EXPERIMENTAL EVALUATION ON COMPATIBILITY OF MINERAL ADMIXTURES FOR GREENER SELF-COMPACTING CONCRETE

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Abstract: The aim of the project is to understand the relationship between the mixing proportion parameters of various mineral admixtures in self-compacting concrete and its environmental impact. The self-compacting concrete is the newest innovating category of high performance concrete and one of the most significant advances in concrete technology. SCC is a concrete which can be placed and compacted under its own weight with little or no vibration effort. It enables faster construction and reduces construction cost. Greener self-compacting concrete aims at reducing carbon dioxide emissions, energy and resource consumptions by decreasing Portland cement content and incorporating mineral admixtures and thereby lowering environmental burden. Mineral admixtures used in the project are ground granulated blast furnace slag (GGBS) and rice husk ash (RHA). Environmental impact assessment of the resulting mixes are done by evaluating the e-carbon dioxide, e-energy and e-resource indices of the mixes. Greener self-compacting concrete incorporating various proportions of mineral admixtures is expected to be feasible from environment and strength point of view.

Index Terms - Self-Compacting Concrete, GGBS, RHA, Environmental Impact Assessment.

I. INTRODUCTION

1.1 General

Concrete is one of the most widely used building materials with a global consumption rate approaching 25 Gigatons (Gt) per year. CO_2 emitted from concrete production and transportation is estimated to be approximately 10% of the total man-made CO_2 in the atmosphere. Consequentially, its environmental burden is significant in terms of environmental emissions, energy consumption and resource use. For these reasons, the sustainable development of concrete has received widespread attention. Domestic and foreign scholars have conducted a series of investigations and explorations on green concrete and, thus, vigorously promoted the development of greening technology for concrete. In China, Zhongwei first proposed the concept of 'green high performance concrete' in the 1990s, pointing out that green high performance concrete is the future of concrete development (Zhongwei Wu (1998)). A diverse audience of decision makers and manufacturers are interested in understanding and lowering the environmental impact of concrete and other buildings materials, which requires a life-cycle assessment (LCA) approach. Various strategies have been followed, separately or in combination, to improve the sustainability of concrete and even to develop green or ecological concrete. These strategies consist of incorporating recycled materials in concrete, optimizing the mix design, reducing CO_2 emissions by decreasing the Portland cement content, partially replacing Portland cement with cementitious by-product materials, increasing the durability of concrete to extend its service life and to reduce long-term resource consumption, and selecting low impact construction methods.

As one of the great innovations in concrete technology, self-compacting concrete (SCC) is the process of casting without imposing additional vibrating forces and only gravity is necessary to completely fill the mould cavity to form a uniform dense concrete. Compared with traditional vibrated concrete, SCC has obvious advantages in terms of reducing construction costs and improving the construction environment, which are significant forward steps in the direction of sustainably developed concrete.

1.2 Scope

1. SCC has obvious advantages in terms of reducing construction costs and improving the construction environment.
2. SCC often requires higher volume binder levels (cement and cementitious materials) which will not only increase the cost of SCC but also significantly elevate its environmental burden.
3. An eco-friendly version of SCC will not only decrease the cost of SCC but also significantly reduce its environmental burden.
4. The published documents on the environmental impact assessment of SCC are still somewhat limited.
5. More detailed research is needed to further promote the sustainable development of SCC and to enrich the content of Eco-SCC.

1.3 Objective

1. To design an SCC mix suitable for the environmental conditions by trial and error.
2. To design SCC mixes incorporating mineral admixtures such as GGBS and rice husk ash in various proportions.
3. To evaluate the environmental impact of SCC mixes developed using three simple indices combining the embodied environmental impacts with engineering properties (such as strength) of SCC.
4. To find out the optimum mix in terms of environmental impact and engineering properties and develop a new Eco-SCC mix design methodology.

II METHODOLOGY

2.1 Materials Used

The raw materials used in the experiment include cementitious materials, fine aggregate, coarse aggregate, superplasticizer and water. Ordinary Portland cement with a compressive strength grade of 53 MPa and Class F fly ash were used. Ground granulated blast furnace slag (GGBS) with a specific gravity of 2.9 and rice husk ash (RHA) with a specific gravity of 2.14 were the mineral admixtures incorporated. Fine aggregate with a fineness modulus of 3.865 and specific gravity of 2.82 was used. Coarse aggregate with maximum size of 12 mm and specific gravity of 2.76 was used. Glenium ace with a specific gravity of 1.145 was used as the super plasticizer. Figure 2.1 shows GGBS and 2.2 shows RHA. The chemical composition of GGBS is shown in Table 2.1 and chemical composition of RHA is shown in Table 2.2.

