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Properties of Concrete Modified with Ultra-Fine Slag

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Abstract

The supplementary cementitious materials (SCM) can be used as a replacement of cement in the construction industry to minimize the drawbacks of normal concrete such as the emission of carbon dioxide so as to be eco-friendly. This paper presents the effect of ultra-fine slag (i.e. 25% of alccofine) as a replacement of cement for different water to binder ratios (i.e. 0.38, 0.4 and 0.45). The effect of alccofine on the concrete strength properties were studied at 7 and 28 days wherein considerable strength enhancement was observed compared to normal concrete. Thermogravimetric analysis was also carried out in which mass loss and decomposition of hydration products from concrete was determined. X-ray diffraction showed the crystalline forms of ettringite and calcium silicate hydrate. Therefore, it was concluded from this study that alccofine can be used as a viable substitute to cement in normal concrete considering its positive effects on property enhancement and eco-friendless.

Keywords

Alccofine, Compressive strength, Thermogravimetric analysis, X-ray diffraction analysis

Cover Page Footnote

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1. Introduction

The most regularly utilized building material is concrete, generally made from Portland cement [1]. Every material utilized for making concrete affects the environment and gives rise to sustainability issues [2]. However, the manufacture of Portland cement creates a problem such as emission of CO_2 (approximately 7–8% of total man-made) to the atmosphere and global warming [3]. By the addition of a few alternative (pozzolanic) materials, the diverse properties of concrete i.e. strength, workability, durability, and permeability may be improved [4]. Researchers have to develop different cementing material which can be used fully or partially to replace cement which will decrease the emission of greenhouse gases [5]. These alternative materials can be added to concrete mixes as replacement of cement or aggregate depending on their physical and chemical properties.

There are so many micro fine materials which are available in the market such as Silica fume, Ultrafine fly-ash, and Iron ore [6]. Alccofine is a new type or generation of microfine material finer than other materials and it has a low calcium silicate. Alccofine is an ultra-fine cementing material produced from slag with optimized size distribution. It can reduce the water content required to achieve specific workability and also reduce cement quantity, thereby reducing the carbon footprint in concrete [7].

S. Kavitha.et al. [8] conducted experimental research on replacement of cement with Ground Granulated Blast-Furnace Slag (GGBS) and alccofine to enhance the rheological and mechanical properties of self-compacting concrete. They have observed strength enhancements at 40% replacement (30% GGBS & 10% alccofine) of cement and the optimum strength values in compressive, splitting tensile and flexural strengths were 42.3 MPa, 7.9 MPa and 8.3 MPa respectively. Gayathri.et al. [9] conducted research on the performance of concrete with partial replacement of cement with alccofine for M30 grade concrete and she observed improvement in the strength of concrete at 15% replacement of cement by alccofine. Siddharth.et al. [10] have done an experimental investigation on high-performance concrete with replacement of sand by Manufactured sand (M-Sand) and partial replacement of cement by alccofine and fly ash for M60 grade of concrete. From the investigation, they observed that the strength improvement in concrete with alccofine is higher than that of fly ash. Ansari.et al. [11] investigated the strength properties of concrete with partial replacement of cement by fly ash and alccofine for a higher grade of concrete (M70 grade). They observed considerable improvement in concrete strength when 20% of cement was replaced with fly ash and alccofine.

Generally, concrete is a very durable material but due to some of the environmental conditions such as chemical attack, sulfate attack, absorption, weathering action and other deterioration processes may change the properties of concrete like loses its weight, strength and durability which can be overcome by using cementitious materials [12].

Cement reacts in the presence of water (hydraulic reaction) to produce a weak form of calcium hydroxide and calcium silicate hydrate (C–S–H) form a strong paste to bond all aggregate together. Alccofine reacts with Calcium hydroxide (pozzolanic reaction) to form more C–S–H gel in concrete shown in Eqs. (1) and (2) respectively [13]. From Massazza's research, only 22% of free calcium hydroxide is available in the system and thus total quantity of calcium hydroxide doesn't react with cementitious materials. The additional C–S–H gel can reduce the porosity and make the concrete denser. Due to this there is improvement in the strength and durability properties of concrete [14].

$$\text{OPC}\ (C_3S\ \&\ C_2S) + H_2O \rightarrow \text{C–S–H gel} + Ca\,(OH)_2 \tag{1}$$

$$Ca\,(OH)_2 + \text{Alccofine 1203} + \text{Water} \rightarrow \text{Secondary C–S–H} \tag{2}$$

In this study, an investigation was carried out on the effect of alccofine (25%) on the properties of concrete in fresh and hardened state. The paper highlights the outcomes of the mechanical and some durability properties of different mixes. Hence the paper shows that alccofine in concrete causes improvement in its strength properties and also checks the analytic methods like thermogravimetric analysis, microanalysis properties and durability issues which lead to a sustainable construction.

