Behaviour of Recycled Aggregate Concrete on exposed to Elevated Temperature

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Abstract

This paper focuses on effect of elevated temperature on recycled aggregate concrete. When concrete is exposed to Elevated Temperature due to fire, the property of a concrete may alters. The effects of elevated temperatures on the physical and mechanical properties of various Recycled aggregate concretes are explained Here w/c ratio 0.27 and 0.36 with replacement of 0%, 30%, 35%, 40%, 45% and 50% of Natural aggregates by Recycled aggregates are taken into consideration. Here 35 specimens (Cubes, Cylinder and prism) for each trial mixes (12 nos) has been casted and heated under four different temperature: 200^{0}C, 400^{0}C, 600^{0}C and 800°C. . Attempt is made to compare with different mixes of recycled aggregate concrete. The results indicate that concrete with aggregate partially replaced with RCA exhibits good performance under elevated temperatures and it can be considered comparable to conventional concrete.

Keywords*:* *Recycled aggregates, elevated temperature, compressive strength, split tensile strength, flexural strength, residual properties.*

I. INTRODUCTION

When concrete is exposed to high temperature, the mechanical properties such as strength, modulus of elasticity and durability decreases, which leads to structural failure. Therefore properties of concrete should be taken care to withstand high elevated temperature. At 110^{0}C temperature CSH bond starts breaking and with increase in temperature beyond 300^{0}C, thermal expansion of the aggregate increase internal stresses and micro cracks are induced. Calcium hydroxide [Ca(OH)2] dissociates at around 530°C resulting in the shrinkage of concrete. The fire is generally extinguished by water and CaO which converts into [Ca(OH)2] causing cracking and crumbling of concrete. Therefore, the effects of high temperatures are visible in the form of surface cracking and spalling. CSH gel decomposes beyond 600^{0}C and concrete gets crumbled at 800^{0}C.

P. Saravankumar et al concluded that the compressive and tensile strength of RAC is lesser than the NAC at all percentage of NA replaced by RA at all age of concrete. Chetna m. Vyas et al conducted durability tests on RAC, they concludes that the sorptivity and water absorption of RAC was less for 40% replacement of NA by RA comparing to other replacement ratio in each grade of concrete According to T.Morita et al (2000), the lower the w/c ratio, the higher the degree of spalling. Spalling slightly occurs, if the W/C ratio exceeds 50% for two month-old concrete, and 45% for one-year old concrete. The age of concrete at the time of fire exposure has a significant effect on spalling. Though age of concrete affects the strength and moisture condition of the concrete, it is observed that the lower the moisture content, the lesser the possibility of spalling caused by vapor pressure in the concrete.

Jaeyoung Lee et al (2013) worked on Entire and partial heating of high strength concrete small columns. The crack, spalling and rupture are severe on partially heated specimens than the entire heated specimens. Thus uneven heating would increase the spalling. According to Manzi, C. Mazzotti, M.C. Bignozzl (2014) Workability decreases with increase in Percentage replacement of recycled aggregate to the natural aggregates. According to Salah R. Sarhat et al (2013), Concrete made with Recycled Aggregate Concrete (RAC) exhibits adequate performance at elevated temperatures.

II. EXPERIMENTAL INVESTIGATION

A. Material and Properties

Cement: the grade of cement used in this work is ordinary Portland cement, 43 grade manufactured as per IS 8112. Fine aggregate: Locally available sand free from silt, organic matter and passing through 4.75mm sieve confirming to zone 2 as per IS 383 is used as fine aggregate. Natural Coarse aggregate: the natural coarse aggregate of maximum size 12.5mm passing and retained on 4.75mm sieve is used. Recycled Coarse aggregate: the recycled aggregate size of maximum size 12.5mm passing and retained on 4.75mm sieve is used and properties of materials are listed in Table.1.

Table.1 Properties of Materials

Test	Fine Aggregate	Natural Coarse Aggregate	Recycled Coarse Aggregate
Fineness Modulus	2.35	6.25	5.45
Specific gravity	2.492	2.657	2.6
Crushing Value	-	27.56%	28.10%
Impact Value	-	21.18%	29.86%
Water Absorption	-	0.31%	1.87%
Moisture Content	0.61%	-	-

The recycled aggregates(RCA) have lesser density than the natural aggregates(NA), because RCA have attached mortar around it. Li (2004) showed that bulk density, apparent density is lower than natural coarse aggregate, while water absorption, crush index of RCA are higher. According to A. K. Padmini et al (2009) water absorption of the recycled aggregates increases with an increase in strength of parent concrete and decreases with increase in maximum size of aggregate. Design compressive strength can be achieved by lowering the water cement ratio and high cement content.