Fig. 2.1 GGBS

Fig. 2.2 RHA

Table 2.1 Chemical composition of GGBS

Compound	Percentage
CaO	32-45
SiO_2	32-42
Al_2O_3	7-16
Fe_2O_3	0.1-1.5
MgO	5-15
MnO	0.2-1

Table 2.2 Chemical composition of RHA

Compound	Percentage
SiO_2	86.94
Al_2O_3	0.2
Fe_2O_3	0.1
CaO	0.3-2.2
MgO	0.2-0.6
Na_2O	0.1-0.8

2.2 Experimental Design

For the evaluation of compatibility of mineral admixtures for greener self-compacting concrete nine SCC mixes were prepared. The determining factor is the mixing proportion of GGBS. The first SCC mix was the control mix (C) with no replacement of OPC with mineral admixtures. All the other mixes involved replacement of OPC with GGBS and RHA in various proportions both individually and in combination. The mixing proportions of the nine SCC mixes are shown in Table 2.3. The water-powder ratio of all the mixes were 0.45.

The workability tests such as slump flow, T500, V funnel, L box and U box tests were performed in the fresh state (EFNARC, 2005) and compressive strength at 28 days of all the mixes were tested and are specified in Table 2.4 and 2.5. From Table 2.4 and 2.5, it can be found that each mix possesses high flowability and good segregation resistance and the compressive strength of hardened SCCs ranges from 25 to 30 MPa.

Table 2.3 Mix proportion of SCC mixes

Mix	Cement (kg)	GGBS (kg)	RHA (kg)	Fly ash (kg)	FA (kg)	CA (kg)	Water (kg)	SP (kg)
C	508.0	0	0	353	438	564	395	8.56
G40	303.4	204.6	0	353	438	564	395	8.56
G50	254.0	254.0	0	353	438	564	395	8.56
R8	465.6	0	42.4	353	438	564	395	8.56
R10	458.6	0	49.4	353	438	564	395	8.56
G30 + R8	315.0	152.4	40.6	353	438	564	395	8.56
G30 + R10	304.8	152.4	50.8	353	438	564	395	8.56
G40 + R8	264.2	203.2	40.6	353	438	564	395	8.56
G40 + R10	254.0	203.2	50.8	353	438	564	395	8.56

Table 2.4 Fresh properties of SCC mixes

Mix	Slump flow(mm)	T_{500} slump flow(s)	V-funnel flow time(s)	L-box (PA)	U-box value(mm)
C	785	3	8	0.86	5
G40	750	5	10	0.97	4
G50	760	4	11	0.93	4
R8	770	5	12	0.83	3
R10	770	3	12	1	3
G30 + R8	715	5	8	0.85	4
G30 + R10	670	5	8	0.82	4
G40 + R8	695	3	7	0.94	3
G40 + R10	700	3	7	0.93	3

Table 2.5 Compressive strength of SCC mixes

Mix	Cube 1 (MPa)	Cube 2 (MPa)	Cube 3 (MPa)	Compressive strength at 28th day (MPa)
C	28.00	29.00	31.50	29.50
G40	29.00	27.70	27.00	27.90
G50	28.00	28.50	26.60	27.70
R8	28.42	28.48	28.48	28.46
R10	27.27	27.23	27.28	27.26
G30 + R8	27.35	27.36	27.34	27.35
G30 + R10	26.01	26.07	26.04	26.04
G40 + R8	27.20	27.10	27.00	27.10
G40 + R10	25.51	25.89	25.70	25.70

2.3 Embodied Environmental Impact Evaluation of SCC

It is well known that the environmental impact evaluation of concrete over its entire life cycle is complex because many factors affect the final evaluating value. Some researchers have concentrated on the embodied carbon dioxide (EC) of concrete, given the growing concern over the global warming impact of the built environment. EC is the carbon dioxide emitted as a result of material processing and transport, construction, and decommissioning and demolition and is analogous to a fixed capital cost. Recently, commentators have published EC values for concrete, either as individual values or a small range depending on certain properties. Hammond and Jones described a monotonic relationship between EC (0.061– 0.188) and characteristic cube strength (8–50 MPa) for CEM I and CEM II concretes (Hammond GP et. al., 2008). Meanwhile, Hacker et al. used a value of 0.200 with no strength discrimination (Hacker et. al., 2008), while Harrison et al. used 0.13 for plain concrete and 0.24 for '2% reinforced' with the additional CO2 attributable to the steel (Harrison et al., 2010). For normal and blended cement concretes, corresponding to an EC of 0.09–0.12. Purnell et al. reported on the variation of embodied carbon dioxide in concrete with common mixing proportion parameters (Purnell et. al, 2012).

