Feasibility Study of Plastic Granules and Alccofine in Fly Ash Based Self-Compacting Concrete

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Abstract Self-compacting concrete (SCC) is a fluidic concrete mix which does not require tamping or vibration and gains its fluid property from high proportion of fine aggregate, super plasticizers and viscosity enhancing admixtures. High amount of cement and chemical admixtures used in SCC reduces its wide scale usage. Alccofine can be used as a better substitute to cement due to its cementitious properties. The work aims at the possibility of recycling waste plastic granules (polyethylene terephthalate (PET) used in the plastic bag production) as a fine aggregate instead of sand in the manufacturing of the self-compacting concrete. Cement is partially replaced with alccofine at 8, 10 and 12% by weight of cement and the optimum percentage of alccofine was obtained. To the mix with optimum percentage of alccofine, the fine aggregate is substituted with the plastic granules at dosages 5, 10, 15 and 20% proportions by the volume of the fine aggregate. The fresh and hardened properties of M40 equivalent fly ash based self-compacting concrete were compared and evaluated.

Keywords Self-compacting concrete · Alccofine · Plastic granules

1 Introduction

Self-compacting concrete (SCC) is a highly flowable type of concrete that spreads into the form without the need for mechanical vibration. Self-compacting concrete is a non-segregating concrete that is placed by means of its own weight.

Supplementary cementitious materials (SCM) are finely ground solid materials that are used to replace a portion of the cement in a concrete mixture [1]. Alccofine is a specially processed product based on slag of high glass content with high reactivity obtained through the process of controlled granulation [2–6].

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Now- a-days due to constant sand mining the natural sand is depleting at an alarming rate. Scarcity of good quality river sand due to depletion of resources and restriction due to environmental consideration has made concrete manufactures to look for suitable alternative to fine aggregate. The replacement of fine aggregate in the mixture with low cost, recycled plastic granules (PG) which reduces the dead load of the structure, overall cost, in turn reduces the pollution.

The experimental program is designed to investigate the strength of fly ash based self-compacting concrete by replacing cement with alccofine at ratios of 8, 10 and 12% by weight of cement and replacing fine aggregate with plastic granules at 5, 10, 15 and 20% by volume of fine aggregate. The experimental program is aimed to study the workability and strength parameters. Slump flow test, T50 slump flow test and J-ring test were conducted for all mixes to ascertain the fresh property of self-compacting concrete. Compressive strength, Flexural strength, and Split tensile strength test was conducted at 7 and 28 days and the values were obtained.

2 Objectives

The main objectives of this investigation are given below:

- To establish M40 equivalent fly ash based Self-compacting concrete based on strength parameters.
- To establish the optimum percentage of alccofine in the fly ash based SCC, the alccofine is partially replacing the cement in the ratios 8, 10 and 12% by weight of cement in the fly ash based SCC based on strength parameters.
- To evaluate the optimum percentage of Plastic Granules (replacing fine aggregate by volume in the order of 5, 10, 15 and 20%) in the SCC mix with optimum percentage of alccofine.
- To analyse fresh and hardened properties of fly ash based SCC with optimum percentage of alccofine and plastic granules.

3 Materials and Properties

The different materials used in this investigation and their physical properties are illustrated in Table 1.

3.1 Mix Design

There is no standard method for SCC mix design and many academic institutions, admixture, ready-mixed, pre cast and contracting companies have developed their own mix proportioning methods. Several methods exist for the mix design of SCC.