B. *Mix Design*

In the present investigation mix design are obtained from Perumal's Method. M60 grade of concrete is used. Mix proportions are listed in Table.2

Table.2 Mix Proportions for M60 Concrete Grade

Mix no	% Replacement	w/c	cement (kg/m^3)	Fine aggregate (kg/m^3)	Silica fume (kg/m^3)	NCA (kg/m^3)	RCA (kg/m^3)	Water (kg/m^3)	S.P in (kg/m3)
1	0%	0.27	500	665.535	55.55	1000	0	150	12.5
2	30%	0.27	500	644.11	55.55	700	300	150	12.5
3	35%	0.27	500	640.54	55.55	650	350	150	12.5
4	40%	0.27	500	636.97	55.55	600	400	150	12.5
5	45%	0.27	500	633.4	55.55	550	450	150	12.5
6	50%	0.27	500	629.83	55.55	500	500	150	12.5
7	0%	0.36	375	781.77	41.67	1000	0	150	9.375
8	30%	0.36	375	760.34	41.67	700	300	150	9.375
9	35%	0.36	375	756.77	41.67	650	350	150	9.375
10	40%	0.36	375	753.2	41.67	600	400	150	9.375
11	45%	0.36	375	749.63	41.67	550	450	150	9.375
12	50%	0.36	375	746.06	41.67	500	500	150	9.375

III. FRESH CONCRETE PROPERTIES:

A. *Workability Test:*

The slump test will give an indication of how easily a mix can be placed, it is mentioned in **IS: 456-2000** that a slump less than 25mm will indicate a very stiff concrete and a slump more than 125mm will indicate a very runny concrete. In the current investigation, high strength concrete (M60) is used, hence the slump is zero.

B. *Compaction Factor Results:*

The compaction factor indicates a moderate decreasing trend of workability when the percentage of recycled aggregate is increased. Table.3 shows the compaction factor ratio recorded during the experiment. As shown in Fig.1, Compaction Factor results showed that continuous increase in percentage replacement of natural aggregates with recycled aggregates was accompanied by a continuous decrease in Consistency also Consistency decreases with decrease in W/C. 0% replacement of 0.36 W/C ratio gave the highest compaction factor of 0.892 while

50% replacement gave the least compaction factor 0.819. Also from Fig.1 workability is more for 0.36 W/C when compared to 0.27 W/C. This implies that workability decreases with increase in percentage replacement and workability increases with increase in W/C ratio. Thus the use of recycled aggregates in concrete reduces the workability of the concrete.

Table.3 Compaction Factor Results for Recycled Aggregate Concrete

% replacement	0%	30%	35%	40%	45%	50%
Compaction factor (0.27 w/c)	0.883	0.841	0.83	0.824	0.816	0.811
Compaction factor (0.36 w/c)	0.892	0.867	0.86	0.835	0.824	0.819

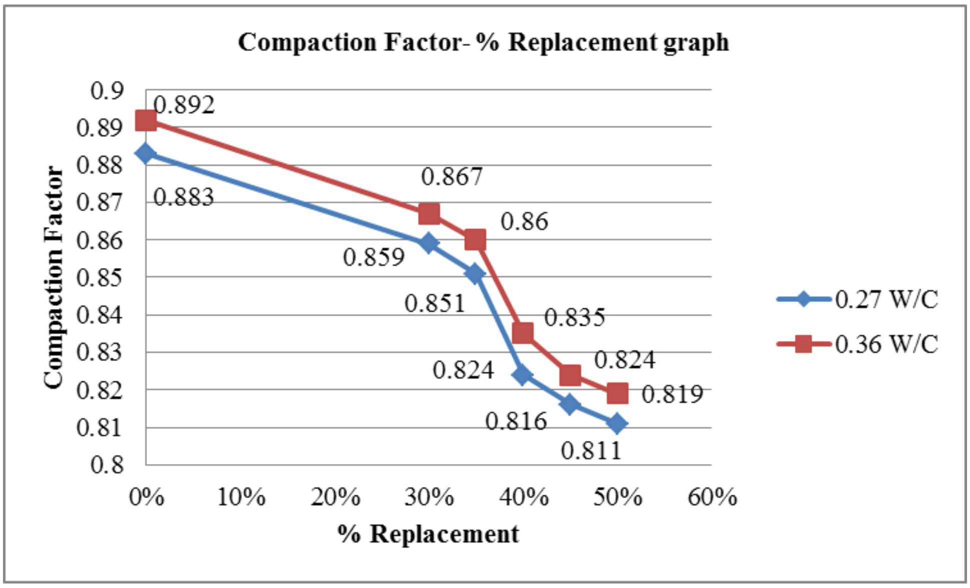

Fig.1 Graph of Compaction Factor Against Percentage Replacement

IV. RESULTS AND DISCUSSION

A. Compression test results

The compressive strength of concrete cubes (150mm x 150mm x150mm) were determined by using CTM machine.

