

# Response of Recycled Brick Aggregate Concrete to High Temperatures

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**Abstract:** The abundant availability of demolition waste from construction industry is leading towards a significant problem of disposal, land and air pollution. The natural aggregate resources are also depleting due to development of construction activities. An attempt is made in this study to convert this waste into wealth by substituting the recycled brick from demolition waste to granite aggregate in production of the concrete. The granite aggregate (GA) is replaced with recycled brick aggregate (RBA) by 25% of its weight to produce M15 and M20 grades of concrete. The granite aggregate concrete (GAC) and recycled brick aggregate concrete (RBAC) were subjected to different temperatures between 100 to 1000°C for a duration of 3 hours and the mechanical properties such as compressive strength and flexural strength were examined to assess its fire performance. The response of RBAC is better than GAC at each temperature. The study revealed that the residual strength increases with the increase in grade of concrete at all temperatures.

**Index Terms:** granite aggregate concrete, recycled brick aggregate concrete, mechanical properties, response, high temperatures, demolition waste.

## I. INTRODUCTION

The concrete and brick waste produced through construction and demolition (C&D) waste in India is estimated to be as 7-8 million tons per annum [1]. This enormous quantity of waste is causing a significant issue of disposal as there is a scarcity of land in India. Further the demolition waste disposed as landfills in open areas, releases toxic gases causing a severe land and air pollution. India consumes around 450 million cubic meter of concrete annually [1], in which the coarse aggregate occupies 60 to 70% of its total mass. During the last decade, lot of research has been reported on reutilization of C&D waste and most studies emphasized on concrete waste. Many researchers [2-5] have reported that the concrete waste can be substituted as an aggregate in place of natural aggregate. But, the recycling of brick waste from the demolition waste is not gaining momentum because of its low strength and high water absorption. The use of crushed bricks as aggregates resolves both the problems of disposal and depletion of natural aggregate resources.

Apart from fire accidents, concrete in nuclear reactor pressure vessels, chimneys, gas & oil wells, silos, storage bins for hot crude oil etc., is exposed to high temperatures for considerable periods of time. Many studies have reported that fire exposure causes the concrete to deteriorate by increasing the cracks. Very limited research have been carried out on the

behaviour of recycled brick aggregate concrete exposed to elevated temperatures, but most of these studies were focused on the concrete produced with fresh or unused bricks. Hence, the present study aims at the response of recycled brick aggregate concrete when exposed to high temperatures.

## II. REVIEW OF LITERATURE

Katz A et al. (2003) stated that the concrete made with recycled aggregate was not as good as granite aggregate concrete in terms of its compressive strength, when the coarse aggregate were replaced with recycled concrete aggregate. Poon et al. (2004) investigated the effects of replacement levels on the properties of fresh and hardened recycled aggregate concretes. The recycled aggregate were air dried, oven dried and saturated surface dried before using in concrete. No significant loss in slump as well as compressive strength was witnessed by the authors between the crushed granite aggregate concrete and recycled aggregate concrete when aggregate were used in air and saturated surface dried condition. The authors concluded that the compressive strength of the air dried recycled aggregate concrete with 50% replacement displayed higher compressive strength than that of the other two types of aggregate. Tam et al. (2005) tried to increase the quality of recycled aggregate by Two Stage Mixing Approach (TSMA) and the micro structure of recycled aggregate concrete produced from TSMA was analyzed. The virgin aggregate was replaced with recycled aggregate in percentages of 0, 10, 15, 20, 25 and 30. An increase in compressive strength was found by authors when the concrete was done by two stage mixing.

Khalaf and Devenny (2005) reported that the concrete made with crushed clay brick displays the same strength and a lower density of about 8 to 15%, when compared to granite aggregate concrete. Farid D et al. (2008) compared the flexural strength of concrete made from crushed brick at replacements of 25%, 50%, 75% and 100% to natural aggregate. The author reported that it is possible to produce concrete by replacing the coarse aggregate with 25% of crushed brick aggregate and observed a reduction of flexural strength of about 15%. Cachim P B (2009) evaluated the mechanical properties of concrete made with crushed bricks by replacing natural aggregate. The results indicated that the crushed bricks can be substituted to natural aggregates by 15% without strength reduction. Jian Yang et al (2011) studied the physical and mechanical properties of concrete made with recycled concrete

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aggregate (RCA) and crushed clay brick (CCB) aggregate. The granite aggregate was replaced by both RCA and CCB in percentage replacements of 20% CCB & 80% RCA, 50% CCB & 50% RCA and 100% RCA. It was reported by authors that the replacement of RCA with 20% CCB produced very good quality concrete, but the quality falls when the replacement level increase to 50%.

