International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 6, June-2018

THERMAL EFFECTS ON MECHANICAL CHARACTERISTICS OF SCC

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Abstract:** The present work addresses the thermal effects on characteristics of medium strength self compacting concrete. Initially, the flowing concrete was designed using a simple technique based on packing factor and s/a ratio. To develop the SCC, the packing density of available filler materials is optimized and Nan su [1] mix designed was modified a little. The casted mixes are investigated for both green and hardened state properties and are compared with the available literature and EFNARC guidelines [2] to meet requirements technically and practically. Apart from this, non destructive, durability and corrosive properties of these concrete mixes are also investigated. Finally, the studies were extended to elevate the influence of high temperatures (100^O, 200^O, 400^O, 600^{O}C) and thermal cycles (at a temperature of 200^{O}C) on characteristics of MSSCC.

Keywords: Packing Factor (PF), Mixture proportioning, Elevated temperature, Thermal cycle.

I. INTRODUCTION

Concrete had under gone from macro to micro level studies in the enhancement of strength and durability properties. Till 1990 the research study was mainly focused only to improve the workability of concrete, so as to enhance the strength but durability did not draw a lot of attention of the concrete technologists. This type of study has resulted in the development of Self Compacting Concrete (SCC), a much needed revolution in concrete industry. The use of Self-Compacting Concrete (SCC) represents a high point in concrete research facilitates by eliminating the need for compaction by vibration and became a most useful implement in construction industry, due to its advanced properties like high fluidity and good cohesiveness. Its ability to self compact without the use of any vibrator allows SCC to pass through dense reinforcement and fill in restricted sections, improving the quality of the structure casted[3]. It improves the efficiency at the construction site enhancing the working conditions and also the quality and appearance of concrete. Regardless of slump, w/cm, column height, or degree of consolidation, the incorporation of proper combinations of VMA and HRWR is shown to significantly reduce bleeding, settlement, and segregation without sacrificing fluidity[4]. The durability of concrete structures is related not only to design and materials but also to construction. Due to improper quality assurance and special problems in construction many durability problems will be developed Therefore, a more controlled durability and service life of important concrete infrastructure can be reached by conducting durability studies.[5,6]. Most of the concretes are exposed to high temperatures when it is near to furnaces in industries or when subjected to firethen the mechanical properties are reduced to great extent. [7].

Excessive spalling of concrete takes place when subjected to high temperature[8,9] The hardened matrix of SCC will be more compacted so these concretes are highly affected when prone to high temperature. Fire poses as one of the most severe risks to buildings (lau and anson 2006)[10].The relative strength of concrete reduces with increase in exposure temperature.(17) The effect of mechanical properties of SCC with varying packing is looked at. The present experimental studies aimed at producing and studying the mechanical and durability properties of Medium Strength Self Compacting Concrete (MSSCC).

II. RESEARCH SIGNIFICANCE

The objective of the present paper is to produce MSSCC for varying PF and s/a ratio and to examine the mechanical and durability properties of MSSCC. For a newly developing material like SCC studies on the effect of thermal cycles and elevated temperature are of supreme importance for installing self-belief among builders. An attempt was made to study the effect of thermal cycles and elevated temperature on MSSCC.

III. MATERIALS

Cement conforming to EN42.5 grade is used in the present investigation. Its physical properties are presented in Table-1. In the present experimental study a Class F Fly Ash confirming to IS 3812 was used. The consistency test was conducted on Fly Ash and the value found to be 0.25 for 23%. CAC hyper fluid R100 super plasticizer with retention for high performance concrete based "polycarboxylic ether" was used. It is a high-range water reducing agent and also helps in attaining flow ability of concrete. CAC Viscosity modifying agent conforming to standard specifications was also used.