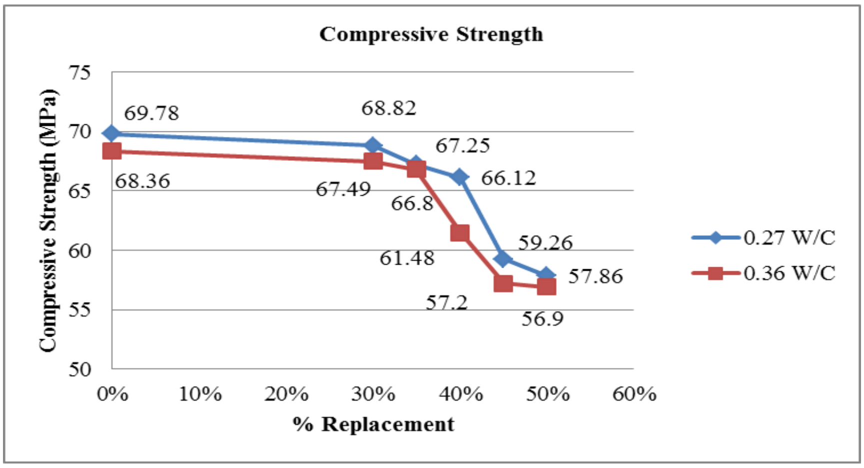

Fig.2 Compressive Strength of Concrete

From Fig.2 the maximum strength developed at 28 days is for NAC (0% replacement) of 0.27W/C and it is 69.78N/mm^2 and for 0.36 W/C, maximum compressive strength at 0% replacement I.e., 68.36 N/mm^2. Thus by increase in w/c ratio, compressive strength decreases. Among RAC (Recycled Aggregate Concrete) the maximum 28 days strength developed for 30% replacement (0.27 W/C) it is 68.82 N/mm^2 with a strength reduction of 1.38% among. RAC 50% replacement of NA(Natural Aggregate) by RA(Recycled Aggregate) has lesser strength as compared to all replacement ratio. And the strength developed for 50% Replacement (0.27 W/C) is 57.86N/mm^2 and it is 17.08% reduction in strength as compared to NAC and for 0.36 W/C with 50 % Replacement is 56.9 N/mm^2 and it is about 16.76% reduction in strength compared to NAC.

B. Split tensile Strength Results

The split tensile strength was carried out by CTM machine.

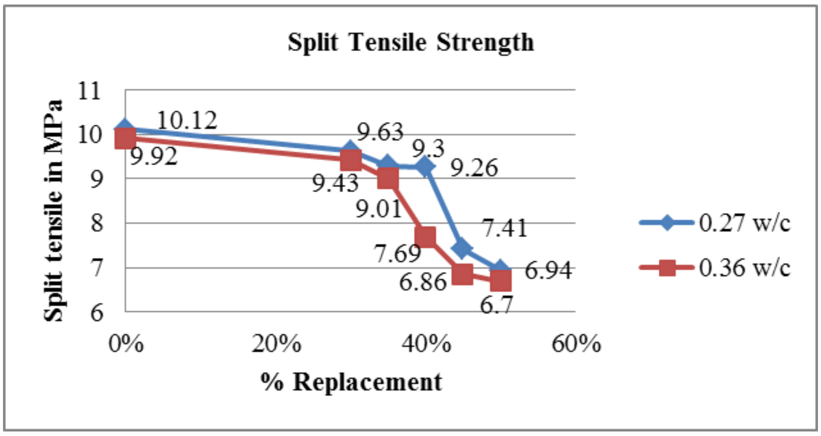

Fig.3 Split Tensile Strength of Concrete

From the Fig.3 the maximum split tensile strength achieved for NAC is 10.12 N/mm^2 and for 0.36 W/C, maximum tensile strength is at 0% replacement I.e., 9.92 N/mm^2. Among RAC the maximum 28 days split tensile strength developed for 30% replacement (0.27 W/C) it is 9.63 N/mm^2 with a strength reduction of 4.84%. Among RAC 50% replacement of NA by RA has lesser strength as compared to all replacement ratio. And the strength developed for 50% Replacement (0.27 W/C) is 6.94N/mm^2 and it is about 31.42% reduction in strength as compared to NAC and for 0.36 W/C with 50 % Replacement is 4.09 N/mm^2 and it is about 32.46% reduction in strength compared to NAC.

C. Flexure Test Results:

The flexural strength was carried out by flexural testing machine.

