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IMPROVEMENT OF FITTING BLENDS OF SELF-COMPACTING CONCRETE FOR NEUTRON SHIELDING FOR A SAFE ENVIRONMENT TO LIVING AND NON LIVING WORLD

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ABSTRACT: In this work, representative samples of coarse aggregate (stone chips) used in the preparation of SCC were procured from twelve different geological formations in the state of Karnataka. These coarse aggregate (CA) samples were subjected to neutron activation at the Dhruva research reactor at BARC, Mumbai. Gamma spectrometric analysis was carried out on these irradiated CA samples to determine the presence of trace elements, and to identify the sample that exhibits the least induced radioactivity Structures built to contain radiation at nuclear installations are designed with higher factors of safety to resist seismic loads. This design consideration can yield higher percentages of steel, leading to possible congestion of reinforcement at the member junctions. The use of mechanical vibrators for compacting the concrete mix in such situations may not be possible. This situation can be effectively tackled with the use of Self-compacting concrete (SCC). As the name suggests, self-compacting concrete is a type of concrete that is capable of flowing and consolidating into the structural formwork all by itself.

I. INTRODUCTION

The primary objective of this work is to identify the appropriate coarse aggregates (CA) (stone chips used in preparation of concrete) procured from twelve different geological formations in the state of Karnataka, India, that may be employed in the preparation of self-compacting, low radio-activation concrete for neutron shielding.To create a database for neutron activation properties of the procured coarse aggregate (CA) samples, and to study the neutron transmission through SCC samples prepared using these CAs. To select an appropriate methodology to proportion SCC mix to meet the target strength, and shielding properties (neutron attenuation and residual activities). To select the most suitable SCC mix for shield design of nuclear installations in the State of Karnataka.

- The above objectives have been achieved through:
- Neutron induced activation measurements for the CA samples collected from the twelve different geological formations in the state of Karnataka.
- Neutron dose transmission measurement through the SCC samples prepared using the above CAs.
- Comparison of the existing mix proportioning techniques available for achieving SCC, and selecting the method that is most appropriate.

II. MATERIALS AND METHODS

twelve CA samples were used separately in attempts to prepare SCC of grades M25 and M30. The details of the mix proportioning method adopted, fresh and hardened properties of the trial mixes are included in Section 3.5

Table 3.1: Rock samples procured from geological formations in Karnataka

Sl. No.	CA Sample Code	Quarry Location	Rock Type
1	KA-1	Karkala	Gneiss
2	KA-2	Hebri	Granite
3	KA-3	Tumkur	Trap
4	KA-4	Tumkur	Basalt
5	KA-5	Mysore	Peninsular Gneiss
6	KA-6	Bagalkot	Dolomite rock
7	KA-7	Kolar	Deccan Trap
8	KA-8	Bagalkot	Sandstone
9	KA-9	Ramadurga	Quartzite
10	KA-10	Chitradurga	Chitradurga Group Granite
11	KA-11	Lokapur	Limestone
12	KA-12	Udupi	Laterite

All the twelve CA samples procured were tested for the following properties:

- Free Moisture Content
- Fineness Modulus after carrying out the Sieve Analysis as per IS 2386-1963: Part I(Reaffirmed 2002)
- Water Absorption, Specific Gravity, and Bulk Density as per IS 2386-1963: Part III (Reaffirmed 2002), and
- Aggregate Crushing Value and Aggregate Impact Value as per IS 2386-1963: Part IV (Reaffirmed 2007).

In the present work naturally occurring river sand was used as Fine Aggregate. The following tests were carried out to determine the relevant properties of Fine Aggregate:

- Grain Size Distribution using Sieve Analysis as per IS 2386-1963: Part I (Reaffirmed 2002), and
- Specific Gravity, and Bulk Density as per IS 2386-1963: Part III (Reaffirmed 2002).

The properties obtained after conducting the tests on Fine Aggregate are listed in Table 3.2.

Table 3.2: Properties of Fine Aggregate

Sl. No.	Property of Fine Aggregate	Result/Value
1	Specific Gravity	2.55
2	Bulk Density	1350 kg/m^3
3	Particle Size Distribution	Zone III

III. RESULTS AND DISCUSSIONS

Results of Tests carried out on the Coarse Aggregate (CA) Samples

The twelve CA samples procured from the various geological formations in the state of Karnataka, listed in Table 3.1 were subjected to tests as per IS standards and the following properties were determined:

- Free Moisture Content (FMC)
- Fineness Modulus from Sieve Analysis as per IS 2386-1963: Part I (Reaffirmed 2002)
- Water Absorption (WA), Specific Gravity, and Bulk Density as per IS 2386-1963:
- Part III (Reaffirmed 2002), and
- Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) as per IS 2386- 1963: Part IV (Reaffirmed 2007).

