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Effect Of High Temperature On Strength And Durability Of Self Compacting Concrete As A Goal For Sustainable Development

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Abstract

Concrete is a composite material consisting of a mixture of fine and coarse aggregates held together by a fluid cement binder. The progress of self-compacting concrete is widely acknowledged as a significant development in the construction industry. With its inherent cohesiveness, SCC can be placed without the need for compaction, enabling efficient filling of intricate formworks and ensuring excellent structural performance when reinforced. However, concrete is susceptible to damage when exposed to higher temperature. In this study, the compressive strength and durability of self-compacting concrete at high temperature is studied. The concrete samples are heated at 185ºC and 470ºC for two hours and then allowed to cool down than compressive strength and durability were studied. Also Recycled Aggregates were used as partial replacement for Coarse Aggregate and their compressive strength and durability were also studied. Comparison was made on Conventional SCC and RCA SCC to see whether Recycled Aggregates can be used as a replacement.

Keywords: Self Compacting Concrete, Recycled Aggregate, High Temperature

1. Introduction

Concrete is one of the largest used materials in construction industry. It is made of Cement, Fine Aggregate, Coarse Aggregate and water. Also, Admixtures are used when the grade of concrete is greater than M25. Conventional Concrete is widely used, it needs proper compaction and in places where compaction cannot be done properly than Self Compacting Concrete is used. SCC is defined as Concrete that flows under its own weight and which does not require compaction for placing. The excellent flowability of self-compacting concrete makes it well-suited for application in areas with high congestion [3,4]. There is less chance of honeycombing and segregation in SCC as compared to Conventional Concrete. SCC has same constituents of materials as compared to Conventional Concrete only the composition of materials. Admixtures increases the flow property of SCC [1,2,4]. Different admixtures such as fly ash, silica fume, limestone, granulated blast furnace slag [6,7,8].

Durability test such as water penetration test were done [6]. Mechanical properties such as compressive strength, split tensile strength, flexure test, modulus of elasticity were done [3,5,6,7,8,9]. Ultra pulse velocity test [6,7,8,12]. Mechanical properties such as Compressive strength, split tensile strength, flexure test on Recycled Aggregate concrete were carried out [1,6,9,10,11]. In this study, self-compacting concrete made with recycled aggregate with coarse aggregate by weight at 28 days is done and fresh state and hardened state properties at high temperature is conducted. The compressive strength of Self compacting concrete at high temperature decreases [3,9,11,12].

1.1 Literature Review

Ravi Shankar Yadav et al. (2015) studied the effect of Recycled Aggregate on Self Compacting Concrete. He found that upto 10% replacement the compressive strength and flexure strength were satisfactory. Also SCC made with 40% fly ash replaced with cement showed satisfactory compressive and flexure strength [1].

H.A.F. Dehwah (2011) investigated self-compacting concrete made by using Quarry Dust, Fly Ash, Silica Fume. It was observed that the mechanical properties of SCC made of Quarry Dust power were better than made of Fly ash and Silica fume combined. Also, the SCC made with Quarry Dust powder was more cost efficient [2].

T. Rajah Surya et al. (2020) investigated SCC at elevated temperature such as 200ºC, 400ºC, 600ºC & 800ºC. It was found that at 600ºC & 800ºC there was a drastic decrease in strength of concrete compared to 200ºC & 400ºC. Also there spalling in concrete at 800ºC [3].

Shariq Masood Khan et al. (2018) studied the properties of SCC made with steel fibre. He stated that the steel fibres increases the flow properties of SCC. Also, the compressive strength and flexural strength increased for 1% steel fibers [4].

Bertil Persson et al. (2001) conducted an experimental and numerical investigation to examine Compressive strength, Elastic modulus, Creep, Shrinkage of SCC. The mechanical properties of SCC were found to be similar to that of Conventional Concrete. The creep coefficient increased during the early stages but decreased eventually [5].

Kanish Kapoor et al. (2020) studied the effect of Recycled Aggregate, Fly Ash and Silica Fume on the properties of Self Compacting Concrete. It was found that the compressive strength of SCC made with fly ash & silica fume was nearly equal with the compressive strength of normal SCC whereas for Recycled aggregate replaced with fine aggregate shows marginally better compressive strength. [6].