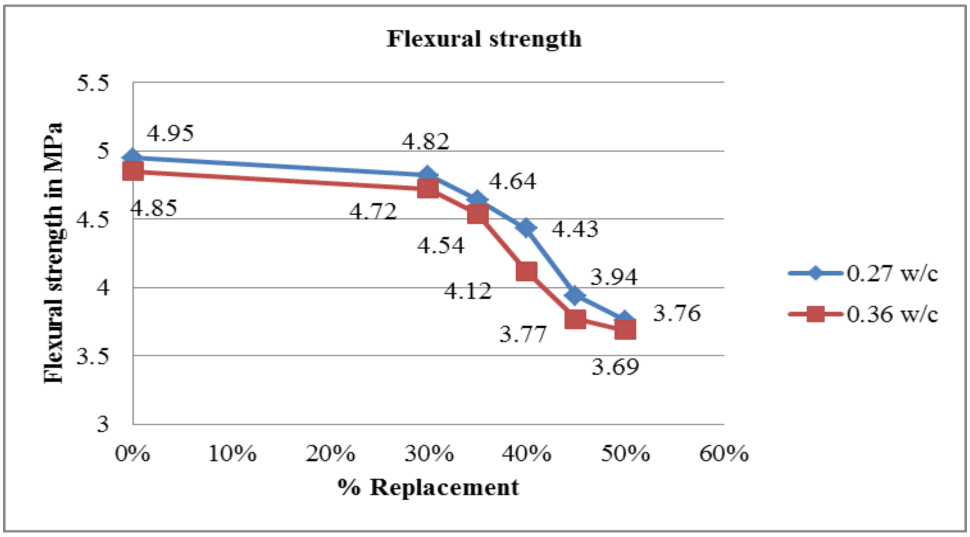

Fig.4 Flexure Strength of Concrete

The above Fig.4 shows Flexure strength and from results we can observe that with increased in percentage replacement of RA the strength gained reduces. The 28 days flexural strength developed is for NAC (0.27 W/C) is 4.95 N/mm^2 and for 0.36 W/C is 4.85 N/mm^2. Among RAC the maximum flexural strength developed for 30% replacement of 0.27 W/C which is 4.82N/mm^2 and it is about 2.63% reduction in strength as compared to NAC. And among RAC the least strength developed for 50% replacement of 0.36 W/C which is 3.69N/mm^2 and it is 23.92% reduction in strength as compared to NAC.

D. Specimens Subjected to Elevated Temperature

Each specimens were heated in Furnace to desired temperature according to temperature time curve (ASTM E119-2000) and constant temperature is maintained for 2 hours.

1) Compressive strength at elevated temperature

Compressive strength of cube subjected to elevated temperature are determined by using CTM machine.

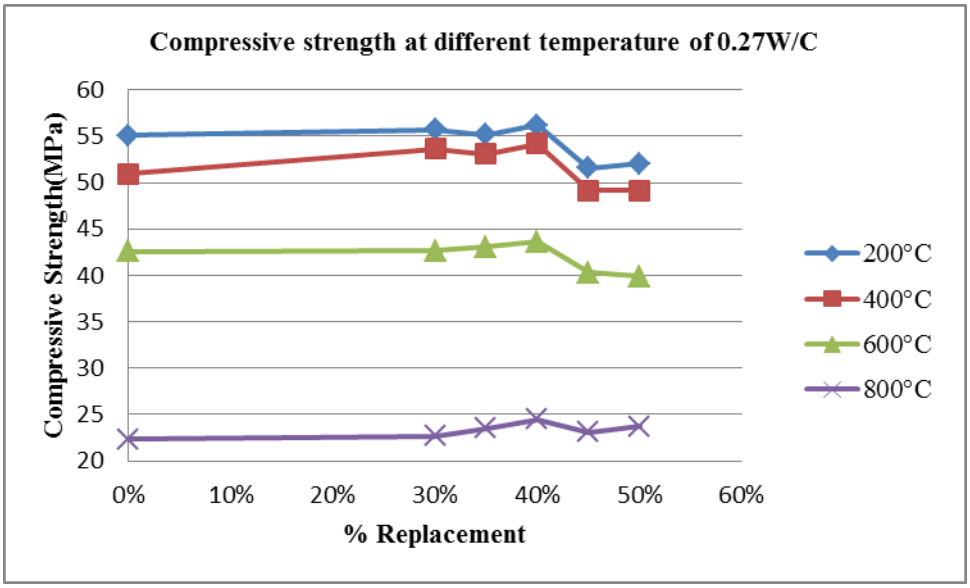

Fig.5 Compressive Strength at Different Temperature of 0.27W/C

From the above Fig.5 we can observe that maximum compressive strength (56.2 N/mm^2 at 200^{0}C, 54.21 N/mm^2 at 400^{0}C, 43.63 N/mm^2 at 600^{0}C and 24.46 N/mm^2 at 800^{0}C) obtained at 40% replacement for 0.27W/C at all the elevated temperature and least compressive strength observed at 50% replacement. Compressive strength increases with increase in % replacement up to 40% and then decreases. The lowest compressive strength 22.32N/mm^2 is obtained at 0% replacement for 800^{0}C.

