

# Effect of Alccofine Addition on the Compressive Strength of High-Strength Concrete Cubes

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## Abstract

Researchers, scientists, and industrialists are involved in numerous research activities worldwide to find suitable replacement materials for cement due to the environmental pollution caused by CO<sub>2</sub> emissions during cement manufacturing. Various materials such as fly ash, silica fume, GGBS, metakaolin, nano silica, and quartz powder have been explored for partial or full replacement in cement concrete. This thesis investigates a new ultrafine material called Alccofine (AF), which is manufactured from glass waste and iron slag from steel industries, as a partial replacement for cement. The study focuses on M60 grade concrete to evaluate the performance of high-strength concrete by replacing cement with Alccofine in various proportions: 5%, 10%, 15%, and 20%. The design mix proportion for M60 grade concrete is achieved as per IS 10262. Several specimens are planned to determine the mechanical properties, such as compressive strength, flexural strength, and elastic modulus of concrete. These specimens are cast and tested according to Indian standards. The results are analyzed and presented in the form of charts and graphs. It is observed that early-age strength is achieved for all combinations, with the 10% Alccofine replacement yielding higher strength than the other dosages.

**Keywords:** Alccofine 1203, Conplast SP- 430, Workability, Elastic modulus of concrete, High strength concrete, Compressive strength, Flexural strength.

## 1. Introduction

### 1.1 General

Creating quality concrete in the present climate does not depend solely on achieving high strength property. Improving the durability of the concrete to sustain a longer life span and producing a greener concrete are becoming one of the main criteria in obtaining a quality concrete. Compressive strength of concrete is important because the main properties of concrete such as elastic modulus, tensile strength are related to this property. Concrete compression strength also plays a vital role when we focus more on load bearing capacity of structures. Compression test is the most common test conducted on hardened concrete because it is an easy test to perform and most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength. In this work the effect of ultra-fine slag (Alccofine) replacement on the mechanical

properties of high strength concrete is studied. It has been found that use of ultra-fine slag not only improves the compressive strength of concrete but also improves the workability and fluidity of the mix. It also shows segregation resistance and improved reliability and durability of the reinforced concrete structures.

A new ultrafine /micro material called Alccofine 1203, which performs in superior manner than all other mineral admixtures used in concrete within India. Due to its inbuilt CaO content, ALCCOFINE 1203 triggers two-way reactions during hydration that i) primary reaction of cement hydration and ii) pozzolonic reaction. The effect of elevated temperatures on mechanical properties of micro cement based High Performance Concrete (HPC) was proved good results [1]. The rising exposure temperature raises peak stress for alccofine blended high strength concrete, but it initially lowers and subsequently increases for high calcium

fly ash blended high strength concrete [2]. The current global acceleration of industrialisation and urbanisation has resulted in massive garbage production. The world's daily solid waste per capita of 0.79 kg, or 2.24 billion tonnes, in 2020 is expected to increase by 73% to 3.88 billion tonnes annually by 2050 [3]. Compressive strength of concrete containing fly ash or GGBS and a superplasticizer and however these cannot be used for very high-strength concrete where the trial mix approach is best for selecting mix proportions for such high strength concrete [4]. Alccofine, when used in part instead of cement, has the combined advantages of being an environmentally benign material that lowers carbon emissions and increases workability and mechanical strength. The outcomes of the optimised mixture were improved by the inclusion of water-dispersed graphene oxide. The system with 15% Alccofine replacement and 0.05% water-dispersed graphene oxide produced the greatest results [5]. Specialised equipment is not needed for high-performance concrete; careful design and manufacture are all that are needed. One of HPC's numerous benefits is that it has better endurance qualities and experiences less microcracking than traditional concrete. High-performance concrete (HPC) is made to provide optimal performance properties for a specific combination of materials, usage, and exposure circumstances while adhering to cost, service life, and durability requirements [6]. High calcium fly ash (FC) and alccofine (AL) as mineral admixtures led to the development of the fracture behaviour of high strength concrete (HSC). The percentage of mineral admixtures in the HSC mixes is kept at 20% of ordinary Portland cement (OPC), while the water binder ratio is kept at 0.26. To get flow values in the 150–200 mm range, a 2% chemical admixture dose is used. The strength of the control specimen is compared to the compressive strength at 7 and 28 days for blended mixtures of FC (i.e., FC-HSC) and AL (i.e., AL-HSC). Notable outcomes are attained [7]. Supplementary cementitious materials (SCMs) are a technical innovation in the construction industry that may be used to augment or partially replace traditional binder mass in the making of concrete. In light of this, the purpose of this work is to review and evaluate the published research on the mechanical and long-term characteristics of