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2. Materials

2.1. Cement

In this investigation, Ordinary Portland Cement 43 grade was used and it was tested as per Indian standard specifications [15].

2.2. Coarse and fine aggregate

Natural river sand with specific gravity 2.68 was used conforming to zone II as per Indian standard specification. Crushed stone angular aggregate was used as coarse aggregate with specific gravity of 2.79. The maximum size of the aggregate was limited to 20 mm [16].

2.3. Alccofine

Alccofine which is a micro-fine material was purchased from Counto Microfine products Pvt. Ltd, a joint venture of Alcon Organization and Ambuja Cements Ltd, Goa, India. Alccofine was significantly superior to other materials which were available in Indian market. Alccofine being a microfine material, it was easy to add it to the mix. In Tables 1 and 2 the physical and chemical properties of alccofine respectively are shown. Figs. 1 and 2 are shown SEM and EDX images of alccofine.

2.4. Water

In this investigation, ordinary tap water available in campus was used for all concrete mixes.

3. Data, and experimental investigation

3.1. Mix proportion

The ingredients of concrete i.e. Cement, coarse aggregate, and fine aggregate were mixed in the proper proportion by addition of water. Alccofine was added to the mixes as a replacement of cement 25% by mass. Table 3 shows the mix proportions of trail mixes.

Table 1
Physical properties of Alccofine.

Characteristics	Test results
Specific gravity	2.9
Specific surface area [m^2/kg]	1200
Bulk density [kg/m^3]	680
Particle size in micron	
D_{10}	1.5
D_{50}	5
D_{90}	9

Table 2
Chemical Properties of Alccofine form EDAX.

Characteristics of element	Results for EDAX	
	Weight %	Atomic %
C K	45.69	57.64
O K	35.26	33.39
Al K	4.01	2.25
Si K	6.38	3.44
Ca K	8.66	3.27

3.2. Tests on hardened concrete

3.2.1. Mechanical tests

Specimens for mechanical properties of different mixes were prepared with partial replacement of cement with alccofine. Cube specimens of 150 mm × 150 mm X 150 mm, cylindrical specimen (d x h) of 150 mm × 130 mm and prism specimens of 100 mm × 100 mm X 500 mm were casted to find the variation of compressive strength, splitting tensile strength and flexural strength respectively. The specimens were demoulded after 24 h and cured till the test date as per IS 516–1959 specification [17]. The compressive strength tests were carried out for three samples for every single mix at 3, 7 and 28 days as per IS 516–1959 specification. The splitting tensile tests were carried out at 3, 7 and 28 days as per IS 5816-1999 specification [18] and flexural strength were evaluated as per IS 516–1959 specification [17].

3.2.2. Thermogravimetric analysis

Total twelve samples (with and without alccofine) were studied by Thermogravimetric analysis. Small samples were taken from the concrete cube and heat

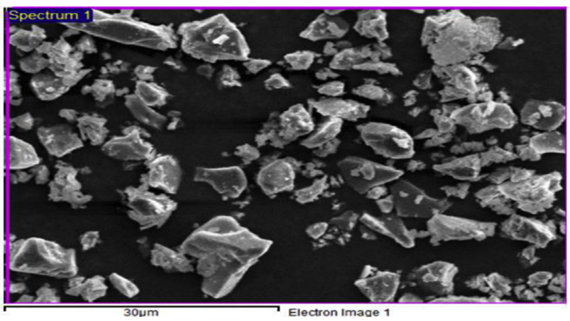

Fig. 1. SEM image of Alccofine.