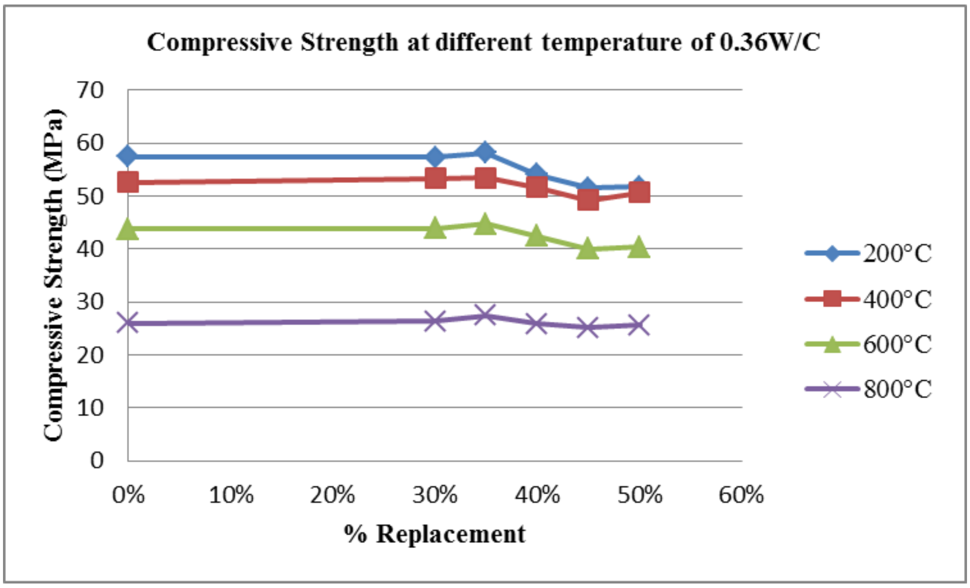

Fig.6 Compressive Strength at Different Temperature of 0.36W/C

From the above Fig.6 we can observe that maximum compressive strength (58.11N/mm^2 at 200^{0}C, 53.44 N/mm^2 at 400^{0}C, 44.75 N/mm^2 at 600^{0}C and 27.38 N/mm^2 at 800^{0}C) obtained at 35% replacement for 0.36W/C at all the elevated temperature and least compressive strength observed at 50% replacement. Compressive strength increases with increase in % replacement up to 35% and then decreases. The lowest compressive strength 25.16N/mm^2 is obtained at 45% replacement for 800^{0}C.

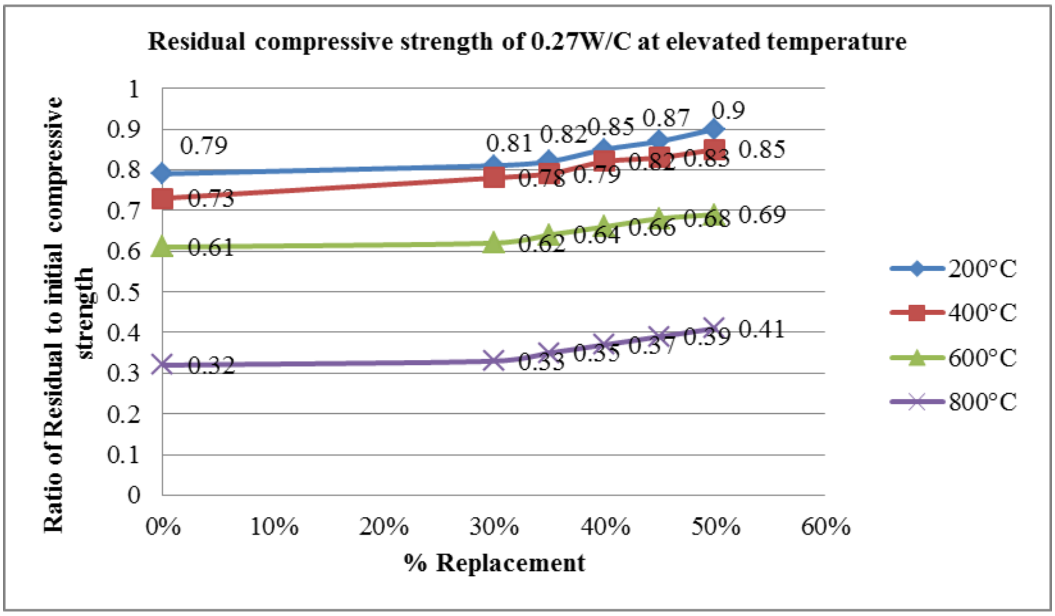

Fig.7 Ratio of Residual to Initial Compressive Strength of 0.27W/C at Elevated Temperature

The ratios of residual to initial compressive strength properties of concretes with different recycled aggregate concrete replacement percentages with 0.27W/C are shown in Fig.7 The lowest ratio of residual to initial compressive strength obtained for 0% replacement with values 0.79 at 200^{0}C, 0.73 at 200^{0}C, 0.61 at 600^{0}C and 0.32 at 800^{0}C. The maximum ratio of residual to initial compressive strength obtained for 50% replacement with values 0.90 at 200^{0}C, 0.85 at 200^{0}C, 0.69 at 600^{0}C and 0.41 at 800^{0}C. In Fig.7 it can be seen residual compressive strength increases with increase in % replacement. This improvement in residual compressive strength can be explained by increasing quantities of recycled mortar and % replacement level increases, resulting in a better match of thermal expansion properties between the aggregate and cement paste. Thus percentage reduction in strength for Recycled aggregate is less when compared to natural aggregate concrete.