concretes based on alccofine-1203. Additionally, it aims to provide a deeper comprehension of the behaviour and impact of alccofine-1203 as an SCM in different kinds of concrete. The alccofine-1203 enhances the hydration process and pozzolanic reaction because of its ultra-fine particles and distinct chemical makeup [8].

The ternary system that is OPC-Fly ash-Alccofine concrete was found to increase the compressive strength of concrete on all age when compared to concrete made with fly ash and Alccofine alone [9]. For their safe disposal, industrial byproducts such fly ash, GGBS, rice husk ash, alccofine 1203, silica fume, and metakaolin need a sizable amount of land [10]. The building industry is more inclined to employ sustainable ingredients to produce concrete that is more benign. Furthermore, performance and economic viability are important considerations in the current study on a variety of novel replacements and alternatives [11]. Alccofine can help the concrete industry overcome these shortcomings and produce stronger, longer-lasting concrete while also reducing the building sector's carbon footprint. It can also be used to utilise an excess of industrial by-products in the right mechanism [12]. Using innovative methods and approaches to make building increasingly self-sufficient and dependable is a popular issue among scholars these days. In the past, high strength and high-performance concrete was created to satisfy the general needs for strength, durability, and sustainability. It was only this idea that gave rise to the usage of micro-fillers [13].

The most popular test for hardened concrete is the compression test, in part because it is simple to execute and in part because the majority of concrete's desirable qualities are directly correlated with its compressive strength [14]. The primary characteristics of concrete make its compressive strength significant. Since the majority of the desired characteristics of concrete are qualitatively connected to its compressive strength, the compressive test is the most often performed test on hardened concrete. The impact of replacing high strength concrete with ultra-fine slag (Alccofine) on its mechanical characteristics is investigated. It has been discovered that adding ultra-fine slag to

concrete increases its workability and fluidity in addition to its compressive strength [15].

For Binary Blended Concrete, a 15% cement substitution with Alccofine typically yields the best strength and workability [16]. With a water binder ratio of 0.45 and 0.5, standard size specimen cubes were used for the compressive strength test. The results show that adding 10% Alccofine and 30% Fly Ash to concrete can maximise its compressive strength [17]. The blend of concrete that contains 59% cement, 15% metakaolin, and 26% alccofine has the highest packing density in terms of compressive strength, and as the quantity of alccofine grows, so does the beam's flexural strength [18]. The transportation of harmful materials from the surrounding environment, together with physical and chemical reactions within the structure, are typically the first steps in the degradation of reinforced concrete buildings [19].

### 1.2 ALCCOFINE-1203

Alccofine-1203 is a specially processed product based on high glass content with high reactivity obtained through the process of controlled granulation. The raw materials are composed of primary low calcium silicates. The processing with other select ingredients results in controlled particle size distribution (PSD). The computed blain value based on PSD is around 12000 cm<sup>2</sup>/gm and is truly ultra-fine. Due to its unique chemistry and ultrafine particle size, ALCCOFINE-1203 provides reduced water demand for a given workability, even up to 70% replacement level as per requirement of concrete performance. ALCCOFINE-1203 can also be used as a high range water reducer to improve compressive strength or as a super workability aid to improve flow.

#### 1.2.1 Necessity of Alccofine 1203

- HSC is required as a construction material in special structures like tunnels in sea beds, off-shore piers and platforms, jetties and ports, and tall structures etc.,
- It can be used as an alternative material for cement.
- To reduce the usage of cement to certain limit.
- To reduce the pollution by decreasing usage of cement.

