

## Strength effect of alccofine on ordinary and standard grade concrete mixes

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### Abstract

Concrete is an indispensable construction material used worldwide. It primarily consists of the binder phase and aggregate phase. In the binder phase, cement replacement with silica fumes, fly-ash and ground granulated blast furnace slag (GGBS) is recommended in design mix guidelines (IS 10262-2019). However, ultra-fine material like Alccofine was not recommended as supplementary cementitious material. This paper addresses the suitability of this admixture for concrete of various grades i.e. M20, M30 and M40 grade mixes. The relevant hardened concrete strength for 5%, 10%, 15%, and 20% cement replacement with Alccofine was tested. All the design mixes established the acceptance criteria of test results. However, the highest test results were obtained for 15% replacement of Alccofine for all the mixes. Surprisingly the 28 days strength of M20 grade concrete was achieved even at seven days curing test results. In summary, the Alccofine material can reduce the consumption of cement and CO<sub>2</sub> emissions in the atmosphere.

### Keywords

IS 10262, Design mix guidelines, Admixture, Alccofine, Hardened concrete, Flexural strength, Compressive strength, Tensile strength.

## 1.Introduction

Concrete, which is an indispensable construction material that occupies the second-largest material after drinking water for humankind. It has an annual consumption of 2.4 tons per person of the world population, which is more consumption when compared to steel, timber, drinking water, and other materials [1]. Similarly, cement has an annual consumption of 0.4 tons per person of the world population. Advancement in research and development has significantly changed from the 19th century to the present scenario. These changes occurred in the design mix methodologies with part replacement of cementitious materials and other than natural aggregates in the aggregate phases in the concrete [2].

These changes have been very significant for sustainable development growth to reduce global warming. This global warming is primarily caused by the carbon-di-oxide (CO<sub>2</sub>) gases released by the industries. In the case of the cement industry, for manufacturing 1 ton of cement, releases 1 ton of CO<sub>2</sub> approximately. Hence, even if we reduce a fraction percentage of cement in concrete, much CO<sub>2</sub> is lessened [3].

In concrete, cement is used as a binder of the aggregates, which forms the composite material [4]. While manufacturing the cement, CO<sub>2</sub> is emitted into the atmosphere. It consists of 9% CO<sub>2</sub> emissions attributed to Portland cement production [5]. The cement industry also releases around 7% of global greenhouse gases (GHGs). Compared to other greenhouse gases, CO<sub>2</sub> represents a more significant

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portion of the energy sector's GHGs. Hence, there is an imperative need in the construction industry to focus on sustainable materials to cater to the exponential growth of the population [6]. Even though concrete has the least embodied energy compared to other engineered materials, its impact on the environment is very high. As a result, CO<sub>2</sub> levels are rising substantially. Hence, the construction industry is responsible for a more considerable amount of release of CO<sub>2</sub>.

In concrete, pozzolanic reactions can reduce the pore space in the interfacial transition zones (I.T.Z.) [7]. Consequently, concrete structures exposed to aggressive environmental conditions are built with newly developed supplementary cementitious materials (S.C.M.) or pozzolana materials [8]. The use of S.C.M.s in concrete manufacturing as a partial replacement for cement is one of the most significant technical developments in the industry. Concrete used a more incredible amount of S.C.M.s as binary, ternary, or quaternary combinations. It is possible to utilize S.C.M.s for both financial and environmental reasons without compromising strength and durable parameters.