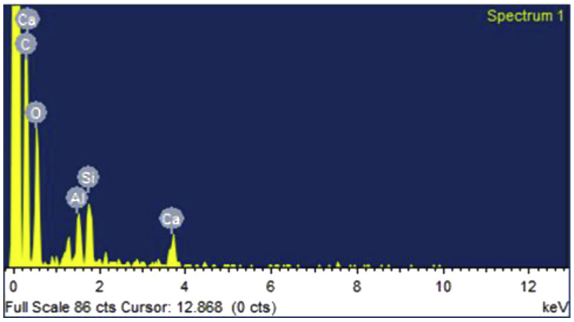

Fig. 2. EDX image of alccofine.

was applied from 25 °C to 1000 °C in a thermal analyzer with a rate of heating 10 °C/min. From TGA experiment, weight losses with respect to increasing temperature and peak temperature for the decomposition of hydrates like Ca $(OH)_2$, calcite, calcium silicate hydrate and C-A-S-H were studied.

3.2.3. X-ray diffraction analysis (XRD)

The XRD test was conducted on samples on 28th day. The diffractometer with CuKu source having a wavelength of $\chi = 1.54\grave{A}$ at the scanning speed of 2s/step and the diffraction angle between 7° and 60° was employed for test conduction.

4. Results and discussion

4.1. Mechanical properties

4.1.1. Compressive strength

It has been recognized that alccofine increases the compressive strength of concrete. It depends on the dosage of alccofine, temperature, the mixing process, water-cement ratio, type of cement and curing condition. In this research, a constant replacement of cement with alccofine (i.e.25%) was taken and the compressive strength of cubes tested at the age of 7 and 28 days for different water-binder ratios 0.45, 0.4 and 0.38 as shown in Fig. 3. The compressive strength of concrete at early age (7 days) for mixes AF1, AF2 and AF3 was enhanced by 7.99%, 7.85% and 6.40% respectively compared to NM1, NM2 and NM3. The compressive strength of concrete at later age (28 days) for mixes AF1, AF2, and AF3 was also found to have improved by 5.26%, 2.97% and 2.32% compared to NM1, NM2 and NM3 respectively. Alccofine did not only act as a filler material to increase density of concrete but also improved the hydration process to enhance strength properties [19,20]. From results, it was observed that the compressive strength of concrete increases with alccofine compared to conventional concrete at all ages.

Table 3
Mix proportions for trail mixes.

Mix	Cement	Alccofine	Sand	Gravel	W/B ratio	% of alccofine
NM1	438.13	0	644.59	1118.42	0.45	0
NM2	492.90	0	610.55	1106.06	0.4	0
NM3	518.84	0	595.98	1098.62	0.38	0
AF1	328.59	109.53	644.59	1118.42	0.45	25
AF2	369.67	123.22	610.55	1106.06	0.4	25
AF3	388.18	155.65	595.98	1098.62	0.38	25

Units: Cement, Alccofine, Sand and Gravel in kg/m^3.

4.1.2. Split tensile strength

The cylindrical specimens were tested for splitting tensile strength at the age of 7 and 28 days for water-binder ratios 0.45, 0.4 and 0.38 as shown in Fig. 4. The split tensile strength of concrete at early age (7 days) for mixes AF1, AF2 and AF3 was found to have increased by 6.79%, 5.15% and 6.78% compared to NM1, NM2 and NM3 respectively. The split tensile strength of concrete at later age (28 days) for mixes AF1, AF2, and AF3 also enhanced by 1.92%, 0.93% and 0.845% compared to NM1, NM2 and NM3 respectively. Alccofine enhances the split tensile strength of concrete by reduction of the binder paste–aggregate transition zone due to its higher surface area and chemical composition. Alccofine being a very fine material decreased the porosity of concrete which in turn increases the density leading to the development of higher split tensile strength [21,22].

4.1.3. Modulus of rupture

The flexural strength results with and without alccofine for concrete mixes with three different water-binder ratios 0.45, 0.4 and 0.38 at the age of 7 and 28

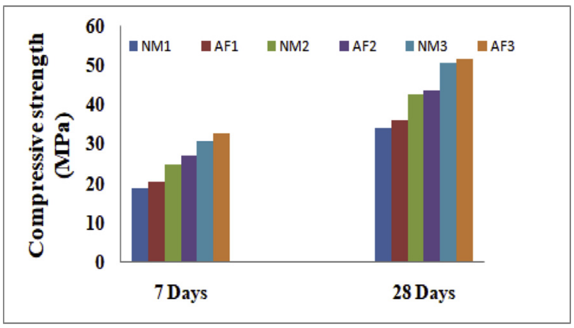

Fig. 3. Compressive strength of the normal and alccofine concrete for different W/B ratios.