Khalaf & Devenny (2004) studied the effect of high temperature on concrete after replacing the coarse aggregate with crushed brick aggregate. The temperature ranges are 200, 400, 600 and 800°C. The study revealed that the crushed brick aggregate concrete has similar resistance to fire as that of granite aggregate concrete.

### III. OBJECTIVE OF THE RESEARCH

The objective of the current research is to study the fire resistance of recycled brick aggregate concrete of two different grades, i.e., RBAC 15 and RBAC 20. The hardened state properties of concrete consisting of crushed bricks as partial substitute to granite aggregate were assessed to evaluate the fire performance.

### IV. MATERIALS AND METHODOLOGY

#### A. Materials

Portland Pozzolana cement used was confirmed to IS 1489-1991[14]. Locally available natural sand conforming to Zone II as per IS 383-1970 [19] was used as fine aggregate. Granite Aggregate (GA) and Recycled brick aggregate (RBA) were used as coarse aggregate. The same procedure adopted by Rekha et al [13] was used to prepare the recycled brick aggregate. M20 grade of concrete designed as per the mix design procedure laid down in IS 10262 -2009[15] was used. The same mix proportions were used for producing both GA concrete and RBA concrete. However, RBA concrete was produced replacing 25% granite aggregate with recycled brick aggregate by volume in the present investigation.

#### B. Methodology

Two series of cubes and prisms of size 150 × 150 × 150 mm and 100mm×100mm ×500mm respectively were cast with & without replacement, cured for 28 days, exposed to temperatures from 100°C to 1000°C for three hours in bogie hearth furnace. These heated specimens were tested for its compressive strength and flexural strength in hot condition immediately after removal of the specimens from the furnace. These tests were conducted in accordance with IS 516-1959 [16]. The load is applied without shock and at a continuously increasing rate of load at 180 kg/ min. The maximum load applied to the specimen at which the specimen failed was noted.

## V. RESULTS AND DISCUSSIONS

### A. Residual Compressive Strength

Figs. 1 & 2 show the comparison between the percentage residual compressive strength of both RBAC & GAC 15 and RBAC & GAC 20 respectively. It was perceived from the figures that as the temperature increased beyond 200°C

the percentage residual compressive strength decreased in both GAC and RBAC. At 100 and 200°C both the grades of GAC and RBAC exhibited higher percentage residual strengths than that at room temperature. The increase in strength at this temperature may be attributed to the effect of accelerated hydration. A sudden fall in residual strength was observed at 300°C in both the grades of GAC and RBAC whereas it decreased gradually beyond 300°C. The percentage retention in compressive strength is between 56 to 61% in both GAC and RBAC at 300°C. It is clear from figs 1 & 2 that the percentage retention in compressive strength is more in RBAC than GAC beyond 300°C. At 400°C the residual strength in RBAC15 is 51% and that of GAC 15 is 43.8%, showing a strength gain of about 7% in RBA concrete. Similarly, the strength retention in RBAC 20 is 55% and GAC 20 is 46% showing a gain of about 10% in RBAC. The rate of gain in strength in RBAC increased between 700°C to 1000°C. The gain in strength at 700°C in RBAC 15 was about 12% and that of RBAC 20 was around 14% compared to GAC 15 and GAC 20 respectively. At 1000°C the retention in GAC 15 is 11% and that in GAC 20 is 14% only. The RBAC 15 retained 26% and RBAC 20 retained 30 %, exhibiting a gain of around 15 percent compared to GAC. The higher residual strengths of RBAC might be attributed to the stiffness of the recycled brick and additional hydration of cement paste [12].

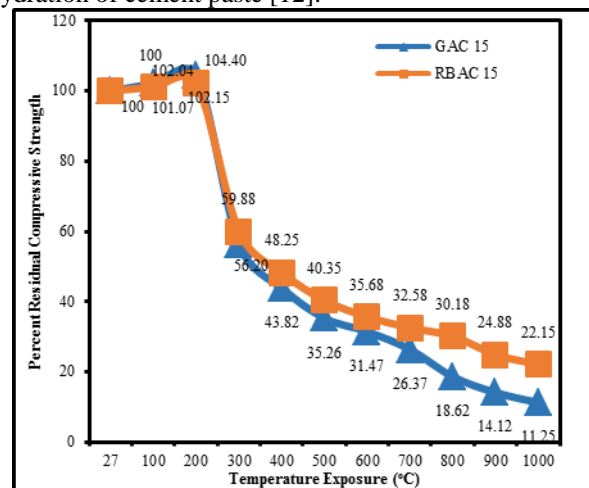


Fig. 1: Comparison of Percentage Residual Compressive Strength of GAC 15 and RBAC 15