Mucteba Uysal et al. (2011) studied the behaviour of SCC at high temperature with partial replacement of cement with fly ash & GBFS. Compressive strength was less compared to conventional SCC for Fly ash & GBFS based SCC at 400ºC. Also, UPV decreased with the increase in temperature and UPV was again low for Fly Ash & GBFS based SCC compared to conventional SCC [7].

Marija Jelcic Rukavina et al. (2015) In this study cement was replaced with Fly ash, metakaolin and limestone in different proportions and the mechanical properties of SCC were studied at high temperature. It was found that decrease in strength at high temperature were almost same for all types of mixtures and the compressive strength of all additives-based concrete was less than that of Conventional SCC [8].

Seyed Mehrdad Mousavi Alizadeh et al. (2021) studies about the residual strength of Self Compacting Concrete with Recycled Ceramic Aggregate at high temperature. It was found that slump decreases with the increase in quantity of Recycled Ceramic Aggregate. Modulus of elasticity at high temperature is less for RCA concrete compared to conventional SCC. Also, Compressive strength is low for RCA concrete [9].

M. Velay Lizancos et al. (2018) studied about the activation energy for conventional concrete and Self Compacting Concrete with replacement of Coarse Aggregate with Recycled Aggregate. It was found that the activation energy increased with the increase in Recycled Aggregate Quantity for both conventional and SCC [10].

Yong Chang Guo et al. (2014) studied the behavior of concrete with Recycled Aggregates, Rubber crumbs at high temperature. It was found that Compressive Strength and Stiffness of concrete at high temperature decreased as the rubber crumb quantity increased although rubber crumb enhanced the energy absorption capacity and explosive spalling resistance [11].

Tung Chai Ling et al. (2011) studied the effect of Recycled Glass and Curing Conditions on Self Compacting Concrete at high temperature. It was found that residual strength and mass losses were high for water cured specimens compared to air cured specimen at high temperature. And the Water Porosity and Water Sorptivity values were high for air cured specimen compared to water cured specimen [12].

2. Materials

The Cement used in this work is Portland Pozzolana Cement (PPC). The standard consistency of cement is 36%. Fly Ash quantity in PPC cement used is 30%. Fine Aggregate used in this work is of zone 3. Coarse Aggregate used in this work was of nominal size 20mm. Size ranging from 6mm to 20mm is used. Recycled Aggregate size used is also ranging from 6mm to 20mm. The materials quality were as per Indian Standards. Super Plasticizer used was Polycarboxylate Ether. Ph value of admixture is ≥ 6. Further Properties of Materials are given in

Table *1*.

Table 1

Properties of Materials

S.No.	Property	Results
1	Fineness of Cement	3 %
2	Initial Setting Time of Cement	135 min
3	Specific Gravity of Cement	2.627
4	Specific Gravity of Fine Aggregate	2.43
5	Water Absorption of Fine Aggregate	2.23
6	Fineness Modulus of Fine Aggregate	2.198
7	Specific Gravity of Coarse Aggregate	2.608
8	Water Absorption of Coarse Aggregate	0.595
9	Fineness Modulus of Coarse Aggregate	6.591
10	Specific Gravity of Recycled Aggregate	2.133
11	Water Absorption of Recycled Aggregate	6.5

2.1 Mix Proportions

Mix Design for Self-Compacting Concrete was Done as per IS-10262 and IS-456 [13,14]. A total of 3 different mixes were made. 18 cubes in each mix were prepared. The First mix was Conventional SCC. Second Mix is made with 12% partial replacement of Coarse Aggregate with Recycled Aggregate and Third Mix is made with 24% partial replacement of Coarse Aggregate with Recycled Aggregate. Super plasticizer is 0.8% of cement. Mix Proportions for 1m3 is shown in **Table 2**. M30 grade of concrete was made. Polycarboxylate Ether based admixture was used in the mix of Self Compacting Concrete.

Table 2

Mix Proportion

Grade	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Recycled Aggregate (kg)	w/c
M30	446.51	891.5	750	-	0.43
12% RA	446.51	891.5	660	90	0.45

24% RA	446.51	891.5	570	180	0.46

2.2 Tests for Self-Compacting Concrete (SCC)

The flowability of Self Compacting Concrete is Checked in its fresh state through V-Funnel test, L-Box test, J-Ring test. V funnel test is done for determining the filling ability of SCC shown in Figure2, L-Box test is done for determining passing ability of SCC shown in Figure 1 and J-Ring test is done for determining passing ability of SCC shown in Figure 3. The results of these tests shows the characteristics of SCC.