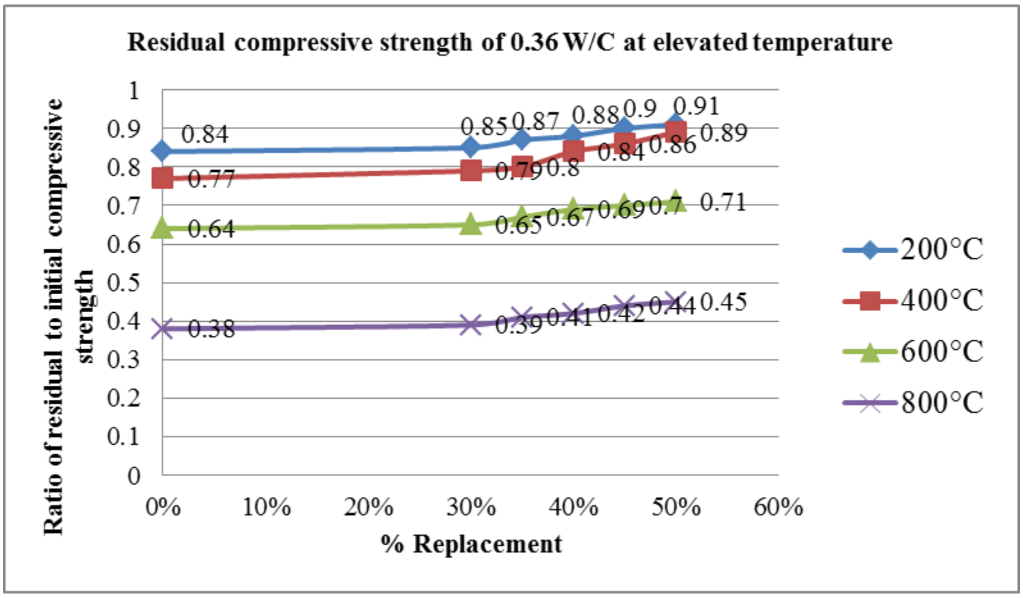

Fig.8 Ratio Of Residual To Initial Compressive Strength Of 0.36W/C At Elevated Temperature

The ratios of residual to initial compressive strength properties of concretes with different recycled aggregate concrete replacement percentages with 0.36W/C are shown in Fig.8 The lowest ratio of residual to initial compressive strength obtained for 0% replacement with values 0.84 at 200^{0}C, 0.77 at 200^{0}C, 0.64 at 600^{0}C and 0.38 at 800^{0}C. The maximum ratio of residual to initial compressive strength obtained for 50% replacement with values 0.91 at 200^{0}C, 0.89 at 200^{0}C, 0.71 at 600^{0}C and 0.45 at 800^{0}C. In Fig.8 it can be seen residual compressive strength increases with increase in % replacement. From Fig.7 and Fig.8, ratio of residual to initial Compressive strength for 0.27W/C at 0% replacement is 0.79 at 200^{0}C, 0.73 at 200^{0}C, 0.61 at 600^{0}C and 0.32 at 800^{0}C and for 0.36W/C at 0% replacement is 0.84 at 200^{0}C, 0.77 at 200^{0}C, 0.64 at 600^{0}C and 0.38 at 800^{0}C.Thus we can conclude that reduction in compressive strength is more for 0.27W/C than 0.36W/C for all replacement percentage. Thus concrete with 0.36W/C having more resistance to elevated temperature than 0.27W/C.

*2) **Split Tensile strength at elevated temperature***

Split Tensile strength of cube subjected to elevated temperature are determined by using CTM machine.

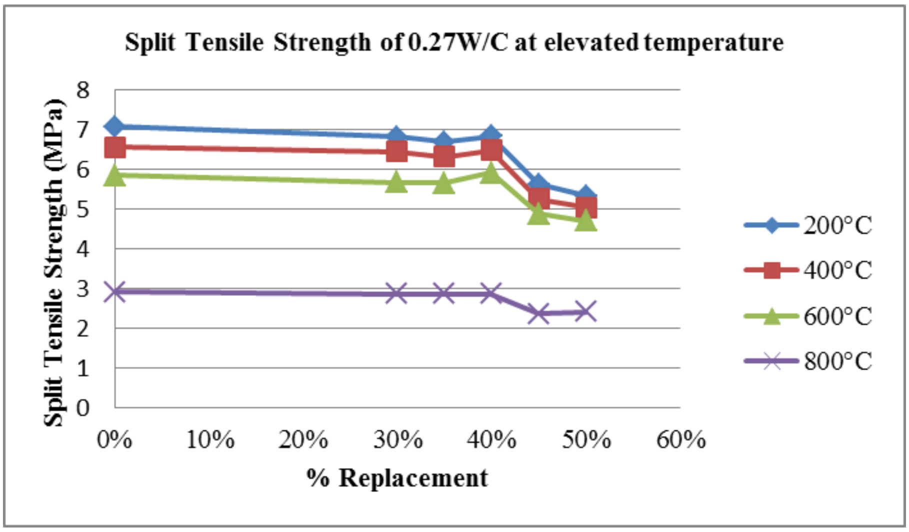

Fig.9 Split Tensile Strength Of 0.27W/C at Elevated Temperature

From the above Fig.9 we can observe that maximum split tensile strength (7.08 N/mm^2 at 200^{0}C, 6.57 N/mm^2 at 400^{0}C, 5.86 N/mm^2 at 600^{0}C and 2.93 N/mm^2 at 800^{0}C) obtained at 0% replacement for 0.27W/C at all the elevated temperature and least split tensile strength observed at 50% replacement. The lowest split tensile strength 2.37N/mm^2 is obtained at 45% replacement for 800^{0}C.