Natural sand with a fineness modulus of 4.4 confirmed to Indian Standard Specifications IS:383-1970 was used for the experimental program. The coarse aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested as per IS: 383-1970. After gradation of aggregates(Table-2), by using DIN Curve weight of each grade of aggregates is calculated. From graph-1 the % weight of coarse aggregate are obtained as 20mm sieve passing and 12.5 retaining is 41.1%, 12.5 passing and 10mm retaining is 15.6% and 10mm passing and 4.75mm retaining is 43.1%. The maximum coarse aggregate size was of 10- 20 mm was selected to avoid the blocking effect in the L-Box as the gap between re-bars in L-Box test was 35mm.

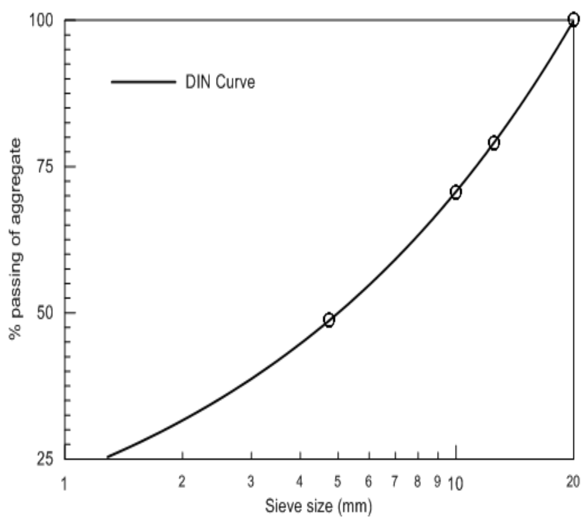
A. Mix design and proportioning

Step1- Calculation of water cement ratio using ACI 211.1 and 211.4[6]

Step2- Packing Factor (PF) is the ratio of mass of tightly packed aggregate to loosely pack in SCC .Choose PF and s/a ratio.

Table 1.Physical characteristics of cement.

S.No	Properties	Values obtained	Standard values
1	Normal Consistency	38%	-
2	Initial ST	40 min	Not <30min
3	Final ST	240min	Not>600 min
4	Fineness	4.8%	<10
5	Specific gravity	3.2	-



Graph 1. Particle size distribution of coarse aggregate used in the present investigation.

Step3-Calculation of coarse and fine aggregate contents are done based on the equations given in Nansu mix design [2]

$$W_{ca} = PF \times W_{gL}\left(1 - \frac{S}{a}\right) \qquad ...(1)$$

$$W_{fa} = PF \times W_{sL} \times \frac{s}{a} \qquad ...(2)$$

W_{ca} and W_{fa} are weight of coarse and fine aggregate

W_{gL} is unit volume of loosely piled saturated surface dry coarse aggregate in air (kg/m3)

W_{sL}= unit volume of loosely piled saturated surface dry fine aggregate in air (kg/m3)

Step4-Calculation of flyash using equation strength vs % of flyash

$$Strength\ of\ concrete = 100 \times e^{-0.04x} \quad ..(3)$$

x= % of fly ash

Step5: Calculate cement, fly ash, and water by considering volumetric proportions.

Table 2. Concrete Mix Proportions.

Type	PF	s/a	Cement (kg)	F (kg)	CA (kg)	FA (kg)	Water (litres)
M30-	1.12	0.5	1	0.428	3.486	3.058	0.428
M50-	1.12	0.5	1	0.21	2.454	2.153	0.498
M60-	1.12	0.5	1	0.145	2.153	1.889	0.408
C11	-		1	-	2.6	1.2	0.45
S11	1.12	0.57	1	0.3	1.912	2.37	0.52
S12	1.14	0.57	1	0.3	2.06	2.56	0.52
S13	1.16	0.57	1	0.3	2.17	2.69	0.52
S14	1.18	0.57	1	0.3	2.28	2.74	0.52
S21	1.12	0.5	1	0.3	2.31	2.16	0.52
S22	1.14	0.5	1	0.3	2.42	2.27	0.52
S23	1.16	0.5	1	0.3	2.55	2.38	0.52
S24	1.18	0.5	1	0.3	2.68	2.51	0.52

IV. PREPARATION OF TEST SPECIMENS AND TESTING

A. *Fresh concrete mixes*

The mixing consisted of initially adding of some quantity of water with super plasticizer and then the coarse aggregates are homogenized. Then cement, fly ash and fine aggregate are introduced with 75% water and mixed and finally remaining SP and VMA were added with remaining water. All the listed fresh concrete tests were carried over a period of 15-20 min after mixing had been completed. Produced fresh concrete was evaluated by different tests such as slump flow test, V-funnel test, L-box test and J-ring test to obtain self compacting properties such as filling ability, passing ability segregation resistance and validated to satisfy the EFNARC guidelines[1] The results of rheological tests are presented in Table 2.

