RESIDUAL FLEXURAL STRENGTH OF RECYCLED BRICK AGGREGATE CONCRETE EXPOSED TO HIGH TEMPERATURES

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Abstract—The practice of using crushed brick in concrete is picking up due to its value addition to the mechanical properties of concrete. In the present experimental investigation the brick from the demolition waste is used as a coarse aggregate to study the flexural behaviour of recycled brick aggregate (RBA) concrete after exposure to high temperatures. The recycled brick aggregate is replaced to granite aggregate up to 25% by its volume to produce RBA concrete. Beam specimens of size 100mm × 100mm × 500mm were used to study the flexural strength (modulus of rupture) of both RBA concrete and granite aggregate (GA) concrete. Both the concretes were heated to desired temperatures from 100^{o}C to 1000^{o}C in an interval of 100^{o}C for three hours in bogie hearth furnace. The residual flexural strengths of both heated RBA and GA concretes were presented in this research to study the performance of RBAconcrete at high temperatures. The RBA concrete performed better than that of GA concrete in flexure at high temperatures by exhibiting higher residual strength.

Key Words - Recycled Brick Aggregate Concrete, Granite Aggregate Concrete, High Temperatures, Flexural Strength, Residual Strength.

I. INTRODUCTION

In developing countries, due to urbanization the old structures are being replaced with new structures resulting in the production of demolition wastes in large scale. Approximately 3.6 to 4.4 million tons of brick and masonry is being generated from demolition waste per annum [1]. This crushed brick can be successfully used as a replacement to coarse aggregate to produce concrete. The concrete produced from recycled brick can be used for non-structural concrete like pavement construction, paving blocks, building blocks etc due to its low strength. The practice of using recycled brick in India has not taken initiation due to many reasons such as poor quality and low strength of brick, lack of codal provisions and lack of understanding the behaviour of brick aggregate.

Fire is the most common manmade disaster that any structure is likely to be subjected due to fire accidents, earth quakes, blasts etc. The exposure duration and the intensity of fire are the main factors for the deterioration of strength of concrete. The loss in strength is attributed to the loss of bond between the aggregate and the surrounding cement matrix. Further, the differential thermal expansion between the cement paste and the aggregate results in spalling.

Farid D et al [2] examined the possible use of crushed brick as coarse aggregate in concrete. The coarse aggregate was replaced with crushed brick aggregate by 25%, 50%, 75% and 100%. The author compared the flexural strength of concrete made with crushed brick to natural aggregate concrete and reported that 25% of natural coarse aggregate can be replaced by crushed brick aggregate. A reduction in flexural strength of about 15% is observed in crushed brick aggregate concrete at room temperature. Sarhat R S [3] investigated the performance of recycled aggregate concrete exposed to temperatures of 200,500 and 750ºC. The residual compressive and tensile strengths of recycled concrete were examined after exposing to temperatures. The author reported that the performance of recycled concrete aggregate at high temperatures was adequate compared to normal (river gravel) aggregate. Khalaf FM [4] 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^{o}C. The author reported that the crushed brick aggregate concrete has similar resistance to fire as that of granite aggregate concrete. Lea and Stradling [5] studied the effect of temperature on concrete containing recycled brick as fine aggregate as well as coarse aggregate. No loss in residual strength was observed for recycled brick aggregate concrete when exposed up to 650°C. At a temperature of 1030°C, a strength loss of 51% was observed in case of recycled brick aggregate concrete whereas the conventional concrete exhibited 91% loss even after the exposure of 830°C.

The main objective of the present work is to replace the granite aggregate in concrete partially with recycled brick aggregate to investigate the influence of the recycled brick on flexural strength of concrete at high temperatures.

II. Materials

A. Cement

Portland Pozzolana Cement supplied by ultra tech company was used and was confirmed to IS 1489-1991[6].

B. Sand

The natural sand which is available locally and confirming to zone II as prescribed in IS 383-1970[7] was used as fine aggregate.

