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Green concrete with high-volume fly ash and slag with recycled aggregate and recycled water to build future sustainable cities

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ABSTRACT

Building sustainable green cities for the future can be difficult or highly challenging as such cities need to reduce their environmental footprint through eco-friendly materials, resource and energy conservation, as well as renewable energy generation. This paper proposes three new types of sustainable concretes in an attempt to further reduce the carbon footprint. In Type I, a total of 4 concrete mixes were made with a high volume GGBFS with 60, 70, 80, and 90% replacement of Ordinary Portland Cement (OPC),100% Recycled Water (RW), and 100% recycled aggregate (RA). The same replacement ratios were used in Type II but with only 100% RA. In Type III, a total of four concrete mixes made with a high volume Fly Ash (FA) cement with 40, 50, 60, and 70% replacement of OPC. The paper provides information on the mix design, full justification of CO2 footprint, and the cost for each concrete mix. The hardened and plastic properties and durability test parameters for each mix are presented. The results showed that the fly ash and slag significantly reduced the carbon footprint and meet the requirements of future sustainable cities. An economical mix with 90% GGBFS and 10% OPC was nominated for use in the future construction of sustainable cities with 125 kg=m3 emissions.

Keywords— *Concrete, Sustainability, Ground Granulated Blast Furnace Slag (GGBFS), Fly ash, Recycled aggregate, Recycled water*

1. INTRODUCTION

In the 21st century and beyond, one of the main challenges confronting the concrete industry is to meet the enormous infrastructure and housing needs of rapidly urbanizing and industrializing cities of the future. At the same time, there are concerns for high energy requirements and greenhouse gas emissions associated with the manufacture of Ordinary Portland Cement (OPC). The production of 1 t of OPC requires 1.5 t of raw material (Sadat et al. 2016; Saravana Kumar and Dhina karan 2013; Maholtra and Mehta 2008). The world's current production of OPC is 3.7 billion tons a year, which contributes approximately 3.0 billion tons of CO2, which is approximately 7% of the total emissions from all sources (Sadatiet al. 2016; Maholtra and Mehta 2008) to the earth's atmosphere. The production of OPC contributes 5% of the global greenhouse gas emissions (Collins and Sanjayan 2002). The production of OPC is highly-energy intensive, consuming 4–7 MJ of fossil fuel energy per kilogram (kg) (Malhotra 1988; Swamy 1998), and releasing approximately one ton of carbon dioxide per ton of OPC. The use of slag (GGBFS), an industrial by-product which other wise would contribute to land pollution, as a replacement for the OPC in concrete will result in less energy for the manufacture of cement and reduce the greenhouse gas emissions due to concrete construction. To build future cities a consistent approach must be adopted with a core concept to consume less OPC.

Based on this rule, one should consider three powerful tools: (1) consume less concrete; (2) consume less OPC; and (3) lower the proportion of clinker in the OPC. In this latter tool, the use of blended cement or concrete containing a high volume cementing material such as GGBFS or fly ash is the subject of this paper. Slag-blended and Fly Ash (FA)-blended cement is becoming popular worldwide in the Construction industry. In recent years, many industrial waste by-products such as slag and fly ash are rapidly becoming the main source of Supplementary Cementitious Materials (SCM) for use in concrete manufacture. These SCMs are well known for having a significant effect on reducing concrete permeability when properly cured, which is the main governing property for producing durable concrete (Mehta 1984; Hooton 2000) suitable for any environment where severe conditions prevail. SCMs can also be used to reduce the heat generation associated with cement hydration and reduce the potential for thermal cracking in massive structural elements. The SCMs modifies the microstructure of the concrete and reduce its permeability, thereby reducing the penetration of water and waterborne salts into concrete and enhancing the service life of the structure.

2. MATERIALS AND METHODOLOGY

2.1 Cement

Cement used for the present work is Portland pozzolana cement with characteristic compressive strength of 53 MPa. The physical properties of cement were determined as per the IS 4031:1968 and results are given in the table.