Alccofine, a novel superfine slag-based material, has been developed recently. It exhibited higher strength and durability properties than other S.C.M.s used in the construction industry [9]. It has remarkable attributes in the overall potency in fresh and hardened concrete properties. The more refined materials produced from the byproducts of steel or iron industries are known as ultrafine slag materials. Alccofine is one such material that contains up to 6-micron individual particle size. Silicon dioxide (SiO<sub>2</sub>) is a significant constituent contributing to the strength parameters [10]. Even high-performance concrete is

more durable with the addition of Alccofine and other such materials [11]. Due to the pozzolanic action of cement, the addition of Ground granulated blast furnace slag (GGBS), and their micro filler effect, the cement paste matrix demonstrated a less pore structure [12]. It was found that concrete with 88.3% Alccofine and 16.3% FA was more substantial in compressive and flexural tests [13]. Past research demonstrated that the 3-18% of Alccofine as a cement replacement is a higher strength parameter in the relevant concrete grades. Further, 13% Alccofine replacement produced a higher cube strength than the cylinder [14]. Concrete with Alccofine and other Pozzolanic material viz., FA and GGBS. can be used as partially replaced by cement [15]. Alccofine has created enhanced self-compacting concrete properties [16].

Even though the Alccofine cannot contain the binding property, as but consequence of the combination of cement, it has a capacity of excellent bonding property. This property established a significant increment in compressive strength [17].

It is economical to use byproduct waste materials in the construction industry to achieve comparable performance with reducing costs. This alternative material can reduce the need for Portland cement to produce a unit volume of concrete and reduce the enormous deflationary effects of GHG emissions.

By and Large, Alccofine performs more effective SCM than many of the mineral admixtures currently used in India. Alccofine 1203 has more strength gain in the early ages than silica fume. The cement and Alccofine materials are shown in *Figure 1* and *Figure 2*.



**Figure 1** Cement



**Figure 2** Alccofine

## 2.Literature review

Gayathri et al. [18] had investigated the mechanical strength characteristics and durability strength parameters of self-consolidating concrete with 30% GGBS and 0 to 20% as a partial substitute for Alccofine. Combining both materials enhanced the mechanical properties at 10% Alccofine replacement only. The combination of Alccofine and GGBS was investigated in nine different ways to compare the strength and durability parameters. The remarkable strength gains were observed for the variety of 10% Alccofine and 30% GGBS replacement in the designed mix proportions.

Sanjeev et al. [19] probed the M40 grade lightweight concrete properties by replacing coarse aggregate with a coconut shell, and Alccofine replaced cement at 6%, 8%, 10%, and 12%. Various tests were conducted to find the wet density, dry density, and compressive strength. The comparative results show that 30% coconut shell replacing coarse aggregate and 8% Alccofine replacing cement established the best results without compromising the strength loss.

Reddy and Meena [20] substituted Alccofine, FA, and GGBS partially into cement in M30 grade concrete. The Alccofine was replaced at 5%, 10%, 15%, 20%, 25%, and 30% of cement. Similarly, Flyash and G.G.B.S. were introduced with 0-40% cement. The 10% Alccofine along with 25% Flyash is found appropriate combinations. However, favorable results were not noticed from the other combination of A.L. and G.G.B.S.

Chandar et al. [21] have experimentally analyzed the influence of Alccofine on debris/recycled aggregate on mechanical strength properties of reinforced concrete beams. Alccofine partially replaced cement at 5%, 10%, 15%, 20%, and 25%. Similarly, recycled aggregates replaced the natural aggregates by 0%, 30%, 50%, and 100%. The results indicated the compressive strength for both 30% and 50% of recycled aggregate together with 20% Alccofine was achieved equal to normal concrete strengths. The maximum splitting tensile values of concrete made of recycled aggregate was obtained at 20% Alccofine. Also at 30% recycled aggregate along with 20% Alccofine, the maximum flexural strength was obtained.

Asad et al. [22] have examined the inclusion of Perlite along with Alccofine as a fractional substitution in M50 grade concrete. The mechanical strength with of the concrete with varying levels of

Alccofine i.e. 0%, 5%, 10%, 15%, 20%, 25% were added and along with Perlite varying at 0%, 1%, 3% and 5% were inspected at 7 days and as well as 28 days curing period. Concrete strength increased compared to nominal mix concrete up to 15% for Alccofine and 5% for Perlite.