Table 3. Fresh Properties Results.

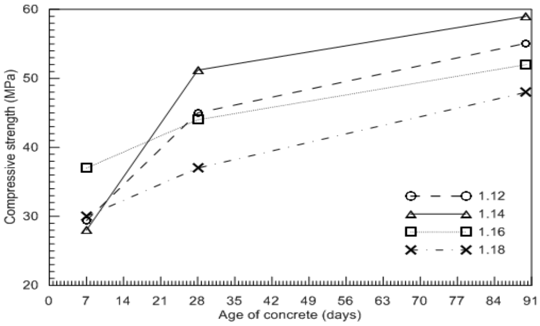
Trial	PF	s/a	Flow Test (650-800mm)	U-Box (0-30mm)	V-Box (6-12sec)	V-t5 (8-12sec)	L-box (0.8-1.0)
C11	-	-	-	-	-	-	-
S11	1.12	0.57	730	30	13	12	1.0
S12	1.14	0.57	780	27	12	11	0.9
S13	1.16	0.57	700	27	11	11	1.0
S14	1.18	0.57	750	29	12	12	1.0
S21	1.12	0.5	700	30	12	14	0.8
S22	1.14	0.5	750	28	8	11	1.0
S23	1.16	0.5	700	30	15	10	1.0
S24	1.18	0.5	800	29	8.36	9.4	0.8

B. Hardened concrete test specimens

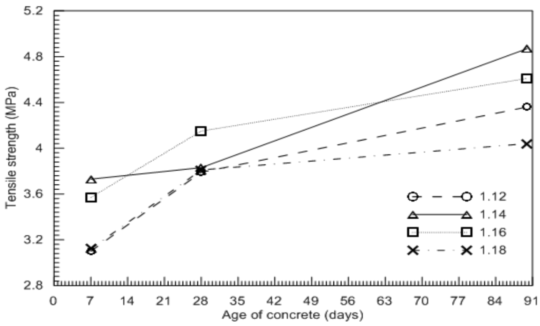
In order to evaluate compressive strength, 100mm cube moulds were used and standard cylindrical moulds with 200mmx100mm dimension were used to measure splitting tensile strength. Demoulding was performed 24 hours after concrete casting and specimens were placed in water with 20 ± 2 °C temperature until taken out prior to test. The hardened properties of these mixes were also studied and the results of 28-90 days are compared with the Vibrated Normal Concrete as shown in Table-4.For these concrete mixes non destructive tests like Rebound hammer, Ultra Pulse Velocity, Resistivity were also carried out. Graph 1 and 2 shows the compressive strength variation with respect to age for varying PF and s/a ratio. The maximum compressive and tensile strength was observed at PF 1.12- s/a 0.5 and at PF 1.14 -s/a 0.57.

Table 4. Hardened properties of M 40, s/a=0.57 and 0.50 for different PF.

Specimen	PF	Compressive strength(Mpa)			Split tesile strength(Mpa)			UPV(m/sec)		Rebound No	
Days		7	28	90	7	28	90	28	90	28	90
C11	-	33	45.2	53	3.98	4.45	5.45	4827	4872	44	48
S11	1.12	29.4	45	55.1	3.79	3.1	4.36	4815	4815	44	49
S12	1.14	28	51.2	59	3.73	3.83	4.87	4900	4900	47	51
S13	1.16	37	44	52	4.15	3.57	4.61	4846	4846	43	48
S14	1.18	30	37	48	3.81	3.12	4.04	4667	4667	40	45
S21	1.12	28.23	49.5	59	3.66	5.1	5.42	4963	4963	46	51
S22	1.14	26.12	45	56	3.52	4.71	5.25	4815	4894	44	50
S23	1.16	32.78	41.22	51	3.98	4.51	4.89	4764	4975	42	46
S24	1.18	30.23	46.3	57	3.82	4.79	5.31	4802	4942	45	50



Graph 2. Variation compressive strength with age for MSSCC.