#### 1.2.2 Properties of Alccofine 1203

Major chemical compositions

- Calcium oxide - 34%
- Silicon dioxide - 35%
- Aluminum dioxide - 24%

Chemical Composition and Physical Properties are presented in Table 1.

**Table 1. Chemical Composition and Physical Properties**

Chemical Analysis	Mass %	Physical analysis	Range
CaO	31.00	Bulk Density	600-700 kg/m <sup>3</sup>
Al <sub>2</sub> O <sub>3</sub>	22.6	Surface Area	12000 cm <sup>2</sup> /gm
Fe <sub>2</sub> O <sub>3</sub>	2.2	Particle shape	Irregular
SO <sub>3</sub>	0.19	Particle Size, d <sub>10</sub>	< 2 μm
MgO	8	d <sub>50</sub>	< 5 μm
SiO <sub>2</sub>	33.6	d <sub>90</sub>	< 9 μm
MnO	0.62		
Na <sub>2</sub> O	0.42		

### 2. Objectives and Scopes

The relevant literatures to the present study are collected and reviewed. Its summary of each literature is given in this chapter. As already said that the Alccofine related works are very few only and hence this study is aimed to carry out the strength aspects of the concrete. The literature review helps to confining the present studies objectives & scope which are as follows.

#### 2.1 Objectives

From the literatures reviewed the following objectives are derived:

- To design the mix portion for Alccofine partially replacing the conventional cement in various percentages such as 5%, 10%, 15% & 20%.



Figure 1. OPC-43



Figure 2. Alccofine-1203

- To determine the Workability of M60 grade of concrete.
- To determine the compressive strength of the partially replaced Alccofine in HSC.
- To determine the flexural strength of the partially replaced Alccofine incorporated concrete.
- To determine the elastic modulus for the HSC with Alccofine.
- To find out the optimum percentage of Alccofine required for early age strength.

## 2.2 Scope

- It is restricted to study the strength properties.
- It is proposed to design the mix proportion for M60 grade concrete only.

## 3. Experimental Investigations

### 3.1 Materials

Cement, fine aggregate, coarse aggregate and water are the common ingredients used. In addition ALCCOFINE 1203, this is to increase the strength of concrete and Conplast sp-430 which is to provide workability and other advantages to the concrete.

#### 3.2.1 Cement

Cement used for all specimens is Ordinary Portland Cement of 43 grade. This is conforming to IS 8112. The sample of cement is shown in Fig. 1.

#### 3.2.2 Alccofine-1203

As can be seen in the chemical composition and physical characteristics listed below, ALCCOFINE1203 has got the unique chemical composition mainly of CaO 30-34% and SiO<sub>2</sub> 30-36%. Table 2 shows the chemical ingredients in Alccofine. The sample of ultrafine material Alccofine is shown in Fig.2.

Table 2. Chemical composition of Alccofine

Chemical Analysis	Mass %
CaO	33
Al <sub>2</sub> O <sub>3</sub>	22.1
Fe <sub>2</sub> O <sub>3</sub>	2.1
SO <sub>3</sub>	0.3
MgO	7.5
SiO <sub>2</sub>	35

### 3.2.3 Fine aggregate

The Fine Aggregate is Asperthe IS 383-1970 Code conforming that is coming under ZONE III.

### 3.2.4 Coarse aggregate

The coarse aggregate conforming to IS: 383-1970 was used. The size of aggregate used was 12mm to 20mm.

### 3.2.5 Water

Potable water was used for mixing concrete and curing the specimens.

### 3.2.6 Conplast SP430

ConplastSP430 is shown in Fig.3 is used where a high degree of workability and its retention are required; where delays in transportation or placing are likely or when high ambient temperatures cause rapid slump loss. It facilitates production of high quality concrete.