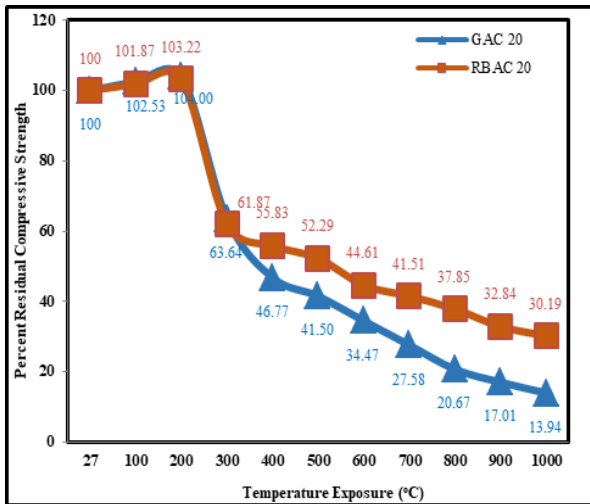


Fig. 2: Comparison of Percentage Residual Compressive Strength of GAC 20 and RBAC 20

**B. Residual Flexural Strength**

Figs. 3 & 4 shows the comparison between the percentage residual flexural strength of both RBAC & GAC 15 and RBAC & GAC 20 respectively. As reported by Khalaf F M

[10] unlike compressive strength, it was observed that the RBAC exhibited slightly lesser flexural strength than GAC at room temperature. The flexural strength of GAC 15 & RBAC 15 is 3.17 & 3.24 N/mm<sup>2</sup> and that of GAC 20 & RBAC 20 is

3.52 & 3.45 respectively at room temperature. The percentage residual flexural strength of both GAC and RBAC decreased with the increase in temperature. RBAC depicted the same residual strength as that of GAC up to 200°C. The residual flexural strength suddenly dropped in both concretes at 300°C and it is gradually decreased beyond 300°C, the residual strength being in the range of 54.6 to 55.9%.

At 400°C the residual strength in RBAC 15 is 45% and that of GAC 15 is 40.86%, showing a strength gain of about 5% in RBAC. Similarly, the strength retention in RBAC 20 is 47% and GAC 20 is 44% showing a gain of about 3% in RBAC. The rate of gain in strength in RBAC increased

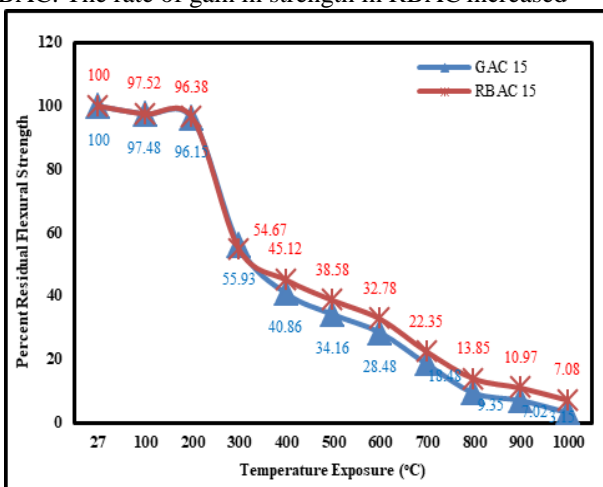
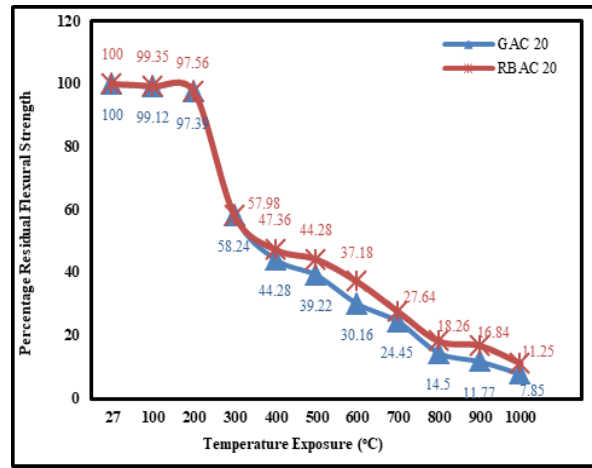


Fig. 3: Comparison of Percentage Residual Flexural Strength of GAC 15 and RBAC 15

**Fig 4: Comparison of Percentage Residual flexural**



**Strength of GAC 20 and RBAC 20**

between 600°C to 1000°C. The gain in strength at 600°C in RBAC 15 was about 4% and that of RBAC 20 was around 7% compared to GAC 15 and GAC 20 respectively. At 1000°C both the concretes almost lost their flexural strength.