C. Coarse Aggregate

The granite aggregate (GA) and Recycled brick aggregate (RBA)were used as coarse aggregate. The recycled brick was prepared in the same procedure adopted by Rekha et al [8] before using them in concrete. IS 10262-2009 [9] was adopted to prepare the mix design of concrete.

III. Laboratory Tests

A total of 66 beams of size 100mm×100mm ×500mm were casted for granite aggregate conctere (GAC) and recycled brick aggregate concrete (RBAC) separately. These beams were cured for 28 days and then exposed to temperatures from 100°C to 1000°C at an interval of 100°C foraduaration of three hours. Fig 1 shows the bogie hearth furnace, which was used to heat the specimen to the required temperatures. These heated specimens were then tested for flexural strength in hot condition immediately after 15 min of the removal from the furnace. The flexural strength test was conducted in accordance with IS 516-1959 [10] using two point loading methodas shown in Fig 2. The load is applied without shock and at a continuously increasing rate of 180 kg/min. The maximum load applied to the specimen at which it failed was noted. The flexural strength was calculated by using the equation 2.1.

$$f_b = \frac{Pl}{bd^2}, \text{ when } a > 13.3\text{cm},$$
$$f_b = \frac{3p \times a}{bd^2}, \text{ when } 20\text{cm} > a > 17.7\text{cm} \quad \longrightarrow \quad (2.1)$$

Where, a – distance of crack formed from the near end

b – measured width of the specimen

d – measure depth of specimen at point of failure

Fig.1. Bogie Hearth Furnace

Fig. 2. Flexural strength test setup

IV. Results and Discussions

A. Crack Pattern

Figures 3,4 and 5 shows the crack pattern of both GA and RBA concretes elevated to temperatures upto 500^{o}C, between 600 to 800^{o}C and beyond 800^{o}C respectively. It is clear that both GA and RBA concretes not exhibited surface cracks upto 500^{o}C. Cracks were started appearing on both the concretes when the temperature is raised beyod 500^{o}C , i.e. between 600 to 800^{o}C as shown in the Fig 4 . These cracks were further extended along the surface and into the cross-section when the concrete is subjected to temperatures beyond 800^{o}C. However, the RBA concrete did not exhibit severe cracks as that of GA concrete.

Fig. 3(a). Crack pattern of GA concrete upto 500 ^{o}C

Fig.3(b). Crack pattern of RBA concrete upto 500 oC

Fig.4(a). Crack pattern of GA concrete between 600 to 800 oC

Fig.4(b). Crack pattern of RBA concrete between 600 to 800 oC

Fig.5(a). Crack pattern of GA concrete beyond 800 oC

Fig.5(b). Crack pattern of RBA concrete beyond 800 oC

B. Mode of Failure

GA and RBA concretes exhibited different failure modes during the flexure test. In case of GA concrete as shown in Fig. 6 failure appeared at the interface of aggregate and mortar matrix. The aggregate from GA concrete was completely separated from the matrix at high temperatures. The failure appeared with in the brick aggregate particles due to the crushing of brick during the flexure [Fig 7]. This phenomenon may be due to the low crushing strength of brick compared to the granite aggregate. These observations are in agreement with the findings of Yang .J [11].

Fig. 6. Failure mode of GA concrete

Fig. 7. Failure mode of RBA concrete

C. Flexural Strength

Fig. 8 shows the variation of residual flexural strength of both GA and RBA concretes with temperatures. The residual flexural strength at any temperature is expressed as the percentage of the flexural strength of respective concrete at room temperature. The flexural strength decreased with the increase in temperature in both GA and RBA concretes at all temperatures.

From Table 1. it is clear that 2% reduction in flexural strength at room temperature was recorded with the substitution of RBA. Khalaf F.M [12], also reported a reduction of about 8% in flexural strength with the inclusion of crushed brick as coarse aggregate.