Figure 3. Conplast SP430

Properties:

Specific gravity -1.21

Chloride content - Nil as per IS: 9103-1999 and BS: 5075

Air entrainment - Approx. 1% additional air over control

### 3.2.7 Concrete

Ordinary Portland cement 43 grade is used. The physical properties and tests of cement are carried out in accordance with procedure laid down in IS: 1489. The maximum size of aggregate shall be 20mm and the size of fine aggregate ranges between 0 and 4.75mm. After casting the specimens need to be allowed to cure in real environmental conditions for about 28 days so as to help the concrete to stabilize its own properties like compressive strength and modulus of elasticity. The strength of concrete under axial compression is determined by loading on a standard cube (150mm x 150mm x 150mm size).

### 3.3 Preliminary tests on materials

Basic tests like specific gravity and sieve analysis were carried out on the materials to be used. Testing was done and the results were tabulated as given below.

#### 3.3.1 Specific gravity of materials

The specific gravity of the materials used for making concrete is determined as per IS 2386 – 1963. The values obtained are given in the Table 3.

**Table 3. Specific Gravity**

Sl. No	Name of the Material	Specific Gravity
1.	OPC Cement	3.15
2.	Alcofine	2.86
3.	Fine Aggregate	2.63
4.	Coarse Aggregate	2.74

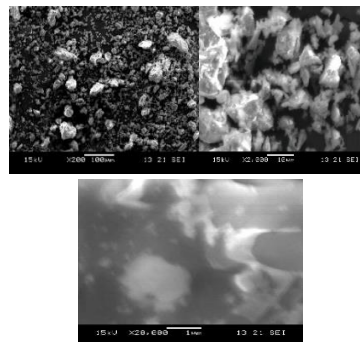
#### 3.3.2 Sieve analysis

The locally available river sand is used as a fine aggregate (0 to 4.75 mm) which is tested for sieve analysis to determine the zone as per IS 383 – 1970. It was found that the fine aggregate Conforming to grading zone III of table 4 of IS 383:1970 and also found that fine modulus 2.23.

### 3.4 SEM analysis

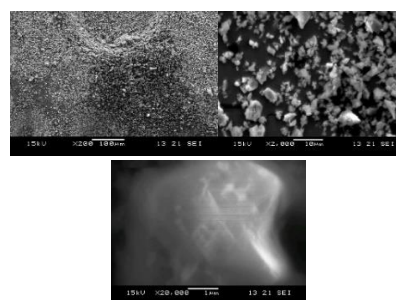
The cementitious materials are analysed in SEM analysis to find in the materials shape and size of the samples

#### 3.4.1 OPC- 43 (Fig.4)



**Figure 4. SEM analysis of OPC 100μ, 10μ and 1μ**

#### 3.4.2 ALCCOFINE-1203 (Fig.5)



**Figure 5. SEM analysis of AF 100μ, 10μ and 1μ**

#### 3.3.4 Slump test

The slump test is carried out using a mould known as a slump cone as per IS 1199-1959. The cone is placed on a hard non-absorbent surface. This cone is filled with fresh concrete in three stages, each time it is tamped using a rod of standard dimensions. At the end of the third stage, concrete is struck off flush to the top of the mould. The mould is carefully lifted vertically upwards, so as not to disturb the concrete and place the cone by the side and the slump value have to be measured from top as shown in Fig.6. The measured slump value is 40 mm.



**Figure 6. Slump test on first trial**

### 3.4 Mix Ratio for M60 Grade of Concrete

The design mix for M 60 grade of concrete is carried out as per the standards IS 10262 – 2009 and [18]. The mix proportions for various dosages of Alccofine are given in Table 4.

**Table 4.** Mix ratio

Sl.No	CEMENT	F.A	C.A	W B	AF	SP
1.	1	1.20	2.68	0.3	0.00	0.0130
2.	1	1.20	2.68	0.3	0.05	0.0130
3.	1	1.20	2.68	0.3	0.10	0.0130
4.	1	1.20	2.68	0.3	0.15	0.0130
5.	1	1.20	2.68	0.3	0.20	0.0130

### 3.5 Mix proportions in kg/m<sup>3</sup>

The mix proportions for various dosages of Alccofine in volume basis per cubic meter are given in Table 5.