Table 1: Properties of OPC

Properties	Values
Initial setting time	30 minutes
Final setting time	10 hours
Standard consistency	28%
Specific gravity	3.10

2.2 Flyash

Flash used for the present work is Class F and obtained from Raichur thermal power plant. The chemical composition of Flyash used is given in table 2.

Table 2: Properties of Class F fly ash

Properties	Values
Specific gravity	2.3
Chemical composition	SiO_2 – 51.1%
	Al_2O_3- 22.9% Fe_2O_3- 12.2%

2.3 Natural aggregate

Granite aggregates were used and its physical properties are given in table 3.

Table 3: Properties of Natural aggregate

Properties	Values
Specific gravity	2.72
Los Angeles abrasion value	30.2%

2.4 Recycled aggregate

Recycled aggregates are taken from the demolished building in the surrounding area. The properties of the used aggregate are given in table 4.

Table 4: Properties of Recycled aggregates

Properties	Values
Specific gravity	2.53
Los Angeles abrasion value	42.4%

3. EXPERIMENTAL INVESTIGATIONS

The numbers of mixes were obtained by changing three parameters - Cement content, amount of coarse aggregate, aggregate-cement ratio. The cement content was varied from 300 kg/m3 to 400 kg/m3 with an increment of 50 kg/m3. Percentage replacement of recycled aggregates was varied from 0%, 50% and 100%. The aggregate-cement ratio was varied as 4 to 6. The pervious concrete for the nine mixes was prepared in nine separate batches. The coarse aggregate was sieved through 20 mm sieve. Cement and fly ash for each mix were batched on the day of casting. Water-cement ratio was obtained based on workability criteria. The mixture was reviewed for consistency by taking a handful of pervious concrete mix and creating a ball. If the aggregate gets separated and was not able to maintain the ball shape, the mixture was considered as too dry. If the ball had a lot of paste, the aggregate was running off and sticking to the glove, and then the mixture was considered as too wet. The range was found to be from 0.32 to 0.45. Although this was subjective, it has been considered a common practice in the industry. Once the observations were noted, the mixtures were then placed in three 150 mm cubes, two 150 x 100 mm cylinders and one 150 x 300 mm cylinder. Each specimen was compacted in 3 layers. After 24 hours, the specimens were demolded and subjected to curing by immersion. Then the cubes and cylinders were tested for compressive strength, split tensile strength and infiltration test at the age of 28 days.

3.1 Mix Proportions

Table 5: Mix proportions

Mix no	Cement (kg/m3)	RCA % of Replacement	A/C (kg)	Cement (kg)	NA (kg)	RCA (kg)	Flyash (kg)	W/C
PC1	300	0	6	3.7	27.6	0	0.9	0.32
PC2	300	100	6	3.7	0	27.6	0.9	0.45
PC3	300	50	4	3.7	9.2	9.2	0.9	0.4
PC4	300	0	4	4.3	21.6	0	1.1	0.35
PC5	300	100	4	4.3	0	21.6	1.1	0.42
PC6	300	50	6	4.3	16.2	16.2	1.1	0.4
PC7	300	0	6	4.9	36.6	0	1.2	0.37
PC8	300	100	6	4.9	0	36.6	1.2	0.38
PC9	300	50	4	4.9	12.2	12.2	1.2	0.38

4. RESULTS AND DISCUSSION

4.1 Compressive strength and tensile strength

All the 150 mm cubes were tested at the age of 28 days for assessing its compressive strength. This test was performed using a compression testing machine. The peak load and stress carried by the cubes were noted.

Fig. 1: Cube under compression test

Tensile strength for concrete cannot be done directly, the split tensile strength test was done by placing the cylinder horizontally in the compression testing machine such that the load was applied perpendicular to the axis. The results are given below.