**Effect of Grade of Concrete**

Fig. 5 illustrates the comparison of percent residual compressive strength of RBAC15 and RBAC 20 with temperature. The compressive strength of both grades of RBAC marginally increased along with temperature increase up to 200°C. A sudden fall in strength was observed at 300°C followed by gradual decrease up to 1000°C. RBAC 20 retained greater residual strength than that of RBAC 15 at every temperature. The difference in residual strength between RBAC 15 and RBAC 20 is more pronounced when the temperature is increased beyond 300°C. The residual compressive strength gain varies between 9 to 12% in RBAC 20 compared to RBAC 15 in the temperature range of 400 to 1000°C. The residual compressive strength of RBAC 15 is 22.15% and that of RBAC 20 is 30.19% showing 12% higher strength gain in RBAC 20 at 1000°C. Hence it can be concluded that the higher residual compressive strength will be observed for higher grades of concrete.

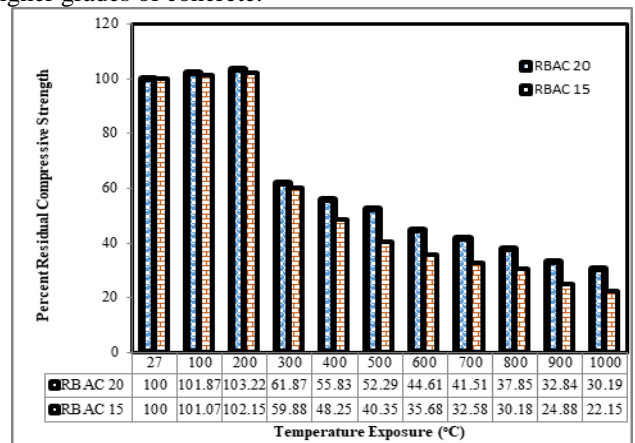
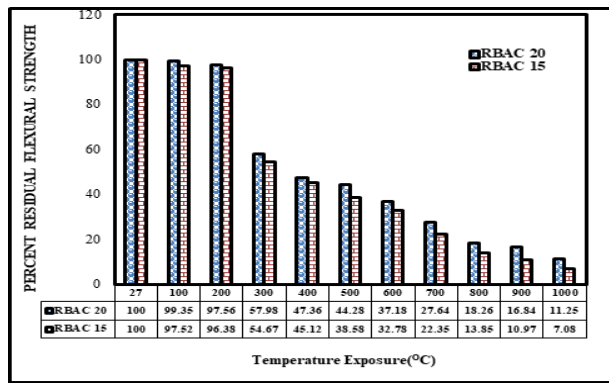


Fig. 5: Comparison of Percentage Residual Compressive Strength of Different grades of RBAC



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**Fig. 6: Comparison of Percent Residual Flexural Strengths of Different Grades of RBAC**

Fig. 6 illustrates the comparison of percent residual flexural strength of RBAC15 and RBAC 20 with temperature. The residual flexural strength of both grades of RBAC decreased with increase in temperatures. A sudden fall in residual strength was observed at 300°C followed by gradual decrease up to 1000°C. The residual flexural strength gain varies between 2 to 4% in RBAC 20 compared to RBAC 15 in the temperatures range of 400 to 1000°C. The residual flexural strength of RBAC 15 is 7.08% and that of RBAC 20 11.25% showing 4% higher strength gain in RBAC20.

### VI. CONCLUSIONS

- Both M15 and M20 grades of RBA concrete produced with 25% of replacement retained the same compressive strength as that of GA concrete.
- Both RBA and GA concretes have exhibited rising to falling trend in residual compressive strength at a temperature about 200°C. Beyond 200°C both the concretes exhibited falling trend.
- The RBA concrete showed more residual compressive strength than GA concrete at all temperatures due to the presence of clay making the RBA concrete strong and stiff at high temperatures. The RBA concrete could able to retain about 22.0 to 55.0 percent of its original compressive strength whereas GA concrete could retain only about 11.0 to 46.0 percent between 400°C to 1000°C.
- The flexural strength reduced with the raise in temperature in both GA and RBA Concretes. RBA concrete exhibited a higher residual flexural strength at all temperatures. Bulk loss of flexural strength occurred between 200 to 300°C in both GA and RBA concretes, the loss being in the range of 41.0 to 45.0 percent.
- Residual strength increases with the increase in grade of concrete at all temperatures. RBA 20 grade of concrete exhibited higher residual strengths than RBA 15 grade of concrete.

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