**Table 5.** Mix proportion

Sl. No	CEMENT kg/m <sup>3</sup>	F.A kg/m <sup>3</sup>	C.A kg/m <sup>3</sup>	W B lit/m <sup>3</sup>	AF kg/m <sup>3</sup>	SP lit/m <sup>3</sup>
1.	483.33	586	1297.39	145	0.00	5.19
2.	458.2	586	1297.39	145	21.73	5.19
3.	434.32	586	1297.39	145	44.05	5.19
4.	410.44	586	1297.39	145	65.78	5.19
5.	386.56	586	1297.39	145	87.51	5.19

The various mix proportions of concrete using cement and AF, are identified and the number of specimens of various test are given in Table 6.

**Table 6.** Test specimen details

Sl. No	Mix	Specimen	Curing Days				Total
			3 days	7 days	14 days	28 days	
1	CA0	Cube	3	3	3	3	12
2	CA5		3	3	3	3	12
3	CA10		3	3	3	3	12
4	CA15		3	3	3	3	12
5	CA20		3	3	3	3	12
6	CA0	Cylinder	-	3	-	3	6
7	CA5		-	3	-	3	6
8	CA10		-	3	-	3	6
9	CA15		-	3	-	3	6
10	CA20		-	3	-	3	6
11	CA0	Prism	-	3	-	3	6
12	CA5		-	3	-	3	6
13	CA10		-	3	-	3	6
14	CA15		-	3	-	3	6
15	CA20		-	3	-	3	6
						<b>Total</b>	<b>120</b>

### 3.6 Casting & curing of specimens

In assembling the mould for use, the joints between the sections of mould shall be thinly coated with mould oil and a similar coating of mould oil shall be applied between the contact surfaces of the bottom of the mould and the base plate in order to ensure that no water escapes during the filling. The interior surfaces of the assembled mould shall be thinly coated with mould oil to prevent adhesion of the concrete.

The standard tamping bar shall be used and the strokes of the bar shall be distributed in a uniform manner over the cross-section of the mould. After the top layer has been compacted, the surface of the concrete shall be finished level with the top of

the mould, using a trowel. The test specimens shall be stored in a place, free from vibration at a temperature of  $27 \pm 2^\circ\text{C}$  for 24 hours  $\pm \frac{1}{2}$  hour from the time of addition of water to the dry ingredients. After this period, the specimens shall be marked and removed from the moulds and, unless required for test within 24 hours, immediately submerged in clean, fresh water. The specimens shall not be allowed to become dry at any time until they have been tested. The stage by stage preparation of moulds, casting, compaction and curing of specimens are as shown Figs.7, 8, 9 (a), (b), 10(a), (b) and 11 (a), (b).



**Figure 7.** Preparation of moulds before casting of specimens



**Figure 8.** Cubes placed on vibrating table under compaction



**Figure 9(a)** Cast specimens



**Fig.9(b)** Cast specimens



**Figure10(a).** Demoulded specimens after 24 hrs



**Figure10(b).** Demoulded specimens after 24 hrs



**Figure11(a).** Specimens under curing



**Figure11(b).** Specimens under curing

### 3.7 Compressive strength test

All the test specimens cast for compressive strength are tested using a compression testing machine as per standard as shown in Fig.12. The values were obtained are shown in Table 7.



Figure 12. Compression test on cube in different view

Table 7 shows the compressive strength values obtained from the experiment.

Table 7. Compressive strength of cube

Sl. No	% of Alccofine	3 Days N/mm <sup>2</sup>	7 Days N/mm <sup>2</sup>	14 Days N/mm <sup>2</sup>	28 Days N/mm <sup>2</sup>
1.	A0	29.77	48.52	53.20	58.82
2.	A5	42.46	55.16	57.46	59.11
3.	A10	46.71	64.45	67.06	74.48
4.	A15	54.48	58.27	60.15	65.27
5.	A20	56.88	59.76	63.43	69.76

### 3.7.1 Flexural test on prism

The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress, here given the symbol  $f_{cr}$ . The flexural strength are tested using a two point loading frame machine as per standard as shown in Fig. 13. The values obtained are shown in Table 8.