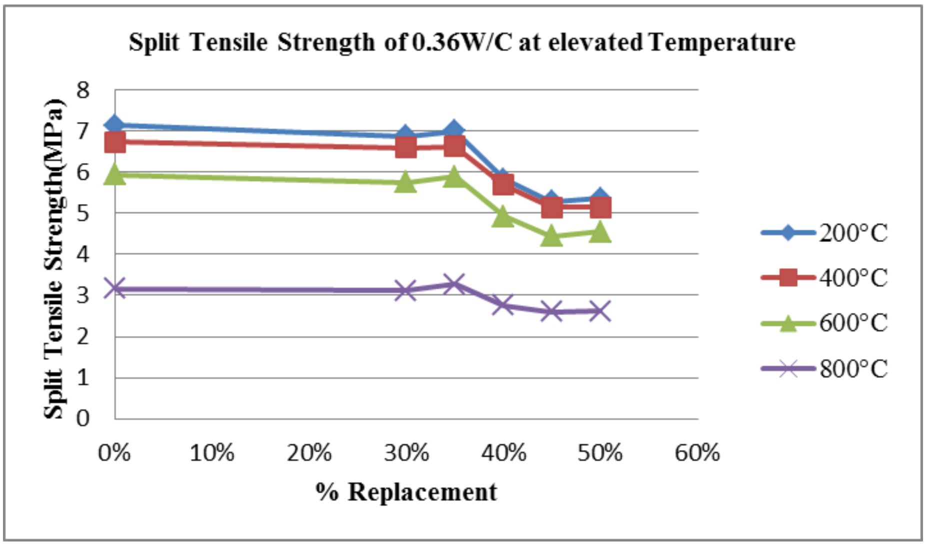

Fig.10 Split Tensile Strength of 0.36W/C at Elevated Temperature

From the above Fig.10 we can observe that maximum split tensile strength (7.14 N/mm^2 at 200^0C, 6.74 N/mm^2 at 400^0C, 5.95 N/mm^2 at 600^0C and 3.17 N/mm^2 at 800^0C) obtained at 0% replacement for 0.36W/C at all the elevated temperature and least split tensile strength observed at 50% replacement. The lowest split tensile strength $2.6N/mm^2$ is obtained at 45% replacement for 800^0C.

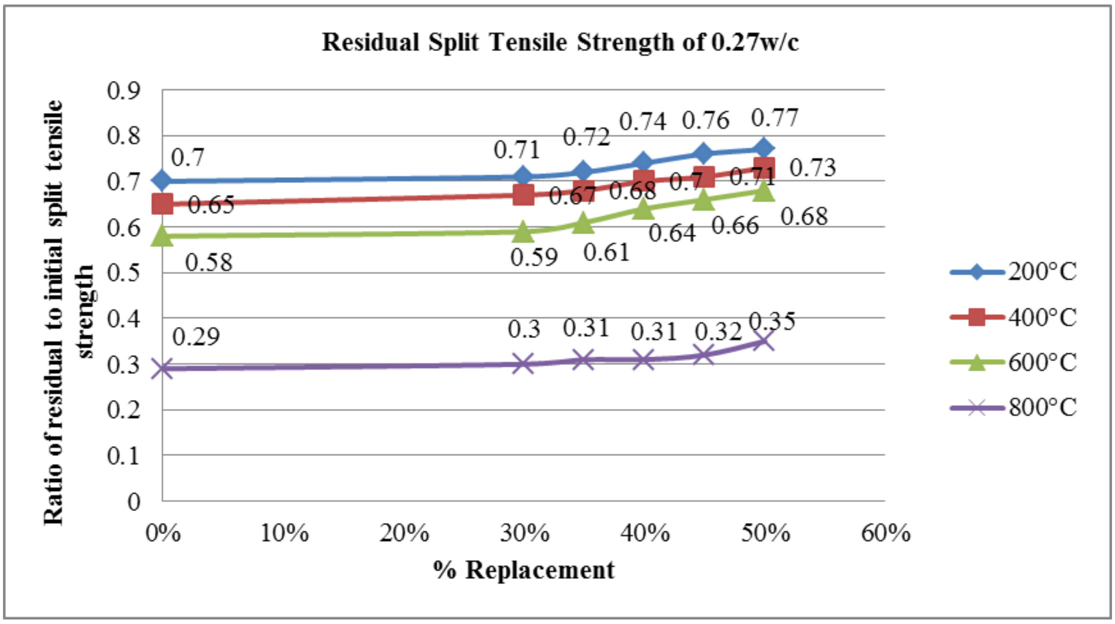

Fig.11 Ratio of Residual to Initial Split Tensile Strength of 0.27W/C at Elevated Temperature

The ratios of residual to initial split tensile strength properties of concretes with different recycled aggregate concrete replacement percentages with 0.27W/C are shown in Fig.11. The lowest ratio of residual to initial compressive strength obtained for 0% replacement with values 0.7 at 200^0C, 0.65 at 200^0C, 0.58 at 600^0C and 0.29 at 800^0C. The maximum ratio of residual to initial split tensile strength obtained for 50% replacement with values 0.77 at 200^0C, 0.73 at 200^0C, 0.68 at 600^0C and 0.35 at 800^0C. In Fig.11, it can be seen residual split tensile strength increases with increase in % replacement. Thus percentage reduction in strength of Recycled aggregate is less when compared to natural aggregate concrete.