Table 1 Material properties

Materials	Properties	Test results	Reference code
Cement	Specific gravity	3.15	IS 4031-1988 Part-IV (Reaffirmed 2009)
	Fineness	5%	IS 4031-1988 Part-IV (Reaffirmed 2009)
	Consistency	32%	IS 4031-1988 Part-XI (Reaffirmed 2009)
	Initial setting time	45 min	IS 4031-1988 Part-V (Reaffirmed in 2009)
Fine aggregate	Specific gravity	2.72	IS 2386-1963 Part-III (Reaffirmed 2016)
	Water absorption	2.54%	IS 2386-1963 Part-III (Reaffirmed 2016)
Coarse aggregate	Specific gravity	2.67	IS 2386-1963 Part-III (Reaffirmed 2016)
	Water absorption	0.335%	IS 2386-1963 Part-III (Reaffirmed 2016)
Alccofine	Specific gravity	2.9	
	Fineness	>12,000 (cm^2/gm)	
Fly ash	Specific gravity	2.3	
Plastic granules	Specific gravity	1.31	

The mix designs were carried out for concrete grade 40 MPa based on European Federation for Specialist Construction Chemicals and Concrete Systems (EFNARC) guidelines [7] and the details are given in Table 2.

Table 2 Mix design of specimen with varying percentage of fly ash, alccofine and plastic granules

Mix	Cement (kg/m^3)	Fly ash (kg/m^3)	Alccofine (kg/m^3)	Fine aggregate (kg/m^3)	Plastic granules (kg/m^3)	Coarse aggregate (kg/m^3)	SP (l/m^3)	Water (l/m^3)
F30	413	177	0	865	0	753	3.54	200
F30AC8	365.8	177	47.2	865	0	753	3.54	200
F30AC10	354	177	59	865	0	753	3.54	200
F30AC12	342.2	177	70.8	865	0	753	3.54	200
F30AC10PG5	324.5	177	59	839.62	25.38	753	3.54	200
F30AC10PG10	324.5	177	59	814.24	50.76	753	3.54	200
F30AC10PG15	324.5	177	59	788.86	76.14	753	3.54	200
F30AC10PG20	324.5	177	59	763.5	101.52	753	3.54	200

4 Results and Discussion

4.1 Fresh Properties

To determine the fresh properties of SCC, various tests were performed like slump flow, T50 slump flow test time and J-ring test. All these tests were carried out to check passing ability, viscosity/flowability and filling ability self-compacting concrete. All the equipment for various tests confirms to dimension as given by EFNARC. The flow values of different mix proportions are listed in Table 3 in which SCC is the normal self-compacting concrete, F28, F30 and F32 represents the self-compacting concrete containing fly ash at 28%, 30% and 32% respectively. F30AC8, F30AC10 and F30AC12 represents the fly ash based self-compacting concrete with alccofine at 8%, 10% and 12% respectively. And F30AC10PG5, F30AC10PG10, F30AC10PG15 and F30AC10PG20 represents the fly ash-alccofine based self-compacting concrete with plastic granules at 5%, 10%, 15% and 20% respectively.

The slump flow test were conducted for finding the filling ability. For self-compacting concrete with plastic granules, slump flow diameter values varies between 707 and 719 mm, which were determined as the average of two measured diameter of flowed concrete. As per EFNARC [7] test results of self-compacting concrete with plastic granules as fine aggregate can be categorized as SF2, which is suitable for many normal applications such as walls and columns.

T50 slump flow test were conducted for finding the viscosity or flowability of the self-compacting concrete mixes. From Table 3, it can be see that by increasing the plastic granules content decreases the slump flow time. It was determined that all self-compacting concrete mixtures were in the boundaries of the VS2 viscosity specified by EFNARC [7].

J-ring test was conducted for finding the passing ability of SCC mixes. The results of J-ring test are given in Table 3.

Table 3 Workability results

Mixes	T50 slump flow (s)	Slump flow (mm)	J-ring (mm)	Passing ability (mm)	Remarks (as per ASTM 1621/C 1621M)
F30 (CM)	2.5	680	671	9	No visible blocking since passing ability values are between 0 and 25 mm
F30AC8	2.2	703	693	10	
F30AC10	1.9	720	711	9	
F30AC12	2.1	716	706	10	
F30AC10PG5	2.8	707	698	9	
F30AC10PG10	2.6	711	701	10	
F30AC10PG15	2.3	716	708	8	
F30AC10PG20	2.2	719	710	9	

4.2 Hardened Properties

The hardened properties of SCC were measured in terms of Compressive Strength, Split Tensile Strength test and Flexural Strength Test confirming to IS 516:1959 (Reaffirmed 2004), IS: 5816: 1999 (Reaffirmed 2004) and IS 516: 1959 (reaffirmed 2004) respectively.