Figure 13. Flexural test on prism

Table 8. Flexural strength of prism

Sl.No	% of Alccofine	7 Days N/mm <sup>2</sup>	28 Days N/mm <sup>2</sup>
1.	A0	6	7.1
2.	A5	4.6	5.8
3.	A10	7.2	9.6
4.	A15	4.4	5.2

### 3.7.2 Compression test and E for concrete test on cylinder

The elastic modulus of an object is defined as the slope of its stress–strain curve in the elastic deformation region. A stiffer material will have a higher elastic modulus. All the test specimens cast for compressive strength are tested using a compression testing machine as per standard as shown in Fig.14. The values obtained are shown in Table 9.



Figure 14. Compression test on cylinder

Table 9. Compressive strength of cylinder

Sl.No	% of Alccofine	7 Days N/mm <sup>2</sup>
1.	A0	29.95
2.	A5	29.68
3.	A10	31.64
4.	A15	30.04
5	A20	28.88

#### 4. Result and Analysis

##### 4.1 Mechanical properties

The mechanical properties of concrete such as compressive strength, modulus of rupture and elastic modulus are determined from the standard experiments. They are as follows.

##### 4.2.1 Analysis of Compressive Strength

The results of compressive strength were presented in Table 7. The test has carried out conforming to IS

516-1959 to obtain compressive strength of concrete at the age of 7 and 28 days. The compressive strength is 64.45 MPa at 7 days and 74.48 MPa at 28 days. There is a significant improvement in the compressive strength of concrete because of the high pozzolanic nature of the Alccofine and its void filling ability. The results are shown in the form of charts and graphs Figs.15 and 16.

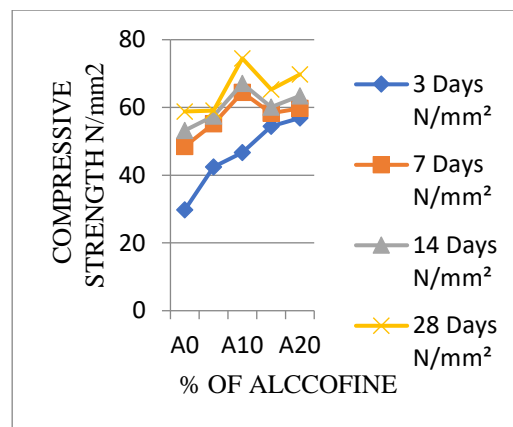


Figure 15. Compressive strength

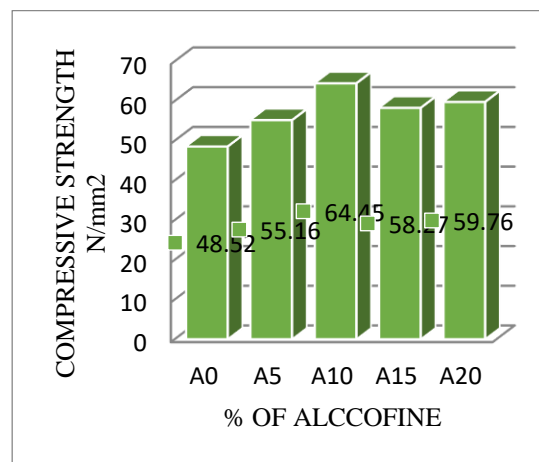


Figure 16. Compressive strength at 7 days

- Compressive strength Test on cubes: The cube compressive strength results of high strength Concrete mixes at the ages of 3, 7, 14, 28 days are presented in Table 7.
- The development of compressive strength of M60 grade of HSC mixes containing 0, 5,10,15 and 20 percent Alccofine at the various stages are plotted in the form of graphs are shown in Fig. 17a&b.
- This result shows that optimum 10% of Alccofine get the excellent result compare with controlled mix and other percentage of Alccofine mix.