The properties of Coarse Aggregates are listed in Table 4.1

Table 4.1: Properties of Coarse Aggregates

Sl. No.	CA Code	Free Moisture Content (FMC) (%)	Water Absorption (WA) (%)	Specific Gravity	Bulk Density (kg/m^3)	Aggregate Crushing Value (ACV) (%)	Aggregate Impact Value (AIV) (%)	Fineness Modulus
1	KA-1	0.366	1.125	2.72	1380	16.23	19.34	7.23
2	KA-2	0.406	1.533	2.63	1330	14.76	15.59	7.61
3	KA-3	0.107	0.396	2.90	1440	13.39	14.95	6.86
4	KA-4	0.178	1.246	2.80	1400	14.44	19.63	7.79
5	KA-5	0.445	1.654	2.72	1380	13.05	13.24	7.06
6	KA-6	0.608	3.654	2.80	1400	18.58	23.82	6.74
7	KA-7	0.168	0.435	2.90	1440	12.18	13.05	6.97
8	KA-8	0.220	0.600	2.45	1330	26.66	27.12	8.05
9	KA-9	0.122	0.412	2.70	1360	25.35	25.68	7.83
10	KA-10	0.128	0.355	2.65	1360	21.22	22.50	7.72
11	KA-11	0.338	2.250	2.45	1310	25.50	26.05	7.61
12	KA-12	0.136	0.617	2.45	1310	34.80	46.89	7.91

The CA Samples that were found to be compatible for preparing SCC, namely, KA-1, KA-2, KA-3, KA-4, KA-5, KA-6, KA-7, KA-10, and KA-11 only have been considered for the analysis of the test results that are discussed in this Chapter.From the test results listed in Table 4.1 the following Charts can be drawn for analysing the interrelationships between the properties of the CA samples that are relevant to the study.

Table 4.22 Neutron Transmission through M 30 Grade SCC slabs

Initial Neutron Dose Rate = 70.9 µSv/hr

CA used in SCC Mix	Dose Rate in µSv/hr for slab of thickness (Average of three readings)		Density of the Mix (kg/m^3)	Linear Attenuation Coefficient, µ (Average) (cm^{-1})	Half Value Layer, $t_{½}$ (cm)
	10 cm	20 cm**			
KA-1	24.7	13.8	2283	0.0936	7.403
KA-2	24.8	14.2	2289	0.0927	7.475
KA-3	24.3	14.3	2310	0.0935	7.411
KA-4	23.8	13.6	2339	0.0958	7.233
KA-5	24.8	13.1	2323	0.0947	7.317
KA-6	24.7	13.3	2303	0.0945	7.333
KA-7	26.1	12.5	2265	0.0933	7.427
KA-8*	---	---	---	---	---
KA-9*	---	---	---	---	---
KA-10	25.9	12.6	2292	0.0935	7.411
KA-11	24.8	13.6	2261	0.0937	7.395
KA-12*	---	---	---	---	---

From the test results listed in the above Tables, charts are drawn to study the interrelationships that exist between the relevant parameters of neutron transmission/attenuation and properties of SCC mixes. Fig. 4.14 through 4.19 show the graphical representations of these relationships.