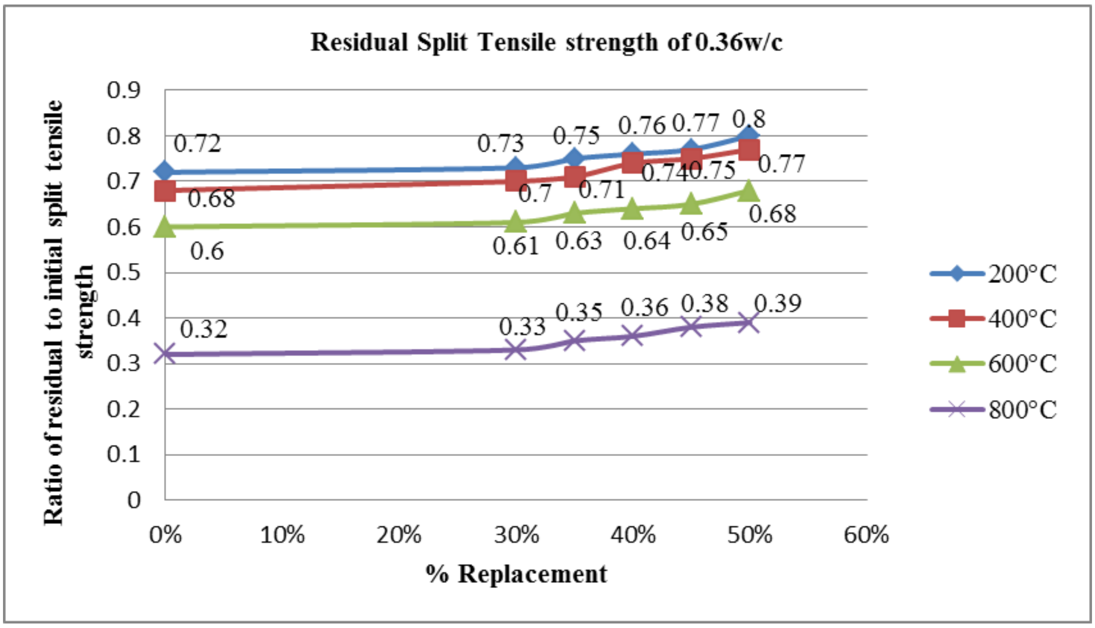

Fig.12 Ratio of Residual to Initial Split Tensile Strength of 0.36W/C at Elevated Temperature

The ratios of residual to initial split tensile strength properties of concretes with different recycled aggregate concrete replacement percentages with 0.36W/C are shown in Fig.12. The lowest ratio of residual to initial compressive strength obtained for 0% replacement with values 0.72 at 200^{0}C, 0.68 at 200^{0}C, 0.6 at 600^{0}C and 0.32 at 800^{0}C. The maximum ratio of residual to initial split tensile strength obtained for 50% replacement with values 0.8 at 200^{0}C, 0.77 at 200^{0}C, 0.68 at 600^{0}C and 0.39 at 800^{0}C. In Fig.12, it can be seen residual split tensile strength increases with increase in % replacement..

From Fig.11 and Fig.12, ratio of residual to initial split tensile strength for 0.27W/C at 0% replacement is 0.7 at 200^{0}C, 0.65 at 200^{0}C, 0.58 at 600^{0}C and 0.29 at 800^{0}C and for 0.36W/C at 0% replacement is 0.72 at 200^{0}C, 0.68 at 200^{0}C, 0.6 at 600^{0}C and 0.32 at 800^{0}C.Thus we can conclude that reduction in split tensile strength is more for 0.27W/C than 0.36W/C for all replacement percentage. Thus concrete with 0.36W/C having more resistance to elevated temperature than 0.27W/C. This holds good that higher the W/C ratio lesser will the temperature effect.

V. CONCLUSIONS

The specific gravity and bulk density of recycled aggregates is lower than the natural aggregates, because of adhered mortar present in recycled aggregates.

Reduction in compressive strength and split tensile strength by increase in the percentage replacement of natural aggregates by recycled aggregates in concrete.

Concrete made with recycled concrete aggregate exhibits adequate performance at elevated temperatures.

The highest ratio of residual to initial compressive strength and split tensile strength was found at the 50% replacement percentage, the 50% replacement level represented the optimal replacement level.

Recycled Aggregate Concrete has higher resistance to reduction in compressive strength when exposed to extreme temperature rise than the natural aggregate concrete.

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