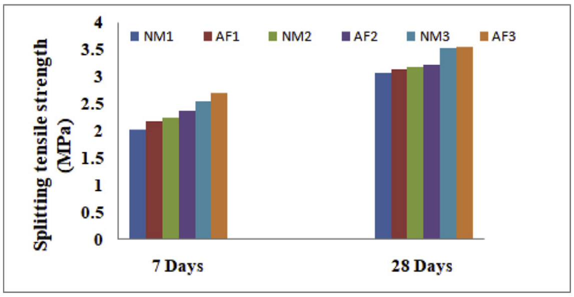

Fig. 4. Split tensile strength of the normal and alccofine concrete for different W/B ratios.

days are shown in Fig. 5. In the present research, it was observed that normal concrete had less flexural strength at the given water-binder ratios. The modulus of rupture of concrete at early age (7 days) for mixes AF1, AF2 and AF3 was enhanced by 3.00%, 3.57% and 2.20% compared to NM1, NM2 and NM3 respectively. The modulus of rupture of concrete at later age (28 days) for mixes AF1, AF2, and AF3 also increased by 1.33%, 0.59% and 0.71% compared to NM1, NM2 and NM3 respectively.

4.2. Thermogravimetric analysis

From thermogravimetric analysis results, the mass loss along with the decomposition of all components with temperature was found. The thermogravimetric analysis showed that significant weight loss can occur in many ways. The primary effect from 25 °C to 100 °C had to do with the residual pore water which evaporated from capillary pores. In this stage, the weight loss depended upon the adsorbed water, inter-layer water and capillary pores. The second effect from 100 °C to 500 °C had to do with dehydration of calcium silicate hydrates, ettringite and C-A-H. The third at about 400–500 °C is due to the decomposition of calcium hydroxide formed during hydration as shown in Eq. (3).

$$Ca(OH)_2 \rightarrow CaO + H_2O \tag{3}$$

The last weight loss effect around 800 °C can be attributed to decarbonisation of $CaCO_3$ as shown in Eq. (4).

$$CaCO_3 \rightarrow CaO + CO_2 (\text{Decarbonation}) \tag{4}$$

Fig. 6 shows the decomposition of all hydration compounds in the temperature range of 23–800 °C and Fig. 7 shows the weight loss of normal and alccofine concrete at different water to binder ratios with respect to temperature. It can be clearly seen from Fig. 7 that the percentage of weight loss in alccofine concrete is less than that of the normal concrete.

From Eqs. (5) and (6), the content of calcium hydroxide and bound water were calculated as a percentage of the weight at 580 °C [23] as follows:

$$\text{Calcium hydroxide } (\%) = \frac{W_{400} - W_{580}}{W_{580}} \times \frac{74}{18} \times 100 \tag{5}$$

Molecular weight of Calcium hydroxide is 74 and that of water is 18.

$$\text{Bound water } (\%) = \frac{W_{26} - W_{580}}{W_{580}} \times 100 \tag{6}$$

From results percentage of calcium hydroxide was more in normal concrete but percentage of bound water had more values in alccofine concrete compared to normal concrete as shown in Figs. 8 and 9. The percentage of calcium hydroxide was less in alccofine concrete because alccofine reacts with calcium hydroxide to form additional CSH gel whereas no such entity exists in normal concrete to react with the same

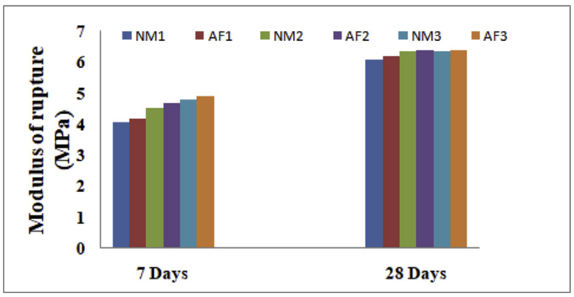

Fig. 5. Modulus of rupture of the normal and alccofine concrete for different W/B ratios.