Figure 1 L- box test

Figure2 V Funnel test

Figure 3 J Ring test

2.3 Test Setup

The size of the cubes are 150×150×150 mm. 27 cubes for Compressive Strength and 27cubes for Water Permeability test were made. 18 cubes for each mix were made. In total 54 cubes were made. The cubes were than cured for 28 days. After curing 18 cubes were heated at 185ºC and 18 cubes were heated at 450ºC and the remaining 18 cubes were kept at room temperature. 3-3 cubes for each mix and for each temperature were tested on Compression Testing machine of Capacity 3000KN according to ASTM C39. Before this Non-Destructive Tests such as Ultra Pulse Velocity (UPV) test according to IS 516 [PART 5/SEC 1] were done on these samples. Similarly, 3-3 cubes for each mix and for each temperature were tested for water permeability according to IS 516 [PART 2/SEC 1] 2018 and DIN 1048 PART 5.

3. Results and discussions

3.1 Tests for Self-Compacting Concrete

Tests were done on fresh concrete to check the characteristics of Self Compacting Concrete such as V-Funnel test, L-Box test and J-Ring test. The results are shown in **Table 3**. The results were within the range as given in EFNARC [15].

Table 3

Properties of Self Compacting Concrete

Grade	L-Box (mm)	V-Funnel (sec)	J-Ring (mm)
M30	0.8	9	3.5
12% RA	0.89	8.4	5.5
24% RA	0.9	7.9	5.5

3.2 Compressive Strength

After curing for 28 days, cubes were subjected to 185ºC & 450ºC. The specimen is kept for 2 hours at that temperature. After heating, the specimen is allowed to cool down. Then the specimens are placed in Compression Testing machine and tested as shown in Figure 4.

The average Compressive Strength of Self Compacting Concrete at 28 Days at Room Temperature of M30 Grade Concrete is 40.83MPa. At 185ºC the compressive strength was 39.4MPa and at 450ºC the compressive strength reduced to 35.06mpa. For 12%RA Concrete, the average compressive strength at 28 days at Room Temperature is 37.56MPa which reduced to 36.56MPa at 185ºC and further decreased to 32.53MPa at 450ºC. For 24%RA Concrete, the average compressive strength at 28 days at Room Temperature is 34.03MPa which reduced to 33.04MPa at 185ºC and further decreased to 29.33MPa at 450ºC. The data for compressive strength is shown in Figure 5. The compressive strength of Recycled aggregate concrete is less than conventional concrete because recycled aggregates often have higher porosity, lower density, weaker interfacial bond and high w/c ratio in comparison to normal coarse aggregate. Hence the strength is low for Recycled Aggregate Concrete. Also, at high temperature there is loss of moisture in concrete, the aggregates undergoes thermal spalling which weakens the concrete mix due to which there is effect on compressive strength of concrete.

Figure 4 Specimen under Testing

3.3 Ultra Pulse Velocity

The Cubes were tested for Ultra pulse Velocity as Shown in Figure 6. The average value of UPV of M30 grade concrete at Room temperature is 4.43 Km/s which reduces to 4.28 Km/s at 185ºC and which further reduces to 4.04 Km/s. For 12% RA, the value of UPV at room temperature is 4.38 Km/s which reduces to 4.08 Km/s at 185ºC and which further reduces to 3.97 Km/s at 450ºC. And for 24% RA, the value of UPV at room temperature is 4.29 Km/s which reduces to 4.02 Km/s at 185ºC and which further reduces to 3.9 Km/s at 450ºC. The usage of Recycled Aggregates tends to decrease UPV values due to their low quality which increases the pore space in the concrete which effects the transmission of ultrasonic waves. The results are shown in Figure 7. At high temperature there is thermal expansion due to which the spacing between particles increases which results in change in density which eventually affects UPV. Also, there is loss in moisture at high temperature, which also affects UPV because water acts as an important medium for ultra sonic wave propagation. Recycle aggregate Concrete often have higher porosity, lower density, weaker interfacial bond which results in more porous concrete mix.