Graph 3. Variation tensile strength with age for MSSCC.

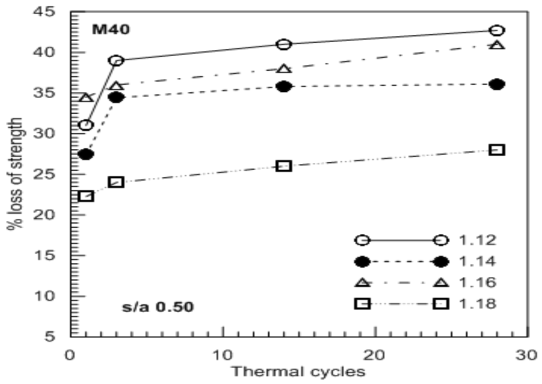
V. DURABILITY STUDIES

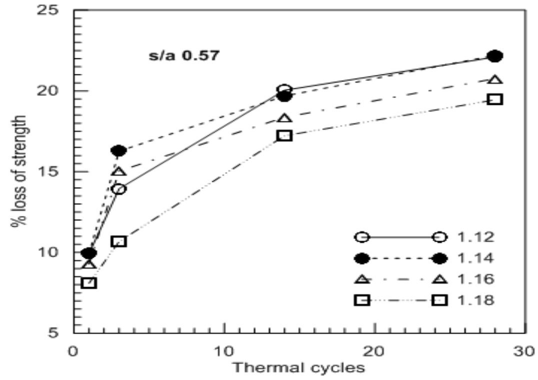
A. Thermal cycles

Concrete in structures when exposed to high temperature gets stressed .Very few work was done on thermai cycles therefore this paper also reports on the experimental study of MSSCC with varying packing factors and s/a 0.5 subjected to thermal cycles at a temperature of 200 degree centigrade. One thermal cycle constitute a heating period of 8 hours at a temperature 200 degrees centigrade and subsequent cooling (in air room temperature) period of 16 hours. The standard cube specimens after curing period were placed in electrical oven at 200 degrees centigrade for 1, 3, 14, 28 thermal cycles. The specimens were naturally allowed to reach the room temperature and they were tested for compressive strength, pulse velocity, weight of the specimens as shown from Table 5..The percentage loss in strength for varying PF and s/a ratios is shown in graphs 5&6 .They clearly indicate that there is a decrease in compressive strength of ordinary concrete mixes in comparison with zero thermal cycles for 50° C is observed to be varied from 14 to 23 % for 1, 3, 14, and 28 thermal cycles. The effect of temperatures is related to either the weaker formation of cement paste hydrates or due the differential thermal expansion of concrete. From table it clearly shows that % loss in weight, UPV and resistivity varies from 3-4%, 2-27% and 8-85%.

Table 5. Thermal Cycle Values for M40 for various PF&s/a=0.5.