However, none of these studies provided results on the embodied environmental impact of SCC. Moreover, detailed quantitative analysis related to the energy consumption and resource usage of concrete is limited. Guangcheng Long et. al. suggested that the environmental impact of unit SCC (per m^3) is investigated from three aspects: CO_2 emissions, energy consumption and primary natural resource expenditure. Thus, three indices, including the embodied CO_2 index (e-CO_2 index, CI), embodied energy index (e-energy index, EI) and embodied primary natural resource (e-resource index, RI), were proposed to assess the greenness of unit SCC. The three indices were obtained by considering a combination of the environmental efficiency and the engineering properties of SCC (i.e., cubic compressive strength), as in the following equations (2.1-2.3).

$$CI = \frac{\text{embodied } CO_2\left(\frac{kg}{m^3}\right)}{\sigma(MPa)} \tag{2.1}$$

$$EI = \frac{\text{embodied energy}\left(\frac{MJ}{m^3}\right)}{\sigma(MPa)} \tag{2.2}$$

$$RI = \frac{\text{embodied primary resources}\left(\frac{kg}{m^3}\right)}{\sigma(MPa)} \tag{2.3}$$

The embodied CO_2, embodied energy and embodied primary natural resource indices are calculated by considering all major emissions or consumptions during the extraction of raw materials, transportation to the site, construction processes etc. The embodied CO_2, embodied energy and embodied primary natural resource values of SCC mixes can be obtained by multiplying each of embodied carbon dioxide (e-CO_2), embodied energy consumption (e-energy) and embodied primary resource consumption (e-resource) value of each of the raw material per unit mass and the mass of each raw material in SCC mix per m^3 and then totalling (Guangcheng Long et. al., 2015). The embodied values of constituents are given in table 2.6.

Table 2.6 Embodied values of constituents (Guangcheng Long et. al., 2015)

Constituents	**e- CO_2 (kg/kg of constituent)**	**e- energy (MJ/kg of constituent)**	**e- resource (kg/kg of constituent)**
Cement	0.83	4.727	1.73
Fly ash	0.009	0.833	0
GGBS	0.019	1.588	0
Rice Husk Ash	0.0169	0.111	0
Fine aggregate	0.001	0.022	1.0
Coarse aggregate	0.007	0.113	1.0
Water	0.0003	0.006	0
Superplasticizer	0.72	18.3	0

III RESULTS AND DISCUSSIONS

3.1 Embodied Indices of SCC Mixes

Table 3.1 shows the embodied indices and fig. 3.1, fig 3.2 and fig. 3.3 show the graphical representation of embodied indices of SCC mixes with different proportions of mineral admixtures.

Table 3.1 Embodied indices of SCC mixes

Mix	**CI (kg/MPa. m³)**	**EI (MJ/MPa. m³)**	**RI (kg/MPa. m³)**
C	14.76	99.25	63.76
G40	9.66	81.92	54.73
G50	8.28	76.91	52.04
R8	14.09	96.00	63.51
R10	14.50	99.04	65.86
G30 + R8	10.20	82.70	56.56
G30 + R10	10.39	85.06	58.73
G40 + R8	8.77	77.58	53.84
G40 + R10	8.93	79.98	56.09