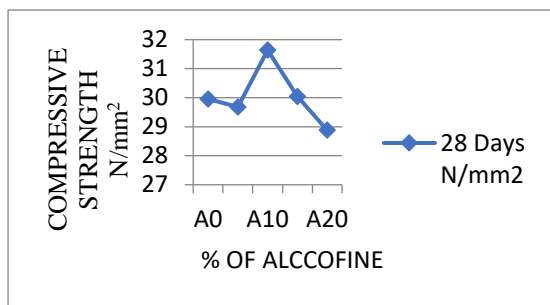


Figure 17 (b). Compressive strength of cylinders

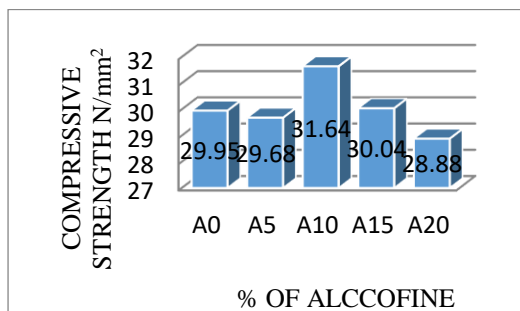


Figure 17 (b). Compressive strength of cylinders

- Compressive strength test on cylinder: The cylinder compressive strength results of high strength concrete mixes at the ages of 28 days are presented in Table 9.
- The compressive strength of cylinder in HSC with 10% Alccofine was higher than that of the controlled mix.

#### 4.2.2 Analysis of flexural strength

- The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress, here given the symbol  $f_{cr}$ . The flexural strength is tested using a two-point loading frame machine as per standard. Flexural strength of HSC: The Flexural strength of HSC after 14 and 28 days curing are shown in Fig. 18 a&b.
- This result shows that optimum 10% of Alccofine get the excellent result compared with controlled mix and other percentage of Alccofine mix.
- It can be clearly seen that the flexural strength value increases with 10% of Alccofine. The flexural strength is higher than the controlled mix.

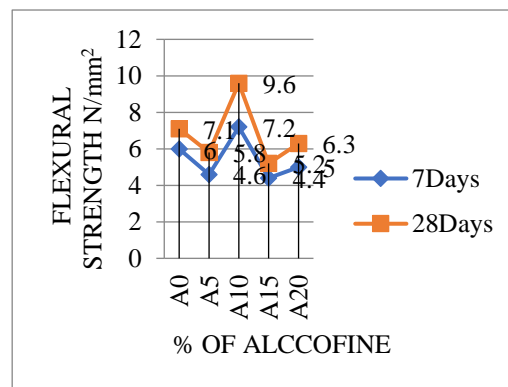


Figure 18(b). Flexural test on prism

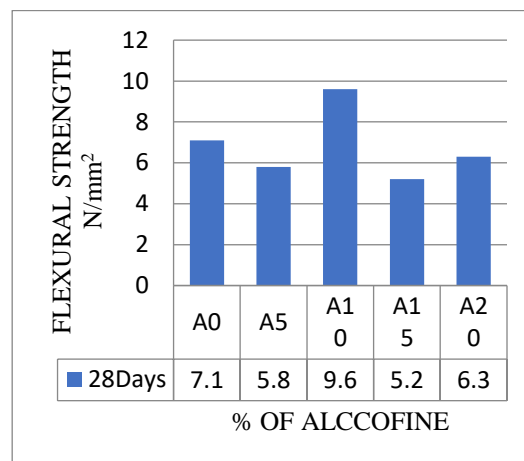


Figure 18(b). Flexural test on prism

#### 4.2.3 Analysis of elastic modulus of concrete

The stress-strain curves for test specimens are shown in Fig.19.

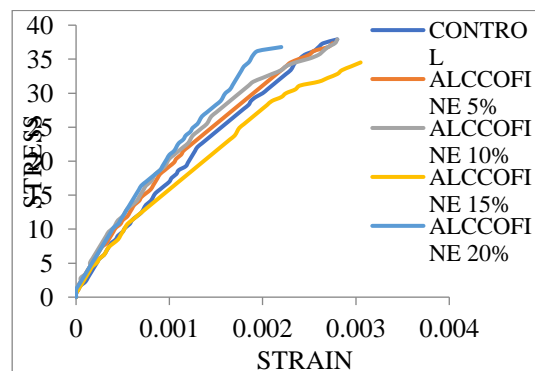


Figure 19. Elastic modulus of concrete

- The AF10% mix showed higher strength than all other mix
- The AF10% mix is 12.58% higher than the control mix (C)

#### 4.2.4 Relationship between compressive and flexural strength

$$f_{cr} = 0.13 \times f_{ck}$$

Relationships between compressive and flexural strength of test specimen is shown in Fig.20.