Kaviya et al. [23] experimentally observed the exhibition of Alccofine concrete by partially adding cement at 5%, 10%, 15% for ascertaining both compressive and cylindrical split tensile strengths for 7 days and 28 days. The maximum compressive strength was attained at 15% Alccofine.

Ghising and Kumar [24] experimentally observed the effect of M35 grade concrete mix properties for different curing regime with 0%, 5%, 10%, 15% & 20% Alccofine. The results found that the at 15 % replacement of Alccofine produced the maximum compressive strength, but 10% replacement produced the highest split tensile strength.

Rajesh et al. [25] conducted the tests to explore the high strength concrete (HSC) M60 grade concrete properties with Alccofine at 5%, 10%, 15%, and 20% replacement. It is proposed that at 10% of Alccofine asserted the highest strengths. When the Alccofine replaced the cement beyond 10 %, it acted as a filler material but yields good workability to the concrete.

Narasimha and Ahmed [26] experimentally analyzed the mechanical strength as well as the durability aspects of M30 grade concrete with and without and green Alccofine substitution. Alccofine was added at 10, 20, and 30% by weight of cement content. The concrete mix proportion was designed for a water/cement ratio of 0.45. It was concluded that up to 20% of Alccofine, the three standard strength properties were increasing.

Mathur and Mathur [27] have inspected the M20 grade concrete at 1%, 2%, 3%, 4%, 5%, 10%, and 15%, 20 % Alccofine substitution. The compressive strength for the ages of 3 days, 7days, and 28 days is determined that 10% of partial replacement of cement with the ultrafine slag i.e. Alccofine in M20 grade concrete witnessed a higher compressive strength.

Nainwal et al. [28] addressed the effectiveness of M20 grade concrete with Alccofine as S.C.M. After adding Alccofine equal to 3 % of total cement; the compressive strength was increased. The result showed that the concrete with Alccofine showed a better result than the nominal concrete. The

compressive strength with 3 % Alccofine increased from 19.8 N/mm<sup>2</sup> to 25.8N/mm<sup>2</sup>.

Gupta [29] experimented the effects of partial cement substitution with ultra-fine slag (Alccofine) for the mechanical strength variations of concrete of grade M50 grade. Concrete containing Alccofine was found to have higher fresh concrete properties. 13% of Alccofine was found to enhance concrete's properties. The lowest difference strength parameter was seen after 10% replacement of Alccofine with conventional concrete.

Suganya and Maheshwari [30] have replaced cement with Alccofine for 0%, 5%, 10%, 15%, 20%, and 25% of partial replacement and fine aggregate was replaced with manufactured sand to evaluated the 7, 14, and 28 days compressive strengths. It was found that the optimum level of Alccofine was found at 15%. The highest compressive strength was achieved at 100% replacing manufactured sand and 15% replacing Alccofine in the concrete.

Nishanth and Patil [31] as part of their study, examined different SCGC mix designs based on slag, flyash, and ultrafine slag i.e. Alccofine, and compared their workability as well as strength characteristics. Across all mixes, binder contents were varied between 400-450 kg/m<sup>3</sup>. For each mix, the NaOH concentration was varied between 10, 12, and 14M. The slag based GGBS composed of 60% and low calcium fly ash composed of 35% were used for each mix to make SCGC. In accordance with the recommendations by EFNARC, SCGC's workability was observed by performing the J-ring test, L-Box test, Slump test, V-funnel test, and T50 slump test. With 450 kg/m<sup>3</sup> binder content and 10 Molar NaOH solution, SCGC mix results in a maximum flow rate of 715 mm. As the molarity of the NaOH solution increased, the flow decreased. In a trial containing 16 M NaOH, 100% GGBS, and 500 kg/m<sup>3</sup> binder content, the least flow was measured at 600 mm.

