International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-5, March 2019

Durability and Mechanical 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 on the properties of concrete with ultrafine slag dosage (i.e. Alccofine of 25%) as a replacement of cement for different water to binder ratios (i.e. 0.38, 0.4 and 0.45). The effect of addition of alccofine on the strength properties (compressive strength, splitting tensile strength and flexural strength) of concrete were studied at 7 and 28 days wherein considerable strength enhancement was observed compared to normal concrete. Water absorption and the effects of acid attack on weight and strength deterioration factor (SDF) were also carried out. It was identified that the concrete with alccofine was more durable as compared to normal concrete. 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.

***Index Terms*: Alccofine, compressive strength, water absorption, acid attack**

I. 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 to 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 (Shadi). 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 [1].

There are so many micro fine materials which are available in the market such as Silica fume, Ultrafine fly-ash, and Iron ore. 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 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 42.3MPa, 7.9MPa and 8.3MPa 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 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, sulphate 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 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 Equation 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.

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

$$Ca(OH)_2 + \text{Alccofine 1203} \rightarrow \text{Secondary C-S-H} \quad (2)$$

In this study, an investigation was carried out on the effect of alccofine (25%) on the properties of concrete in fresh and hardened state.

Manuscript published on 30 March 2019.
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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 its other properties like thermogravimetric analysis, microanalysis properties and durability issues which lead to a sustainable construction.

II. MATERIALS

A. Cement

In this investigation, OPC 43 grade was used and it was tested as per Indian standard specifications [14]. Figure 1 shows the SEM picture of cement.

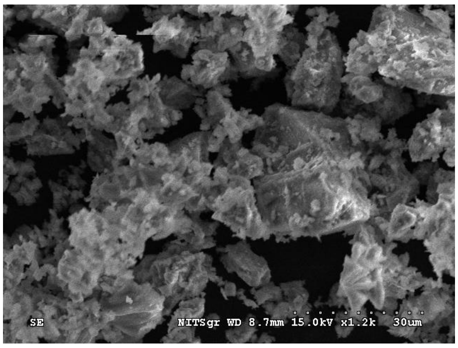

Fig. 1. SEM picture of cement

B. 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. Alccofine being a ultrafine slag material, it was easy to add it to the mix. In Table 1 & 2 the physical and chemical properties of alccofine respectively are shown. Figure 2 shown SEM image of alccofine.

TABLE 1
Physical properties of Micro-fine material (Alccofine)

Specific gravity	Fineness (cm^2/gm)	Bulk density (Kg/m^3)	Particle size distribution		
			D_{10}	D_{50}	D_{90}
2.9	> 1200	700-900	1.5	5	9

TABLE 2
Chemical composition of Micro-fine material (Alccofine) (%)

CaO	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*SO_3*	*MgO*
61-64	21-23	5-5.6	3.8-4.4	2-2.4	0.8-1.4

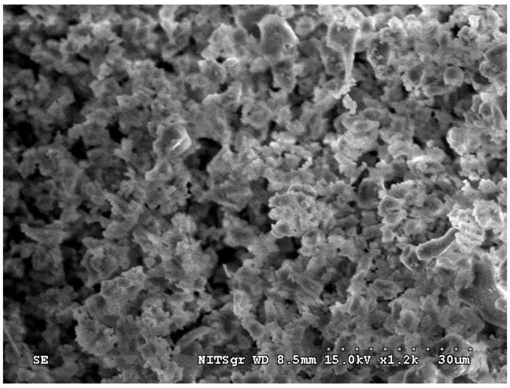

Fig. 2. SEM image of Alccofine

C. 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 [15].

D. Water

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

III. DATA AND EXPERIMENTAL INVESTIGATION

A. 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%).

B. Tests on mechanical properties

Specimens for mechanical properties of different mixes were prepared with partial replacement of cement with alccofine. Cube specimens of 150mm*150mm*150mm, cylindrical specimen (d x h) of 150mm*130mm and prism specimens of 100mm*100mm*500mm were casted to find the variation of compressive strength, splitting tensile strength and flexural strength respectively. The specimens were demoulded after 24 hours and cured till the test date as per IS 516-1959 specification[16]. 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 and flexural strength were evaluated as per IS 516-1959 specification.

