{100}$ concrete mix was significantly reduced in both cases. Several variables affect the performance of concrete, including the water-to-cement ratio, aggregate properties, curing mechanism, and water quality in the concrete mix. The concrete showed that both compressive strength and tensile strength were affected by water for more than 28 days. The strength of the concrete was reduced somewhat efficiently, because the water enlarged the pores of the concrete.

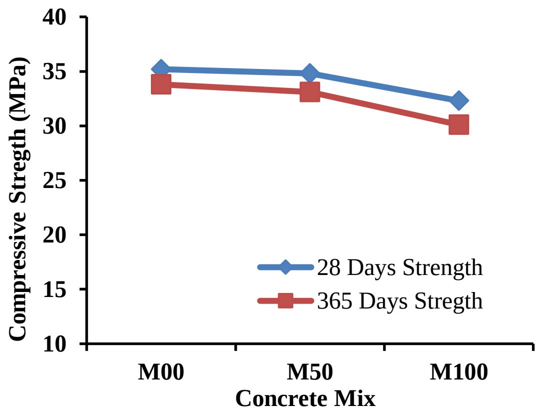


**Figure 3.** Compressive strength of concrete

**Table 4.** Tests result of the concrete mixtures

| Mixture | Slump (mm) | Compressive strength (MPa) | | Splitting tensile strength (MPa) | |
|---|---|---|---|---|---|
| | | 28 days | 365 days | 28 days | 365 days |
| $M_{00}$ | 105 | 35.20 | 33.80 | 3.71 | 3.55 |
| $M_{50}$ | 102 | 34.80 | 33.10 | 3.69 | 3.45 |
| $M_{100}$ | 98 | 32.30 | 30.10 | 3.05 | 2.75 |

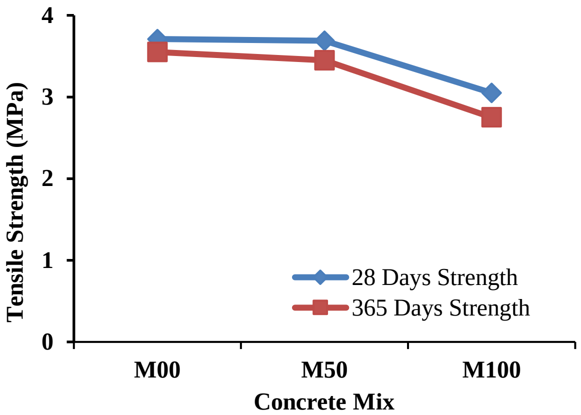


**Figure 4.** Tensile strength of concrete

Figure 5 demonstrates that the RCA had fractured in the concrete sample following testing. Consequently, the RCA adhere mortar was the weakest component of this RAC. Crushing caused cracks in the RCA structure, and the adherence of old mortar reduced the RAC's strength. After comparing results, no major impact of fresh and wastewater curing was observed on the strength properties of RCA concrete. However, it may contain toxic elements that may damage RCA concrete over time.

**Effect of alkali-silica reactivity on the concrete**

Alkali hydroxide and specific types of silica aggregates in concrete react to form a gel that swells as it absorbs water from the cement paste or the surrounding environment. When these gels absorb water, they can expand and provide enough expansion pressure to damage concrete. Figure 6 shows that alkali-silica reactivity is usually shown by map cracks, closed joints, and speckled concrete surfaces. Cracking is most common in locations with a constant supply of moisture, such as along the waterline in piers, behind retaining walls from the earth, between joints and free edges in pavements, or in wick-action piers or columns. Cracking is especially common in areas where there is constant moisture.

**Figure 5.** Tensile strength test at 365 (left) and 28 days (right)

**Figure 6.** Map cracking on concrete

**Effect of elevated temperature on the weight of concrete**

Due to its low thermal conductivity and high specific gravity, concrete offers excellent fire resistance relative to other materials and can be used to cover other structural components such as steel. When used in places with very high temperatures, like missile landing pads, concrete is considered disposable. However, in most cases, it is better to keep the physical qualities of the concrete from breaking down as much as possible. Figures 7 and 8 show the reduction (%) in weight of cubes and cylinders of concrete after 28 days, at a temperature of 200°C and 300°C for 2 hours. More weight was lost from $M_{100}$ (100% RCA) concrete than from other combinations. This was mostly because the free water in the concrete evaporated. The quantity of RCA in concrete is directly proportional to the water absorption capacity of concrete, and with the RCA rising, more water was absorbed by the specimens.