Patil [32] described that the substantial delay due to hand compaction or vibrating of concrete during casting is one of the major reasons for the change in concrete properties. Considering this issue in this study, research was conducted on the development of an SCGC with various industrial by-products such as FA, GGBS, and Alccofine in varying binder percentages of 80:10:10, 65:20:15. This ratio of 65:20:15 performed well for mechanical strength and durability. Due to environmental issues and global warming, research has to be conducted on such

industrial waste products to find ways to repurpose them in environmental-friendly projects.

Harish et al. [33] developed a new material in order to overcome the problems associated with concrete strength. Due to the advent of large construction equipment and plants throughout the world, as well as the enlargement of the use of construction materials, the use of additive mineral by-product admixtures to improve the quality of concrete has grown. Developed through experiments and research is cement-based concrete that has special performance with regards to strength, durability, and adaptability called "High-Performance Concrete (HPC)". With the replacement of cement by Alccofine, strength was observed to increase by 10%. By replacing cement with Alccofine, both normal and high strength concrete experiences an early development of strength.

### **2.1 Significance of the research**

From the above Literature, it was found that various percentage replacements of Alccofine from 3% to 25 % attributed the strength parameters of different concrete mixes from the standard grade concrete to High strength grade mix proportions. Along with the other additives. The Indian standard concrete design mix guidelines (I.S. 10262:2019) recently recommended the partial substitution of cement with GGBS and FA and silica fume materials only. Secondly, but not advocating the usage of the ultra-finer materials like Alccofine. Hence the design mix guidelines were adopted as a trail mix for M20, M30 and M40 concrete grades are proportioned with 5%, 10%, 15%, and 20% replacement of cement with Alccofine to ascertain the strength parameters replaced with cement to find the standard strength properties. The design method is shown in the flow diagram.

## **3. Methodology**

The Alccofine based concrete mix proportions were computed as shown in *Figure 3* with the recommendations of Indian Standard code 10262-2019 version [34].

### **3.1 Cement**

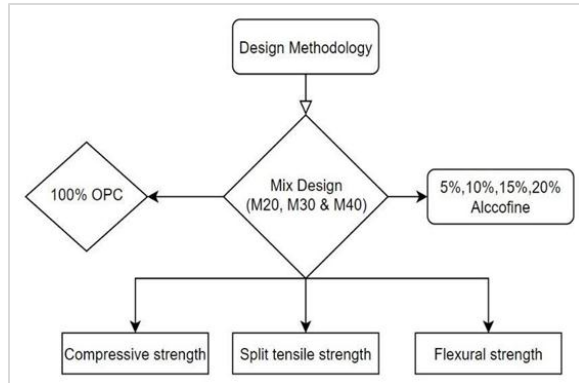
The test properties of Grade 53 Ordinary Portland Cement are shown in *Table 1*.

#### **3.1.1 Fine aggregates**

The Natural sand obtained from the nearby river is tested for the physical properties according to I.S. 2386:1963(Reaffirmed 2002) [35]. The results are



shown in *Table 2* with fineness modulus of 2.77, which signifies the medium grade sand.



**Figure 3** Methodology

**Table 1** Physical properties of cement

S. No.	Features	Values	Units
1	Fineness	310	m <sup>2</sup> /kg
2	Soundness	1.2	mm
3	Specific gravity of cement	3.15	-
4	Standard consistency	33	%
5	Initial setting time	33	minutes
6	Final setting time	600	minutes

**Table 2** Physical properties of fine aggregate

S.No.	Properties	Values	Units
1	Specific gravity	2.65	-
2	Fineness modulus	2.77	-
3	Zone	II	-
4	Bulk density	1652	Kg/cum

### 3.1.2 Coarse aggregate

The coarse aggregate used was machine crushed hard granite 20 mm (MSA). The tested properties as per I.S. 2386:1963 are shown in *Table 3*.