The loss in flexural strength at 100^{o}C is around 0.7% and the same at 200^{o}C is about 3% followed by a sudden drop of 40% beyond 200^{o}C in both the concretes. RBA concrete exhibited a higher residual flexural strength at all temperatures than that of GA concrete. Bulk loss of strength was recorded at 300^{o}C, the loss being 47% and 42 % for GA and RBA concretes respectively. The residual flexural Strength of RBA concrete at 1000^{o}C was found to be 11.25% and that of GA concrete was 7.58%. The higher residual strength of RBA concrete at high temperatures may be attributed to the fact of low thermal conductivity of brick aggregate and good bond between matrix and brick aggregates [Fig.7]. This shows that recycled brick aggregate concrete is more fire resistant than GA concrete.

TABLE I. MODULUS OF RUPTURE OF GA AND RBA CONCRETES AT DIFFERENT TEMPERATURES

Exposure Temperature (^oC)	Average Modulus of Rupture (kN/mm^2)	
	GAC	RBAC
27	3.52	3.45
100	3.49	3.43
200	3.43	3.36
300	2.05	1.91
400	1.56	1.63
500	1.38	1.53
600	1.06	1.28
700	0.86	0.95
800	0.51	0.63
900	0.41	0.58
1000	0.28	0.39

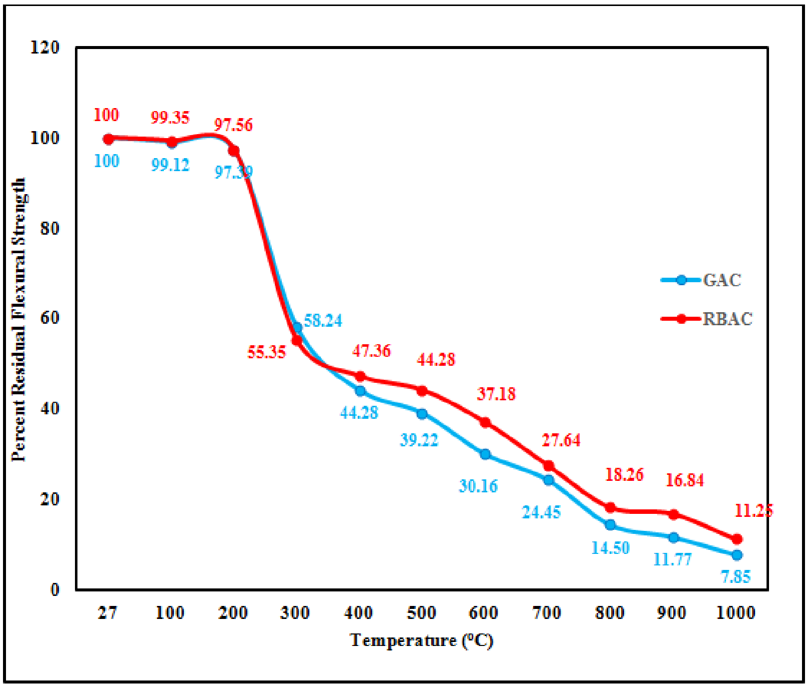

Fig. 8. Variation of residual flexural strength of GA and RBA concretes

V. CONCLUSIONS

[1] RBA concrete did not exhibit severe cracks as that of GA concrete. GA concrete started spalling beyond 800^{o}C where as the RBA concrete remained intact.

[2] The aggregate from GA concrete was completely separated from the matrix at high temperatures showing the complete loss of bond. The RBA concrete did not exhibit bond failure. The failure appeared within the brick aggregate particles due to the crushing of brick.

[3] The flexural strength decreased with the increase in temperature in both GA and RBA Concrete.

[4] RBA concrete exhibited a higher residual flexural strength at all temperatures than that of GA concrete.

[5] The flexural strength of both concretes suffered from high loss when the temperature is raised from 300^{o}C to 400^{o}C .

[6] The study shows that recycled brick aggregate concrete is more fire resistant than GA concrete.

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