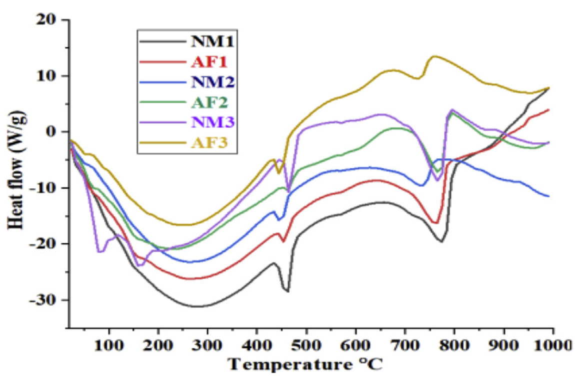

Fig. 6. Differential Scanning Calorimetry curves of the normal and alccofine concrete for different W/B ratios.

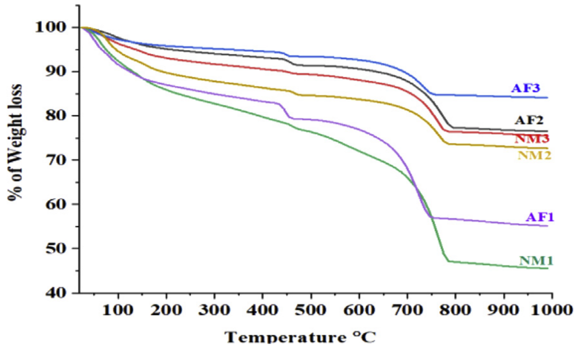

Fig. 7. Percentage of weight loss curves of the normal and alccofine concrete for different w/b ratios.

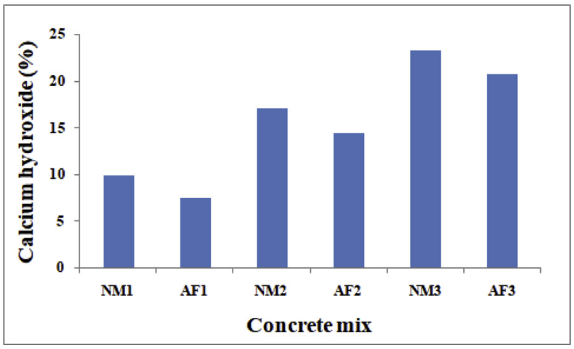

Fig. 8. Calcium hydroxide (%) of the normal and alccofine concrete for different water to binder ratios.

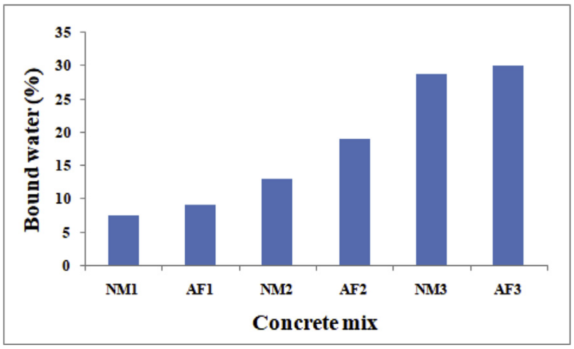

Fig. 9. Bound water (%) of the normal and alccofine concrete for different W/B ratios.

thereby increasing the percentage of calcium hydroxide in normal concrete [24,25].

4.3. X-Ray diffraction analysis (XRD)

XRD analysis is a one of the method to find mineral composition like calcium silicate hydrate (C−S−H), calcium aluminosilicate hydrate (C-A-S-H),

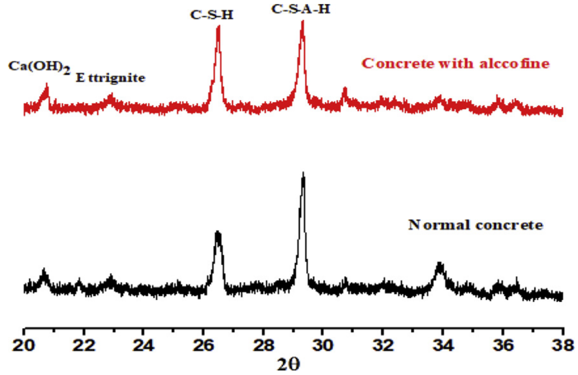

Fig. 10. XRD analysis of the normal concrete and alccofine concrete at W/B = 0.45.

portlandite ($Ca(OH)_2$) and ettringite present in the concrete. Figs. 10−12 show the peak intensities for control and alccofine concrete at different water to binder ratio (i.e. 0.38, 0.4 & 0.45).