**Table 3** Physical properties of coarse aggregate

S. No.	characteristics	Values	Units
1	Specific gravity	2.85	-
2	Bulk density	1822	Kg/m <sup>3</sup>
3	Fineness modulus	7.1	-
4	Type	Angular	-

### 3.1.3 Alccofine

Alccofine is an ultra-fine slag that is sourced from Ambuja Cement Pvt. Ltd and shown in *Figure 2*. *Table 4* and *Table 5* show the properties of Alccofine. The chemical composition of Cement and Alccofine are depicted in the *Table 5*.

**Table 4** Physical properties of Alccofine

S. No.	Characteristics	Character/ magnitude	Units
1	Pattern	powder	-
2	Odour	odorless	-
3	Colour	Grey	-
4	S.G.	2.86	-
5	Fineness	1200	m <sup>2</sup> /kg
6	Density	2.74	-
7	Bulk density	700	Kg/m <sup>3</sup>

**Table 5** Chemical composition of cement and Alccofine

S. No.	Properties	Cement	Alccofine	Units
1	CaO	64.5	34.4	%
2	SiO <sub>2</sub>	23.6	34.7	%
3	Al <sub>2</sub> O <sub>3</sub>	6.5	22.0	%
4	Fe <sub>2</sub> O <sub>3</sub>	3.8	1.18	%
5	MgO	2.2	6.1	%
6	SO <sub>3</sub>	3.5	1.2	%

### 3.1.4 Superplasticizer (S.P.)

Super Plasticizers are used to increase the concrete rheology characteristics. Fosroc Conplast SP430 is one of such admixtures which is adapted in this research. The dosage quantity of the superplasticizer is calculated with respect to mix design. According to the manufacturer, the superplasticizer provided in the research work has properties which are shown in *Table 6*.

**Table 6** Properties of superplasticizer

S. No.	Property	Character/Limits
1	Colour	Brown viscous liquid
2	Specific gravity	1.20
3	Air entrainment	Less than 2%
4	Chloride content	-

### 3.1.5 Water

Potable water from the University Laboratory is used for casting and curing and its pH value is 6.5.

### 3.2 Mix proportions

IS 10262-2019 guidelines have been adopted to design M20, M30, and M40 grade concretes mix proportions. Alccofine replaces the cement at 5%, 10%, 15%, and 20% weight. The mix proportions for the materials are shown in *Table 7*, *Table 8*, and *Table 9*. After 28 days curing period, the general hardened concrete strength properties have been examined in the lab to find the suitability of the mineral admixture.

**Table 7** Mix proportions of M20 grade concrete/cum

	0%	5%	10%	15%	20%
Cement	345	344	326	308	290
Alccofine	0.0	18.16	36.31	54.47	72.62
Water	148.0	152.	152.0	152.0	152.00
F.A.	750.0	652.2	652.2	652.2	652.27
C.A.	1170.	1322.	1322.	13223	1322.3
SP	3.45	3.63	3.63	3.63	3.63

**Table 8** Mix proportions of M30 grade concrete/cum

	0%	5%	10%	15%	20%
Cement	356.	353	334	316.	297.
Alccofine	0.00	18.60	37.20	55.80	74.40
Water	148.0	152.0	152.0	152.0	152.0
F.A.	759.0	646.0	646.6	646.6	646.6
C.A.	1155	1322	1322	1322	1322
SP	3.60	3.70	3.70	3.70	3.70

**Table 9** Mix proportions of M40 grade concrete /cum

	0%	5%	10%	15%	20%
Cement	367.0	399.0	378.0	357.0	336.0
Alccofine	0.00	21.0	42.0	63.0	84.0
Water	148.0	152.0	152.0	152.0	152.0
F.A.	767.0	646.6	646.6	616.0	646.6
C.A.	1140	1322	1322	1308.	1322
SP	3.7	4.2	34.2	4.2	3.4.2

**3.3 Casting and curing of test specimens**

**3.3.1 Compressive strength**

The fresh concrete properties, including slump values, have been ascertained for the desired workability of the concrete. The digital compressive testing machine (CTM) shown in *Figure 4* was used for compression testing at 7 days and 28 days.