Fig. 2: Cylinder under split tensile test

Table 6: day Compressive and tensile strength values

Mix	Tensile stress (MPa)	Compressive stress (MPa)
PC1	5.77	11.13
PC2	3.24	13.79
PC3	9.03	12.77
PC4	7.17	11.75
PC5	4.44	13.18
PC6	2.79	12.77
PC7	6.12	12.16
PC8	3.52	12.36
PC9	4.58	12.16

4.2 Effect of W/C ratio on compressive strength

The plot between w/c ratio and compressive strength were shown below. The results indicate that the compressive strength increases with increases in w/c ratio. The compressive stress varies linearly with w/c ratio.

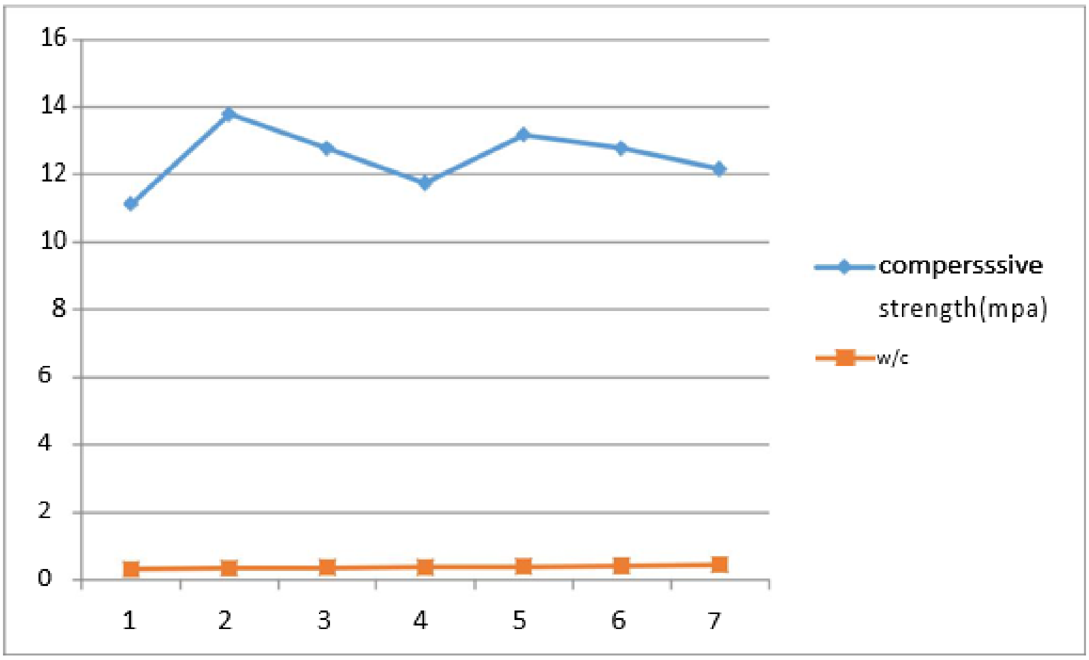

Fig. 3: Effect of w/c ratio vs. compressive strength

4.3 Effect of cement content and Agg/cement ratio on infiltration

Table 7: Infiltration Test Results

Mix	Cement content (kg/m3)	Time (s)	Infiltration (in/h)
Pc1	300	30	544.44
Pc2	300	32	510.41
Pc3	300	40	480.41
Pc4	350	45	363.71
Pc5	350	50	327.09
Pc6	350	37	442.21
Pc7	400	47	348.76
Pc8	400	51	320.92
Pc9	400	38	432.56