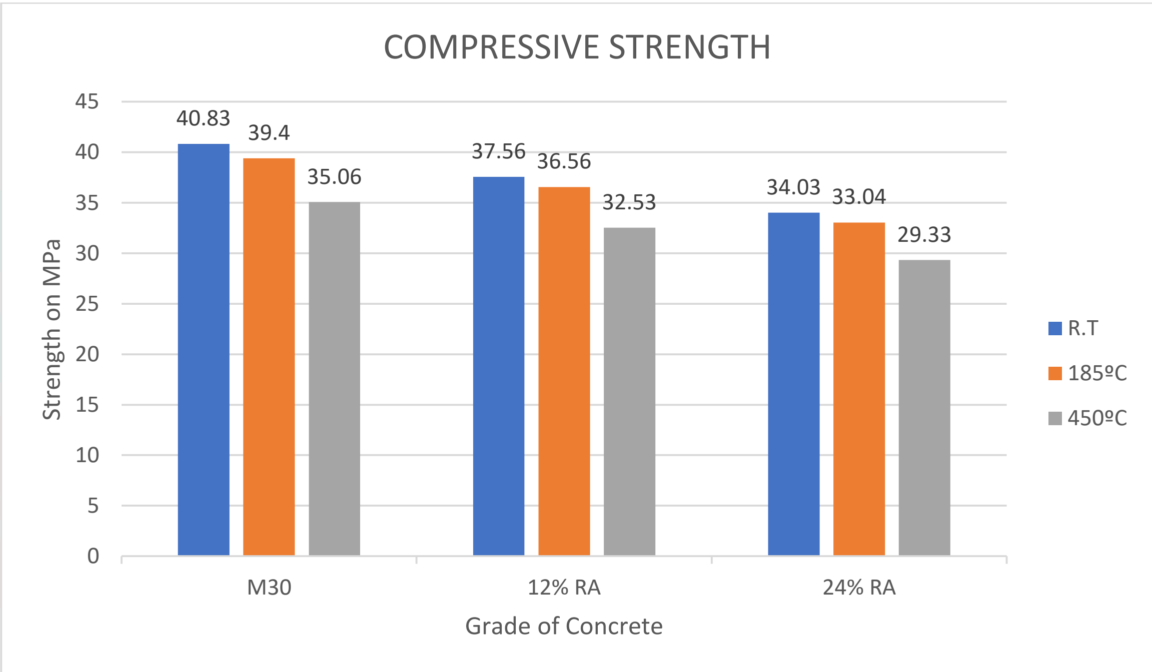

Figure 5 Compressive strength for SCC at high temperature

3.4 Water Penetration

Water penetration test was done on cubes after 28 days of curing to determine the durability of concrete against water penetration. The results are shown in **Table 4**. It is observed that water penetration depth was more with the increase in Recycled aggregate content. Also, the values of water penetration increased with the increase in temperature. The test was done according to IS 516 [PART 2/SEC 1] 2018 and DIN 1048 PART 5. The test setup is shown in Figure 8.