Retrieval Number: E2984038519/19©BEIESP
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International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-5, March 2019

TABLE 3
Mix proportions for trail mixes

Mix	*Cement*	*Alccofine*	*Sand*	*Gravel*	*W/B ratio*	*WAF*
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

C. Water absorption

Water absorption test was carried out on cube specimen of size 150 mm. The specimens were taken out from curing tank at the age of 7 and 28 days followed by oven drying at 105ºC for 24 hrs[18]. After this the samples were cooled to ambient temperature and dry weight was measured. These specimens were then placed in water at 23ºC for 48 hours subsequent to which they were taken out from water and the surface was wiped with a dry cloth before weighing. The water absorption value of the cube specimen was determined as per ASTM C 642-06.

D. Resistance of concrete against acid attack

Acid resistance tests were carried out on the cube size of 150 mm. Cubes were cast and demoulded after 24hours and cured for 28 days. After 28 days, specimens were kept in the atmosphere for 2 days for getting constant weight and the initial weights were taken. All specimens were placed in 5% sulphuric acid (H2SO4) solution for 28 days[19]. Specimens were taken out from solution at the end of 28 days. The surfaces of all specimens were cleaned with nylon wire brush under running water and were kept in the atmosphere for getting constant weight. The difference between initial and final dry weights indicates the percentage of weight loss and strength deterioration factors (SDF) were calculated.

IV. RESULTS AND DISCUSSION

A. 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 Figure 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. From results, it was observed that the compressive strength of concrete increases with alccofine compared to conventional concrete at all ages [20-22].

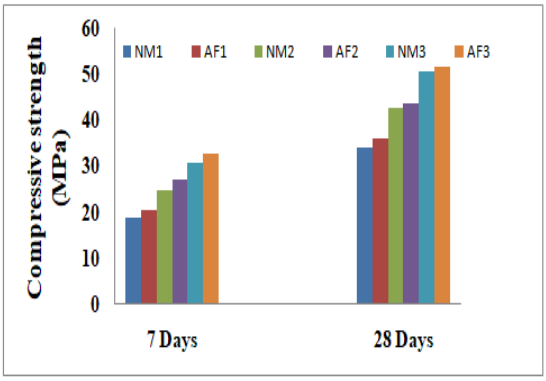

Fig. 3. Compressive strength of the concrete for different water to binder ratios

B. Split tensile strength

The cylindrical specimens were tested for split tensile strength at the age of 7 and 28 days for water-binder ratios 0.45, 0.4 and 0.38 as shown in Figure 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.

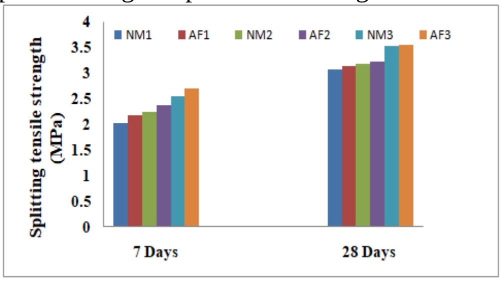

Fig. 4. Split tensile strength of the concrete for different water to binder ratios

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C. Modulus of rupture

The modulus of rupture 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 days are shown in Figure 5. In the present research, it was observed that normal concrete had less modulus of rupture 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.