Mix(M40)	Thermal cycle	Initial Weight (Kgs)	% of loss in weight	Initial UPV (m/s)	% of loss in UPV	Initial resistivity(Kohms-cm)	%loss in resistivity	Initial Compressive Strength (Mpa)	% of loss in Comp. Strength
PF 1.12&s/a0.5	1	2.40	3.91	5155	2.52	35.26	17.41	49.5	31.00
	3	2.46	3.05	5025	23.16	35.26	45.15	45	39.00
	14	2.49	3.97	5155	22.09	35.26	55.64	41.2	41.00
	28	2.48	4.19	5155	26.51	35.26	100.00	46.3	42.70
PF 1.14&s/a0.5	1	2.23	3.68	4902	4.67	33.12	8.06	49.5	27.40
	3	2.45	3.51	5025	22.26	33.12	25.66	45	34.20
	14	2.25	3.15	4673	10.46	33.12	39.01	41.2	35.80
	28	2.25	3.15	4673	10.46	33.12	79.38	46.3	36.11
PF 1.16&s/a0.5	1	2.40	4.88	4784	12.54	30.54	10.84	49.5	34.50
	3	2.51	4.69	4673	19.55	30.54	52.39	45	36.00
	14	2.32	4.95	4902	22.13	30.54	40.31	41.2	38.00
	28	2.44	4.67	4566	16.40	30.54	71.61	46.3	41.00
PF 1.18&s/a0.5	1	2.59	11.85	4902	10.91	28.33	11.33	49.5	22.27
	3	2.55	4.51	4673	23.83	28.33	40.84	45	24.00
	14	2.33	4.37	5025	20.07	28.33	60.64	41.2	26.00
	28	2.39	4.76	4785	24.28	28.33	66.33	46.3	28.00





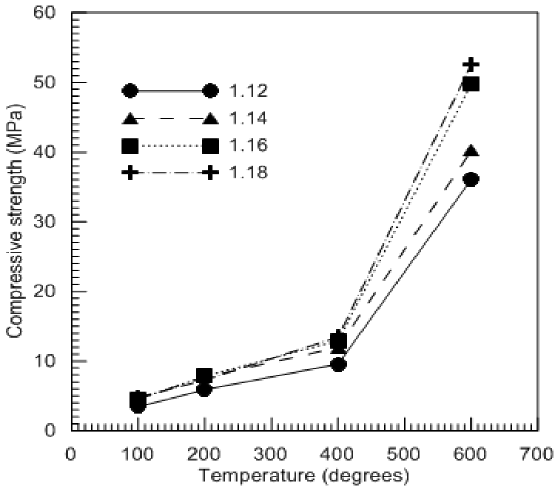
Graph 5&6. M40 s/a 0.5 & 0.57 Strength loss percentage for all cycles.

B. Elevated temperature studies

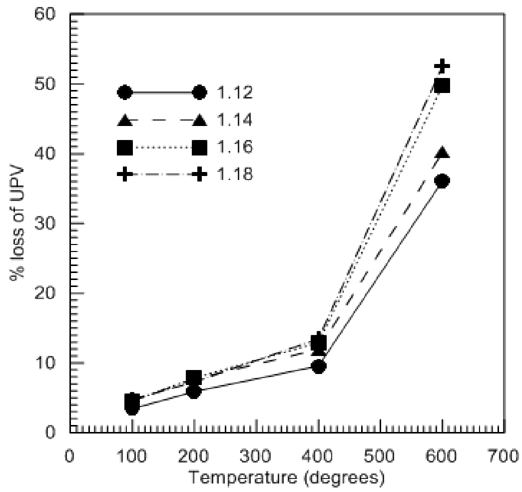
In case of fire accidents concrete elements such as beam, columns, slabs, walls etc will be subjected to high temperature. The surface cracks become visible when temperature reaches 600^0C [10] .The unit weight and, compressive strength decreases when exposed to elevated temperature. The weight reduction due to loss of bound water from cement paste and compressive strength reduction due to reduction of Ca(OH)2 [11]. The risk of spalling for self-compacting high-strength concrete was greater than that of conventional high-strength concrete[12-18]In order to access the performance of concrete members it is important to understand the changes in concrete properties due to high temperature. Therefore in this paper we concentrated on studying the mechanical properties of MSSCC cubes subjected to elevated temperature of 100, 200, 400, 600 degrees centigrade for duration of 60 min. After that these specimens are not disturbed for a day. The strength, pulse velocity, weight of the specimens was found after cooling the specimens and the results of elevated temperature on MSSCC were provided in Table 10 to 13.Graphs 7&8 shows that compressive strength and UPV decreases as the specimens are subjected to higher exposure temperature .At temperature 600^0C cracks were observed during heating and excessive spalling took place during testing.The % loss in UPV is around 2-50% for various PF and resistivity loss is 2-60%.