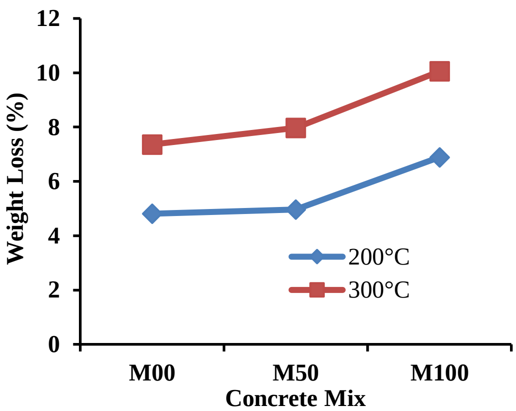


**Figure 7.** % Weight reduction in cubes

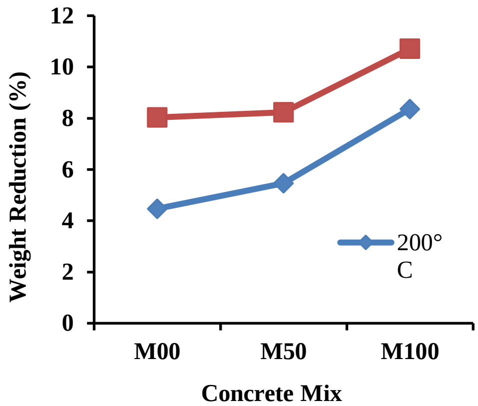


**Figure 8.** %Weight reduction in cylinders

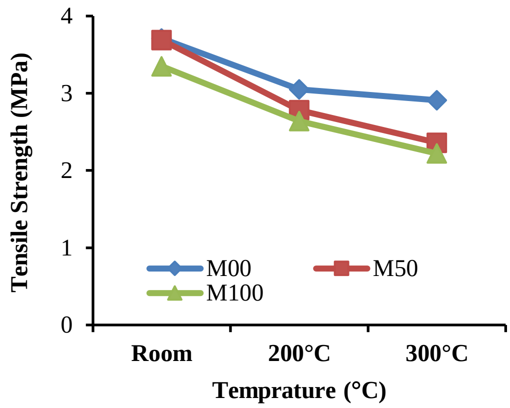


**Figure 10.** Effect of temperature on tensile strength

**Effect of elevated temperature on compressive and tensile strength**

As the temperature rises, the compressive and tensile strengths of concrete decrease due to the percent of RCA in the RAC, as illustrated in Figures 9 and 10. The compressive strength of $M_{00}$, $M_{50}$ and $M_{100}$ at 200°C was found lower by 9.65 %, 12.04 % and 12.84 % and at 300°C it was found lower by 13.83 %, 14.36 % and 15.01 % respectively, with respect to initial compressive strength of concrete. Figure 9 shows the compressive strength was not affected significantly because of the duration of heat and temperature. This heat influence, might affect the loss of free water present and the decomposition of hydration products in concrete. If a heating time and temperature increase, the compressive strength will show a significant reduction in the results. The concrete's compressive strength is also affected by high temperatures. When the temperature rises above 100°C, the cement paste begins to harden and dry, losing chemically combined water of hydration and gradually weakening the paste and paste-aggregate bond. Concrete gets weaker as a result of increased porosity caused by heating, which promotes greater moisture hydration.

Depending on the concrete constituents, it may be impacted by high temperatures above 70°C. At the temperatures present in almost all applications, concrete works remarkably well. However, concrete can lose its stiffness and strength when exposed to fire or very high temperatures. It is well accepted that when concrete containing siliceous aggregates is heated for 2 hours at 200°C and 300°C, the sample turns red and a whitish-grey, as illustrated in Figure 11. The progressive water loss and dryness of the cement paste, as well as changes within the aggregate, cause the color change in heated concrete.