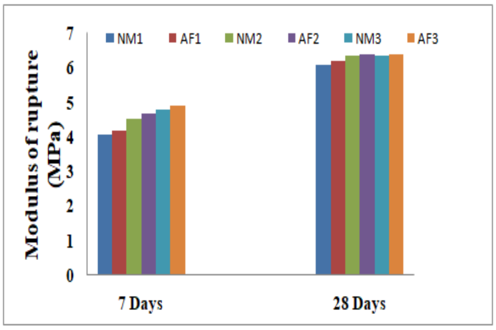

Fig. 5. Modulus of rupture of the concrete for different water to binder ratios

D. Water absorption

Water absorption is the most important factor for finding the durability of concrete. The penetration of water, ions and gases depends on the porosity and microstructure of the concrete but in some cases it also depends upon absorption and diffusion of concrete. The water absorption test results are shown in Figure 6. From experimental results, it can be seen that the concrete with alccofine has lesser water absorption than that of normal concrete. The water absorption for cubes of water-binder ratio 0.38 (i.e. NM3 &AF3) was found to be less than the concrete with water-binder ratios 0.4 & 0.45 (i.e. NM1, AF1, & NM2, AF2) respectively. The reason behind this behaviour is that higher water content in concrete causes water occupy more spaces which can then evaporate from concrete and create more voids which increase water absorption.

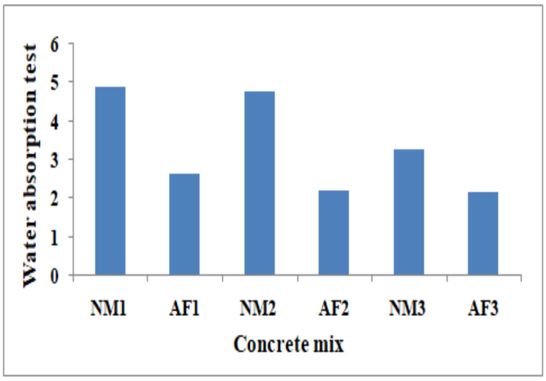

Fig. 6. Water absorption test of the concrete for different water to binder ratios

E. Resistance of concrete against acid attack

Structural elements which are constructed in marine regions are subjected to acid attack. When concrete reacts with the acid, it can produce calcium compounds and leach away. Acids can react more with calcareous aggregates where as siliceous aggregates are more resistant to acid exposures like industrial effluents, groundwater, and seawater than calcareous aggregates. In the present research, the effect of H_2SO_4 was analyzed on alccofine concrete (25% replacement of cement with alccofine). The concrete samples were tested for all mixes to find out mass loss and strength deterioration factors. These are shown in Figure 7 & 8. Through visual observations, it was seen that the conventional concrete cubes were more affected than that of alccofine concrete cubes. The conventional concrete permitted penetration of sulphuric acid on all surfaces up to 30 days. In alccofine concrete, the sulphuric acid penetration was very less due to high-density packing and a very fine microstructure of alccofine concrete.

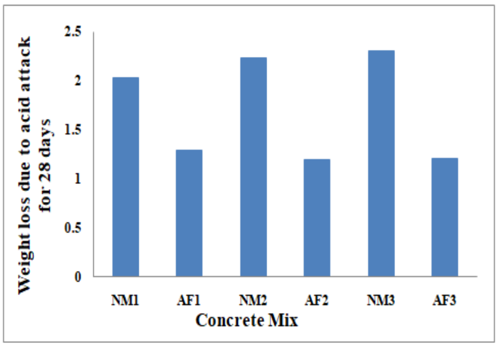

Fig. 7. Weight loss due to acid attack of the concrete for different W/B ratios

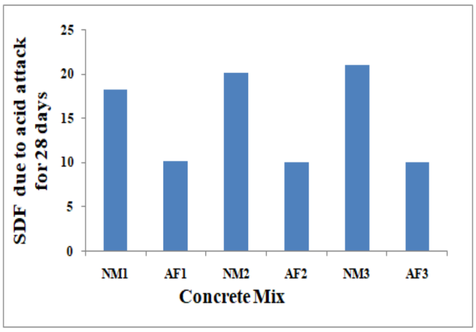

Fig. 8. Strength deterioration factor due to acid attack of the concrete for different W/B ratios

V. 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. Durability properties of alccofine concrete are also better due to high density packing and filling of pores in the microstructural by alccofine.

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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.

ACKNOWLEDGMENT

The authors acknowledge the National Institute of Technology, Srinagar, (Jammu and Srinagar), providing laboratory testing facility. The authors are further thankful for the Ambuja Cement Ltd, Goa and BASF chemicals, Mumbai for providing the required material.

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