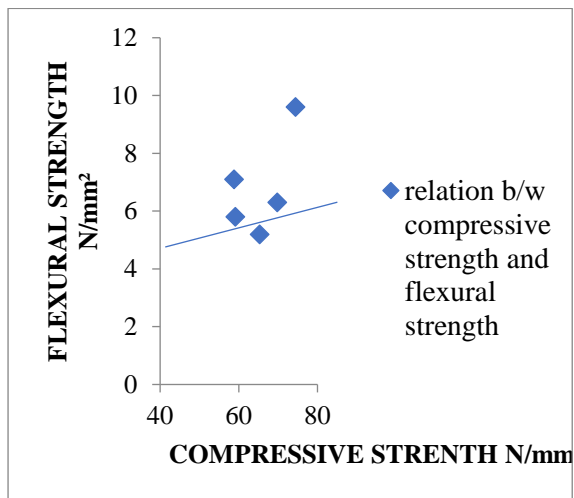


Figure 20. Relationships between compressive and flexural strength

#### 4.2.5 Relationship between compressive and elastic modulus

Relationships between compressive and elastic modulus of test specimen is shown in Fig.21.

$$E_c = 272.72 \times f_{ck}$$

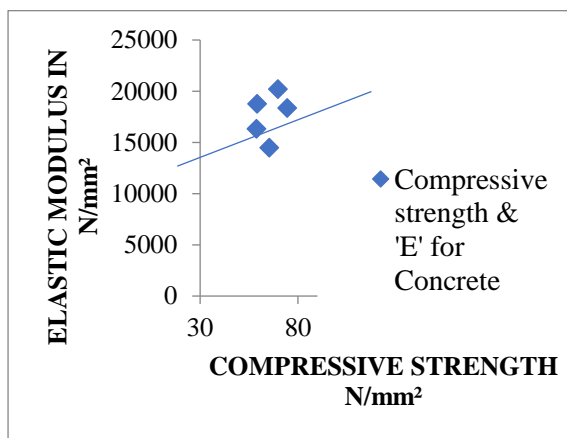


Figure 21. Relationships between compressive and elastic modulus

- It is observed that the random variation is identified and average line is drawn. Then it is found to be the modulus of rupture is 272.72 times the compressive strength of the concrete for the same mixes.

$$E_c = 272.72 \times f_{ck} \text{ N/mm}^2$$

#### 5. Conclusion

The conclusions from the experimental investigations are as follows:

- The cementitious materials are analysed in SEM analysis to find out shape and size of the samples
- The optimum replacement of cement by the Alccofine is 10 % of the volume of the cement.
- The cement replacement by 10% of Alccofine gives higher values of all other mix.
- Compressive strength mainly depends upon the percentage of Alccofine based on this its high pozzolanic nature to form more dense of calcium silicate hydrate (C S H) gel.
- The strength development of concrete is carried out at all ages of curing and it is observed that the strength increasing suddenly at the initial stage but after that it is increasing gradually.
- From the experimental results, when 7 days compressive strength as compared to control and AF10 mix 25.5 % improved.
- From the experimental results, when 28 days flexural strength compare to control and AF10 mix 27.6 % improved
- It is clearly known that the Alccofine material increases the strength only at the addition of 10% replacement of cement.
- If the percentage level of Alccofine is increased beyond that level it acts as a filler material and yields good workability to the concrete.
- Since the materials are costlier than the cement, concrete cost will be higher but that can be adjusted during the execution/construction of structures.
- It is recommended to utilize the Alccofine material with cement after checking its durability studies.

#### Conflict of interest:

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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