Figure 6 UPV Test

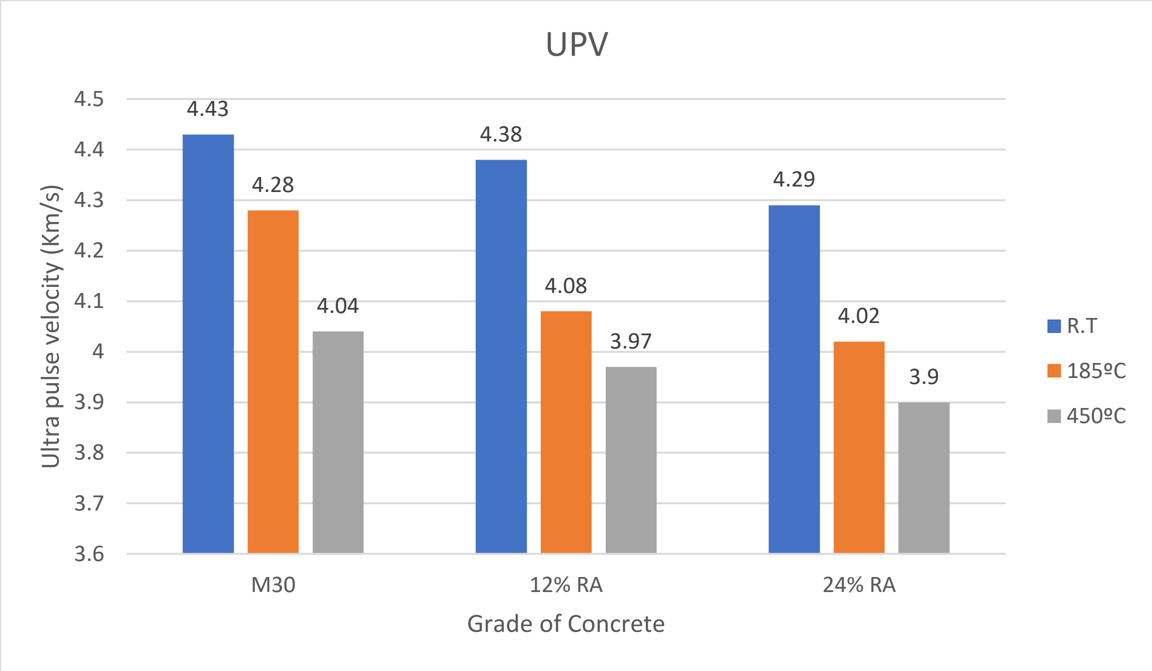

Figure 7 UPV for SCC at high temperature

Table 4

Water penetration test result

Grade	**R. T.**	**185ºC**	**450ºC**
M30	17.66	18.67	-
12% RA	21	22.33	-
24% RA	28.67	30.33	-

Figure 8 Water penetration test

4. Conclusion

The compressive strength of M30 grade Concrete at 28 days is 40.83 MPa, 39.4 MPa & 35.06 MPa at room temperature, 185ºC & 450ºC respectively. For 12% RA concrete at 28 days 37.56 MPa, 36.56 MPa & 32.53 MPa at room temperature, 185ºC & 450ºC respectively. For 24% RA concrete the compressive strength at 28 days is 34.03MPa, 33.04MPa & 29.33 MPa at room temperature, 185ºC & 450ºC respectively. The percentage decrease in strength of concrete of M30 grade is 3.50% & 14.13% at 185ºC & 450ºC respectively. For 12% RA concrete the percentage decrease is 2.66% & 13.39% at 185ºC & 450ºC respectively. For 24% RA concrete the percentage decrease is 2.91% & 13.81% at 185ºC & 450ºC respectively. The percentage decrease in strength of concrete at room temperature is 8% & 16.65% for 12% RA & 24% RA respectively. At 185ºC the percentage decrease in strength of concrete is 7.20%& 14.13% for 12% RA & 24% RA respectively. At 450ºC the percentage decrease in strength of concrete is 7.23%& 16.34% for 12% RA & 24% RA respectively.

The UPV for M30 grade of concrete decreases by 3.38% & 8.80% at 185ºC & 450ºC respectively. For 12% RA concrete, UPV decreases by 6.84% & 9.36% at 185ºC & 450ºC respectively. For 24% RA concrete, UPV decreases by 6.29% & 9.09% at 185ºC & 450ºC respectively. The percentage decrease in UPV at room temperature is 1.13% & 3.16% for 12% RA & 24% RA respectively. At 185ºC the percentage decrease in UPV is 4.67%& 6.07% for 12% RA & 24% RA respectively. At 450ºC the percentage decrease in UPV is 1.73%& 3.46% for 12% RA & 24% RA respectively.

The water penetration test gives idea about the durability of concrete against water. In case of M30 grade concrete, as the temperature increases the water penetration value also increases. The M30 grade of concrete was safe against water penetration at room temperature & 185ºC but failed at 450ºC. The limit for water penetration depth is 25mm as per section 1700 of MORTH 5th revision clause 1717.7.5. Similarly, 12% RA also failed at 450ºC in durability. But 24% RA concrete failed at all temperatures, the reason being the strength and bonding of concrete is not good in 24% RA concrete.

Thus, it was established that the compressive strength of concrete decreases with the increase in temperature. Also, as the percentage replacement of Recycled aggregate increased compressive strength again decreased. Similarly, UPV also decreased with the increase in temperature. Again, UPV also decreases as Recycled aggregate quantity increases. Self-Compacting Concrete failed in durability at high temperature.

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