The 7th and 28th day compressive strength of mixtures is given in Table 4. The optimum percentage of fly ash is found to be 30% and it is taken as the control mix. After 28 days of curing the SCC with 10% alccofine gives the maximum compressive strength. This is due to high pozzolanic nature and unique chemical composition of alccofine [8–10]. Then the compressive strength of self-compacting concrete cubes made with optimum percentage of fly ash, alccofine and varying percentage of plastic granules is tested (Fig. 1) and the range of compressive strength values in this work were about 48.31–41.8 MPa. Decrease in compressive strength was observed as plastic granule content is increased in comparison with the control mix and the mix with fly ash and alccofine without plastic granules. This may be because the plastic granule has lesser density when compared with natural aggregate [11].

Table 4 Compression test results

S. No.	Mix	Compressive strength (N/mm^2)	
		7 days	28 days
1	F30 (CM)	36.56	48.5
2	F30AC8	42.3	51.2
3	F30AC10	45.5	56.6
4	F30AC12	44.6	52.8
5	F30AC10PG5	36.23	48.31
6	F30AC10PG10	34.55	46.21
7	F30AC10PG15	33.36	44.54
8	F30AC10PG20	32.2	41.8

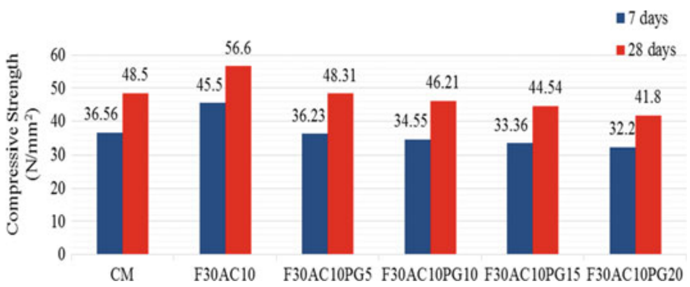

Fig. 1 Variation of compressive strength with optimum percentage of fly ash, alccofine and varying percentage of plastic granules

Split tensile strength test was conducted after 7 and 28 days of mixtures and the tensile strength value of SCC increases with increase in percentage of cement replacement with alccofine upto a percentage of 10%. The tensile strength increases a maximum of 4.86 N/mm^2 for 10% alccofine content and as the alccofine content exceeds the value of 12%, the split tensile strength decreases to 4.35 N/mm^2. The range of split tensile strength values in fly ash-alccofine based SCC with varing percentage of plastic granules were about 3.9–3.4 MPa (Fig. 2). Decrease in split tensile strength was observed as plastic granule content is increased in comparison with the control mix and the mix with fly ash and alccofine without plastic granules. This may due to the poor adhesive strength between the surface of the plastic granules and the cement paste [12–14] (Table 5).

Flexural strength test was conducted after 28 days and the maximum flexural strength is 6.34 N/mm^2 for 10% replacement of alccofine. The range of flexural strength values for fly ash-alccofine based SCC with varying percentage of plastic granules were about 5.32–4.73 MPa (Fig. 3). Decrease in flexural strength was observed as plastic granule content is increased in comparison with the control mix and the mix with fly ash and alccofine without plastic granules. This may due to the low resistance of the plastic granules [12] (Table 6).