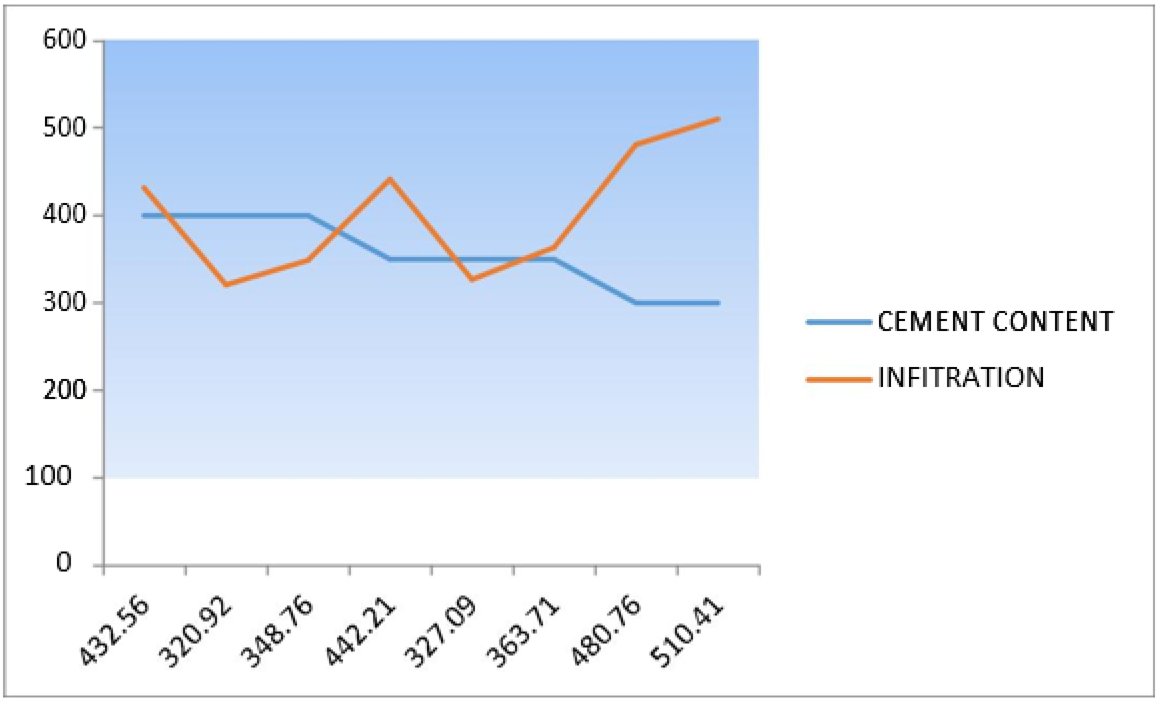

Fig. 4: Plot between infiltration and cement content

From the above graph, it can be seen that the infiltration rate is in the range of 480 - 540 in/hr for the cement content value of 300 kg/m3. The cement content values are between 350 kg/m3 and 400 kg/m3 it is in the range of 320 - 440 in/hr. Hence the infiltration rate is high for a cement content value of 300 kg/m3.

Fig. 5: Infiltration test using single ring infilterometer

5. CONCLUSIONS

- The overall results indicate that the use of recycled concrete aggregate as coarse aggregates with fly ash binder for making pervious concrete was found to be feasible with acceptable properties.
- The optimum cement content should be from 300 to 400 kg/m3. The replacement of fly ash can be upto 20%. The aggregate-cement ratio can be in the range 4-6 of which 6 gave good infiltration and strength results.
- Using natural aggregate with partial replacement of recycled concrete aggregate resulted in significant losses in strength as compared to a natural aggregate pervious concrete.
- Use of fully recycled aggregates gave desirable results in both strength and infiltration when compared to partially replaced RA.
- Further research is required to examine the effect of recycled water on the durability of high volume GGBFS concrete;
- To eliminate the negative effect of recycled aggregate on the strength, durability, and workability, it should be subjected to a mechanical scrubbing treatment to remove the cement paste.
- It is recommended to use the 56-day strength, as the rapid hardening of slag and fly ash cement continued beyond the standard 28 days.

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