Figure 12 shows the thermal cracking of concrete. When concrete is heated, it expands, and when it cools, it

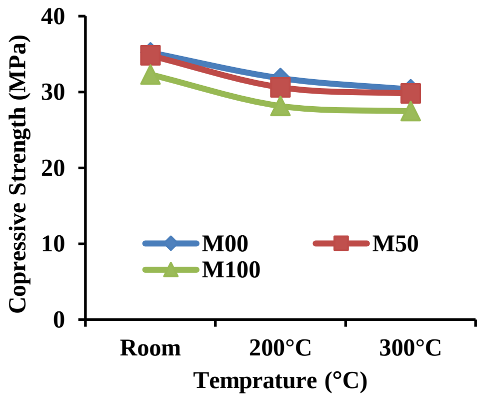


**Figure 9.** Effect of temperature on compressive strength

**Figure 11.** Color changes of samples after heating

**Figure 12.** Thermal cracking on typical cylinder

shrinks. The typical thermal expansion of concrete is approximately 10 millionths per degree Celsius. This means that the length of 10 meters of concrete will change by 5 mm if the temperature goes up or down by 50°C. No changes were found in the size of the samples. The thermal expansion and contraction of concrete are affected by the type of aggregates, the ratio of water to cement, the amount of cement, the temperature range, the age of the concrete, and the relative humidity. The most important of these is the aggregate type used in the concrete. The elevated heat may shorten steel and structural lifespans.

## CONCLUSION

Based on these investigation outcomes, the following conclusions are made:

- The compressive and split tensile strengths of RCA concrete decrease after 365 days of curing, because the water has enlarged the pores of the concrete.
- The percentage of mass, tensile strength, and compressive strength loss increased as the heat increased. The properties of concrete will deteriorate when it is subjected to high temperatures. This is due to the changes in the physical properties and chemical composition of concrete. The concrete constructions working under such conditions should comply with the highest standards both in the case of concrete and surface protection quality.
- Increased strength and greater resistance to spalling will be achieved by incorporating fiber reinforced elements. Alternately, the concrete mixture might be designed to have a higher strength, so that any property losses caused by long-term thermal exposure would still provide enough safety margins.
- RCA can be used instead of NCA in structural concrete. It has worthy mechanical and durable properties when it is cured in waste water and heated up to 300°C.

In summary, the characteristics of RCA differ depending on their origin. To assess the mechanical characteristics of RAC, a test sample should be prepared and tested before it is used in structural parts. RCA is an excellent material to make long-lasting and energy-efficient concrete structures through solid waste management.

## CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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**Persian Abstract**

**چکیده**

در این مطالعه، سنگدانه‌های درشت طبیعی با سنگدانه‌های بتن بازیافتی درشت(RCA) در صفر، ۵۰ و ۱۰۰ درصد استخراج شده از ضایعات ساختمانی و تخریب جایگزین شدند. بازیافت آنها می‌تواند منجر به تصمیمی سبزتر برای حفظ محیط زیست و هموار کردن راه برای پایداری از طریق مدیریت زباله جامد شود. مقاومت فشاری صفر درصد، ۵۰ و ۱۰۰ درصد RCA در ۳۶۵ روز به ترتیب ۳/۹۷، ۴/۸۸ و ۶/۸۱ درصد در مقایسه با مقاومت فشاری در ۲۸ روز کاهش یافت. استحکام کششی در ۳۶۵ روز نسبت به استحکام کششی در ۲۸ روز به میزان ۴/۳۱، ۶/۵۰ و ۹/۸۳ درصد کاهش یافت. هیچ اثر قابل تشخیصی از نوع آب بر خواص مقاومتی بتن وجود نداشت. در مقایسه با سایر ترکیبات، بتن ۱۰۰٪ RCA درصد بیشتری از کاهش وزن را به دلیل تبخیر آب آزاد تجربه می‌کند. با افزایش دما، ماتریس بتن منبسط می‌شود و ترک‌های عمیقی بر روی سطح بتن مشاهده می‌شود. عملکرد کلی بتن سنگدانه‌های بازیافتی چندان تحت تأثیر استفاده از چنین سنگدانه‌هایی قرار نگرفت. بنابراین این یافته‌ها دستاورد جدیدی را به ساخت و ساز پایدار از طریق مدیریت زباله جامد اضافه می‌کند.