The intensity of calcium hydroxide ($Ca(OH)_2$) in the presence of alccofine at 2θ = 20.64 has increased

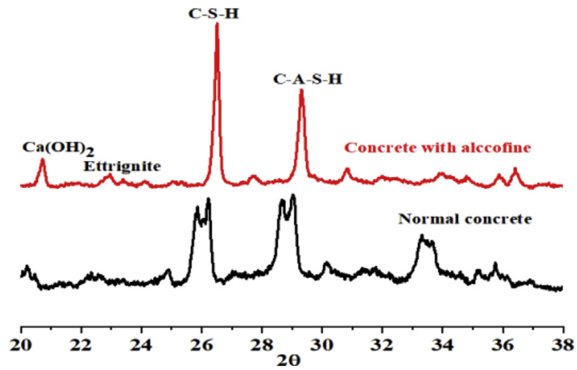

Fig. 11. XRD analysis of the normal concrete and alccofine concrete at W/B = 0.40.

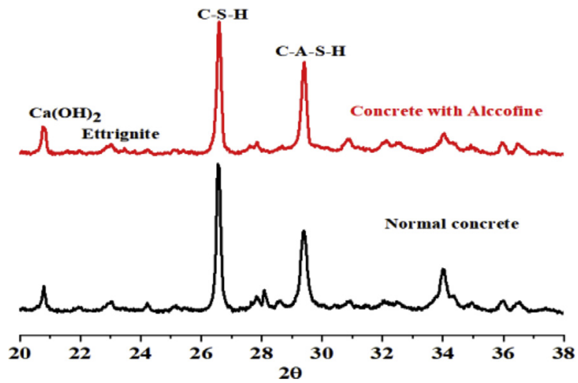

Fig. 12. XRD analysis of the normal concrete and alccofine concrete at W/B = 0.38.

compared to normal concrete for all water to binder ratios. Formation of $Ca(OH)_2$ is more in normal concrete compared to alccofine concrete [23]. Further, the intensity of ettringite in the presence of alccofine at $2\theta = 22.87$ has decreased compared to without alccofine. The peak intensity of calcium silicate hydrate at $2\theta = 26.46$ has increased more in the presence of alccofine compared to normal concrete and the intensity of calcium aluminosilicate hydrate is more in normal concrete at $2\theta = 28.29$ indicating rapid hydration. The formation of CSH is more in with alccofine concrete due to $Ca(OH)_2$ converted to secondary CSH and therefore enhancing strength of the concrete.

5. Conclusion

In this research, effect of alccofine on the properties of concrete was studied. From the experimental results it is concluded that alccofine enhanced strength properties of concrete at early and later ages. Compressive strength of concrete with alccofine improved by 7.99%, 7.85% and 6.40% at 7th day and 5.26%, 2.97% and 2.32% at 28th day compared to 7 and 28th day compressive strength of concrete without alccofine. Split tensile strength of concrete with alccofine was enhanced by 6.79%, 5.15% and 6.78% at 7th day and 1.92%, 0.93% and 0.845% at 28th day compared to 7 and 28th day split tensile strength of concrete without alccofine. Concrete with alccofine improved the modulus of rupture by 3.00%, 3.57% and 2.20% at 7th day and 1.33%, 0.59% and 0.71% at 28th day compared to7 and 28 day modulus of rupture of concrete without alccofine. From thermogravimetric analysis alccofine concrete was found to have more bound water and less calcium hydroxide (due to pozzolanic action) with respect to normal concrete at different water to binder ratios. It was also found that alccofine concrete had less weight loss and decomposition of hydrates compared to normal concrete thereby making it more stable. From XRD it was observed that alccofine improved the formation of calcium silicate hydrate and calcium silicate aluminum hydrate in concrete. Hence from the results obtained in this study it can be concluded that substituting the cement in concrete by alccofine is a feasible mean considering enhanced properties and eco-friendly nature of concrete.

Conflicts of interest

We declare that none of the authors have any competing of interests in this manuscript.

Acknowledgement

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