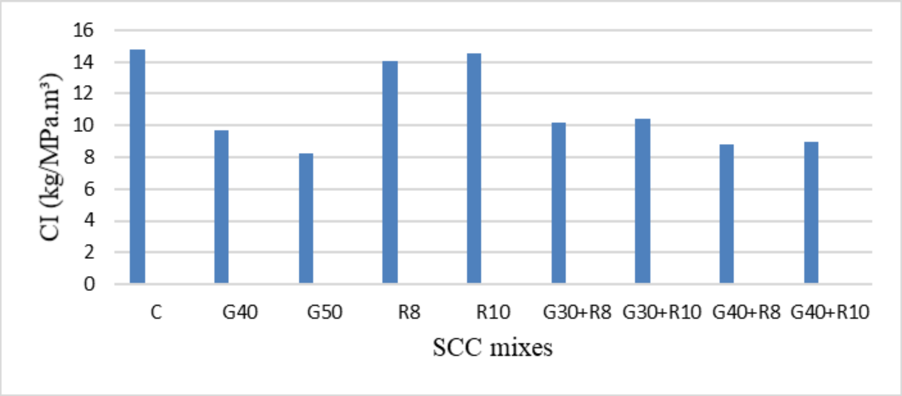

Fig. 3.1 CI of SCC mixes

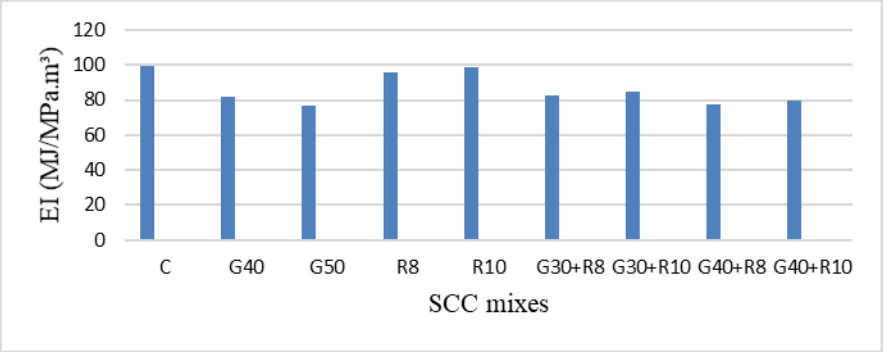

Fig. 3.2 EI of SCC mixes

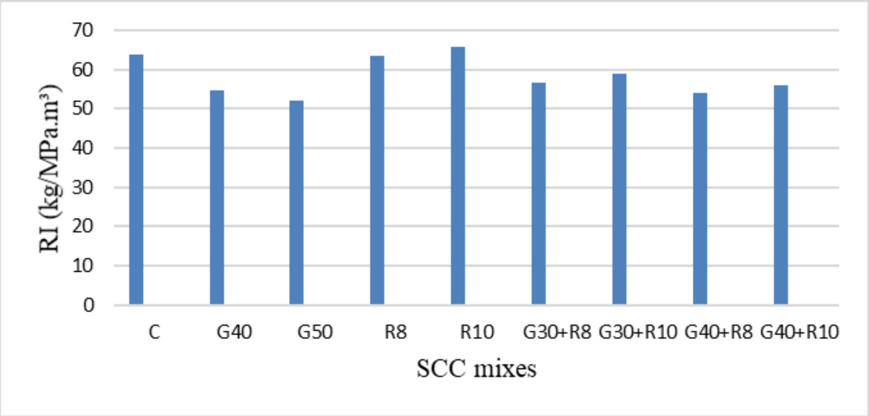

Fig. 3.3 RI of SCC mixes

3.2 Inferences

1. For mix G40, the indices decreased by about 35-15% when compared with the control mix C.
2. Mix G50 showed better results when compared with mix G40. For mix G50, the indices decreased by about 15-5% when compared with mix G40.
3. The indices are found to decrease with the addition of RHA but the decrease was marginal when compared with the control mix (5-0.4%).
4. The e-resource index of mix R10 with 10% of cement replacement by RHA was even higher than the control mix (by about 3%).
5. For mix R10 the indices were higher by about 3-4% when compared with mix R8.
6. In the mixes involving combinations of GGBS and RHA, the mixes with 10% of cement replacement by RHA is found to be inferior to their counterparts with 8% of cement replacement by RHA (by about 2-4%) whereas the mixes with 30% of cement replacement by GGBS is found to be inferior to their counterparts with 40% of cement replacement by GGBS (by about 15-5%).
7. The combination mixes G40+R8 and G40+R10 were better than the mixes G40, R8 and R10 which incorporated mineral admixtures individually.
8. For mix G40+R8 the indices were lower by about 18-40 % when compared with mix R10.

IV CONCLUSIONS

1. The e-CO_2, e-energy and e-resource indices which combine the environmental impact of SCC mixes with compressive strength, were studied to arrive at an optimum SCC mix.
2. The e-CO_2, e-energy and e-resource expenditure indices are found to decrease with the incorporation of GGBS significantly.
3. The indices are found to decrease further with an increase in addition of GGBS.
4. The indices are found to decrease only marginally with the addition of RHA.
5. The indices are not found to decrease further with an increase in addition of RHA.
6. The combination mixes G40+R8 and G40+R10 were better than the mixes G40, R8 and R10 which incorporated mineral admixtures individually.
7. Among all the mixes developed mix G50 with 50% of cement replacement by GGBS is the most optimum and the mix G40+R8 incorporating 40% cement and 8 % RHA is the second optimum in terms of both compressive strength and environmental impact point of view.

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