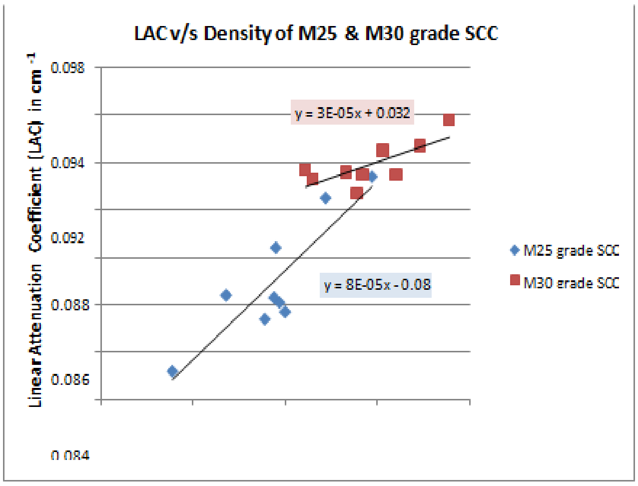

Fig. 4.14 Linear Attenuation Coefficient (LAC) v/s Density of SCC Mixes

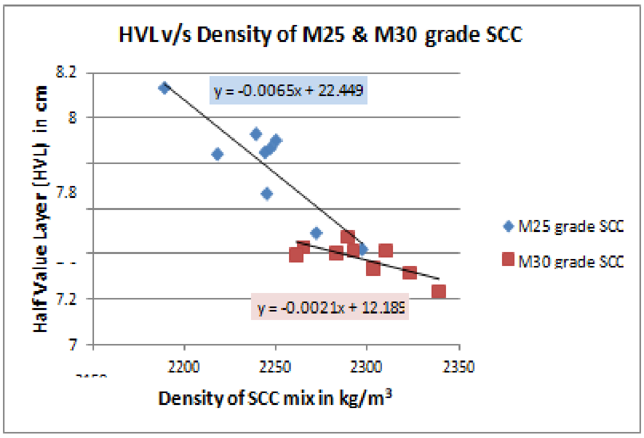

Fig. 4.15 Half Value Layer (HVL) v/s Density of SCC Mixes

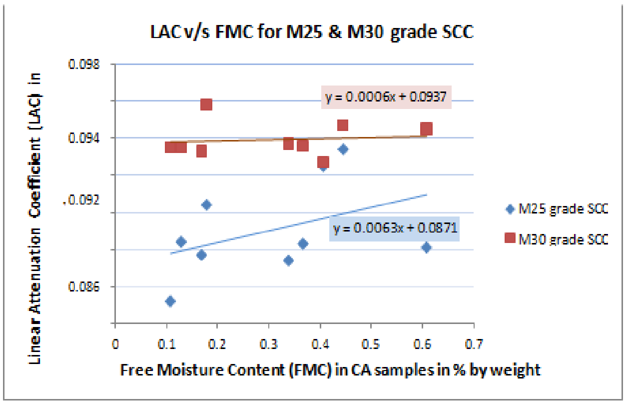

Fig. 4.16 Linear Attenuation Coefficient v/s Free Moisture Content of CA Samples

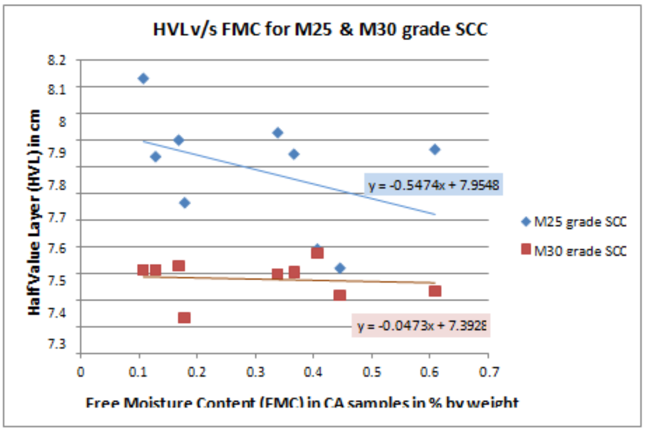

Fig. 4.17 Half Value Layer (HVL) v/s Free Moisture Content (FMC) of CA Samples

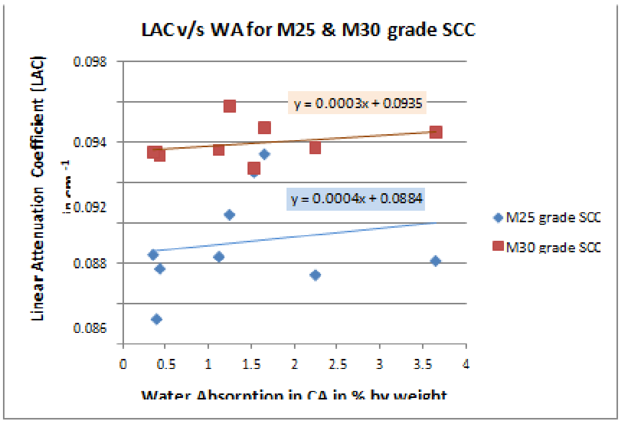

Fig. 4.18 Linear Attenuation Coefficient v/s Water Absorption of CA Sample

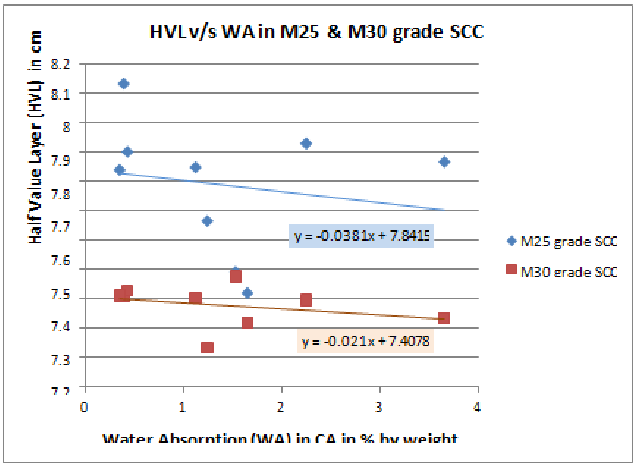

Fig. 4.19 Half Value Layer (HVL) v/s Water Absorption (WA) of CA Samples

Following interpretations can be drawn from the test results of this Section on neutron transmission studies:

- It can be seen from Table 4.21 that the M25 grade SCC mixes exhibit the highest LAC of 0.0934/cm and the lowest LAC of 0.0852/cm when the CA sample used in them are KA-5 and KA-3 respectively. Consequently, the corresponding lowest and highest HVL for the above two M25 grade SCC mixes are 7.419 cm and 8.133 cm respectively. Reduction in the thickness of HVL would reduce the amount of concrete that is required in shield fabrication, and can lead to greater economy.
- While the average LAC of the nine M25 SCC specimens (slabs) was found to be 0.0890/cm, their average HVL thickness was found to be 7.787 cm.
- It can be seen from Table 4.22 that the M30 grade SCC mixes exhibit the highest LAC of 0.0958/cm and the lowest LAC of 0.0927/cm when the CA sample used in them are KA-4 and KA-2 respectively. Consequently, the corresponding lowest and highest HVL for the above two M30 grade SCC mixes are 7.233 cm and 7.475 cm respectively.
- While the average LAC of the nine M30 SCC specimens (slabs) was found to be 0.0939/cm, their average HVL thickness was found to be 7.378 cm. A comparison of the corresponding values for M25 grade SCC shows that the LAC is directly proportional to the grade of the SCC mix.
- The SCC mixes containing the CA sample KA-6 that showed the least radio- activation (as discussed in Section 4.4 of this Chapter) showed LACs of 0.0881/cm and 0.0945/cm for grades M25 and M30 respectively, and the corresponding HVLs for the mixes were 7.866 cm and 7.333 cm respectively (Tables 4.21 & 4.22).
- It was found that as the density of the mix increased the linear attenuation coefficient (LAC) also increased, and consequently the thickness of half value layer (HVL) decreased. For an increase of 100 kg/m3 of density of M25 grade SCC the LAC increased by 0.008/cm, and the HVL thickness decreased by 0.65 cm; and for an increase of 100 kg/m3 of density of M30 grade SCC the LAC increased by 0.003/cm, and the HVL thickness decreased by 0.21 cm. These can be seen from the trendlines in Fig. 4.14 & 4.15. This result is in line with the well-established fact that higher density concrete can make better radiation shields.
- It was found that as the free moisture content (FMC) in the CA sample used in the mix increased the LAC also increased, and consequently the HVL decreased. For an increase of 0.1% in FMC the LAC increased by 0.00063/cm, and the HVL decreased by 0.0547 cm for M25 grade SCC; and for an increase of 0.1% in FMC the LAC increased by 0.00006/cm, and the HVL decreased by 0.0047 cm for M30 grade SCC. These can be seen from the trendlines in Fig. 4.16 & 4.17.
- It was found that as the water absorption (WA) in the CA sample used in the mix increased the LAC also increased, and consequently the HVL decreased. For an increase of 1% in WA the LAC increased by 0.0004/cm, and the HVL decreased by 0.0381 cm for M25 grade SCC; and for an increase of 1% in FMC the LAC increased by 0.0003/cm, and the HVL decreased by 0.0210 cm for M30

grade SCC. These can be seen from the trendlines in Fig. 4.18 & 4.19. This result is in line with the well-established fact that higher water retention in concrete shields can lead to greater attenuation of neutrons.

SCOPE FOR FUTURE WORK

Following are some of the areas that may be explored fruitfully as a continuation of the work on studies on concrete as radiation shield:

- The above study may be carried out on SCC mixes of higher grades (M40, M50, etc.) and the relationships of parameters like density and LAC of the mixes; and WA, FMC, AIV, ACV of the CAs, with the concrete grade may be examined.
- Combinations of different mineral admixtures like silica fumes, rice husk ash, metakaolin, etc. may be explored in preparing SCC, and the successful sample mixes may be tested for their neutron attenuation properties.
- Similar studies may be carried out on normal vibrated concrete (NVC), and high density concrete (HDC) and their merits and demerits vis-à-vis SCC may be found and analysed.
- Gamma ray transmission/attenuation studies may be tried on the SCC, NVC, and HDC slab samples

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