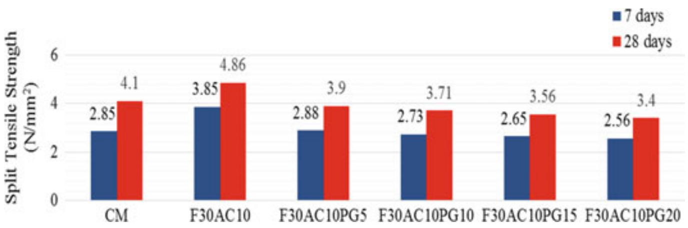

Fig. 2 Split tensile strength of fly ash based self-compacting concrete with optimum percentage of alccofine and varying percentage of plastic granules

Table 5 Split tensile test results

S. No	Mix	Split tensile strength (N/mm^2)	
		7 days	28 days
1	CM	2.85	4.1
2	F30AC8	3.3	4.65
3	F30AC10	3.85	4.86
4	F30AC12	3.45	4.35
5	F30AC10PG5	2.88	3.9
6	F30AC10PG10	2.73	3.71
7	F30AC10PG15	2.65	3.56
8	F30AC10PG20	2.56	3.4

Table 6 Flexural strength results

S. No	Mix	Flexural strength (N/mm^2) (28 days)
1	CM	5.36
2	F30AC8	5.64
3	F30AC10	6.34
4	F30AC12	5.82
5	F30AC10PG5	5.32
6	F30AC10PG10	5.1
7	F30AC10PG15	4.89
8	F30AC10PG20	4.73

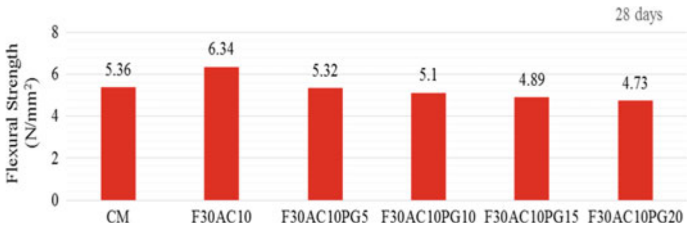

Fig. 3 Flexural strength of fly ash based self-compacting concrete with optimum percentage of alccofine and varying percentage of plastic granules

5 Conclusions

This work intended to analyse the mechanical properties of fly ash based Self-compacting concrete prepared with partial replacement of cement with alccofine and partial replacement of fine aggregate with plastic granules. Based on the results of presented work, the following main concluding remarks are made:

- The utilization of Fly ash as a partial replacement of cement increases the workability of concrete and also reduces the construction cost with efficient utilization of industrial waste.
- The compressive strength, split tensile strength and flexural strength increases with the replacement of fly ash for cement at 30%, so it was adopted as the control mix (optimum percentage of fly ash).
- The result of the fresh-state properties of fly ash based and fly ash-alccofine based SCC fulfilled the workability parameters.
- The optimum amount of alccofine was obtained as 10% in terms of strength parameters. 10% replacement of cement with alccofine showed an increase of 16.7% in compressive strength, 18.29% in split tensile strength and 18.28% in flexural strength compared with control mix. It was due to optimized size, ultra-fine nature (finer than other hydraulic materials), unique chemical composition and high glass content in alccofine.

- Slump flow test results of self-compacting concrete with plastic granules as fine aggregate were categorized as SF2, which is suitable for many normal applications such as walls and columns.
- Test result of T50 slump flow test shows self-compacting concrete with plastic granules mixtures were in the boundaries of the VS2 viscosity.
- The addition of 5% plastic granules into the alccofine-fly ash based SCC decreased the compressive strength by 0.39%, split tensile strength by 5.12% and flexural strength by 0.75% in comparison with control mix.
- Decrease in compressive strength, split tensile strength and flexural strength were observed as plastic granule content increased in comparison with control mix and the mix with fly ash-alccofine based SCC without plastic granules. This may be because the plastic granule has lesser density when compared with natural aggregate and also due to the poor adhesive strength between the surface of the plastic granules and the cement paste.
- So, it can be concluded that, the fly ash based SCC with 10% alccofine and 5% plastic granules gives better strength than the target strength. So it can be effectively replaced with fine aggregate.

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