Table 6. Elevated temperature studies for various PF and s/a ratios..

Temp	PF	Initial Weight (Kgs)	% of loss in weight	Initial UPV (m/s)	% of loss in UPV	Initial resistivity(Kohms-cm)	%loss in resistivi ty	Initial Compressive Strength (Mpa)	% of loss in Comp. Strength
100^0C	1.12	2.48	0.00	5025	3.44	35.26	60.86	49.5	1.01
	1.14	2.41	0.00	4785	4.57	1.23	45.45	45	0.00
	1.16	2.40	0.42	5155	4.52	3.22	13.82	41.22	0.72
	1.18	2.54	0.39	4902	4.79	1.76	2.92	46.3	0.64
200^0C	1.12	2.27	0.53	5155	5.91	2.85	58.94	49.5	3.00
	1.14	2.21	2.99	4785	7.72	1.29	13.17	45	2.22
	1.16	2.35	3.02	5025	7.85	1.67	26.34	41.22	2.52
	1.18	2.38	1.34	4902	7.27	1.73	15.60	46.3	2.01
400^0C	1.12	2.53	4.11	5291	9.56	2.21	39.82	49.5	18.98
	1.14	2.24	3.97	4902	11.93	1.31	25.19	45	20.00
	1.16	2.37	3.28	5155	12.91	1.52	26.31	41.22	22.03
	1.18	2.39	4.56	5155	13.46	1.37	8.03	46.3	22.01
6000C	1.12	2.31	4.67	5155	36.09	2.21	39.81	49.5	44.00
	1.14	2.41	4.23	5025	40.15	1.31	25.19	45	43.00
	1.16	2.29	5.32	5155	49.73	1.52	26.31	41.22	43.03
	1.18	2.46	4.87	5025	52.56	1.37	8.02	46.3	43.00



Graph 7. Shows variation of Compressive strength vs Temperature.



Graph 8. Shows variation of % loss of UPV vs Temperature.

VI. CONCLUSION

- From the mix proportions developed, it was observed that mainly PF affect the aggregate content. The aggregate content increases with the increase in PF which has its effect not only on the fresh and hardened properties of concrete but also influences the strength, flow-ability and self compacting ability of the concrete.
- The designed MSSCC with different packing factors satisfies both flow-ability and strength characteristics.
- From the experimental results on MS-SCC it is perceived that at PF 1.12 the workability of concrete is good due to its high paste content but due to its low aggregate content there is decrease in compressive strength.
- At packing factor 1.14 due to proper mix proportion we observed high strength and workability. In literature we observed that as PF increases the fresh and hardened properties decreases but in our study optimum strength and workability was observed.
- At PF1.16 and 1.18 we have less paste content than required. So more amount of chemical admixtures are required to achieve desired fresh properties which effect strength characteristics and setting time of concrete.
- For interpretation of the fire results the thermal methods results showed that the data is very useful and supportive for evaluation in the fire behavior of materials. It was observed that the SCC's are more susceptible to spalling but the fall of relative residual strength is slower at high temperatures.
- The decrease in compressive strength of ordinary concrete mixes in comparison with zero thermal cycles for 50° C is observed to be varied from 14 to 23 % for 1, 3, 14, and 28 thermal cycles. The effect of temperatures is related to either the weaker formation of cement paste hydrates or due the differential thermal expansion of concrete.
- The compressive strength of SCC has a pessimistic effect on elevated temperature, as the strength increases due to its less void content due to the thermal stress are developed in MSSCC.
- There is also perfect correlation between the characteristic strength and loss of strength.
- The overall reduction in the Pulse velocity of SCC specimens with various PF is in the range of 70% to 80% when the specimens are heated from room temperature to 600 degrees centigrade, 30% to 40% at 400 degrees centigrade, 10% to 15% at 200 degrees centigrade and 5% to10 % at 100 degrees centigrade.
- From the above results the reduction in weight is significant which is inevitable.

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