**Figure 4** Compression testing machine (CTM)

**3.3.2 Split tensile strength**

The splitting tensile strength was performed on 150x300mm cylinder specimens. The tests were conducted after 28 days of water curing. *Figure 5* shows the broken cylinder pieces in the machine.



**Figure 5** Split tensile strength testing

### 3.3.3 Flexural strength

Prisms of size 100×100×500mm are tested for flexural strength after 28 days of the curing period. The UTM machine is shown in *Figure 6*.



**Figure 6** Flexural tensile strength testing

## 4. Results

With the due procedure adopted for other supplementary cementing materials in the concrete mix proportions, a similar approach is adopted for mix design of M 20, M 30, and M 40 grades for the 5 to 20 % replacement of Alccofine with cement. The basic hardened strength properties were tested after 28 days of normal water curing. The compressive strength variations are shown in the *Figure 7* to *Figure 9*. Similarly, the split tensile strength variations are shown from *Figure 10* to *Figure 12*. Finally, the changes in flexural strength are shown in *Figure 13* to *Figure 15*. The accepted limits of the strengths are also shown in the respective figure for ascertaining the acceptability criteria in all the results.

Three design mixes comprising M20 grade concrete as ordinary concrete mix and M30 and M40 grade as standard concrete mixes have been proportioned with IS 10262-2019 design guidelines with the acceptable limits of cement content and the water-cement ratios as well as water binder ratios. The proportion mixes are worked out for the max w/c for M20, M30 and M40 grade concrete is 0.46, 0.43, and 0.40, respectively. Similarly, the w/b ratio for M20, M30 and M40 are 0.41, 0.40, and 0.36 respectively.

### 4.1 Compressive strength

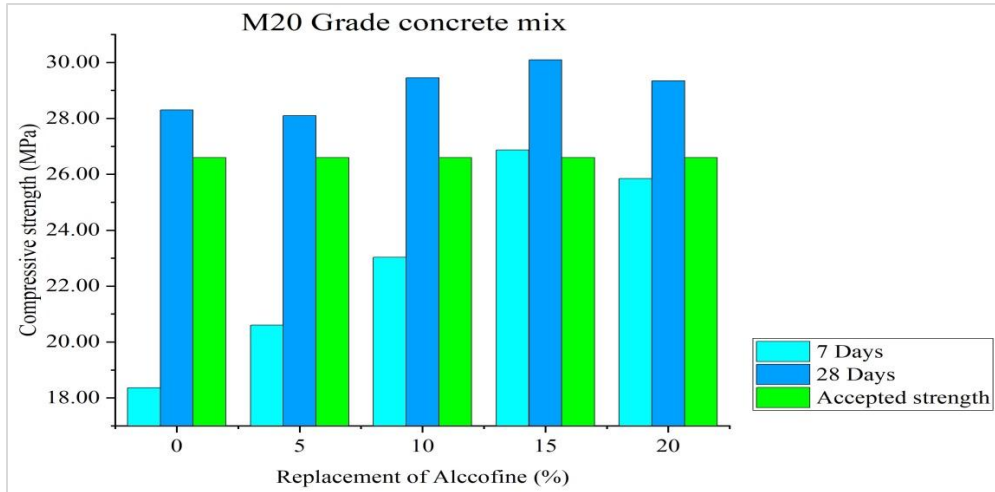
Generally, the acceptance of any design mix is found by the 28-day cube compressive strength of the concrete in the laboratory. However, the seven days compressive strengths were also tested for ascertaining the rate of strength attained during the first seven days. The 7 days compressive strength of M20 grade concrete varies from 18.37 N/mm<sup>2</sup> to 26.87 Mpa up to 15% replacement of Alccofine, but a little decreasing trend after 20% replacement. Similarly, the 28days compressive strength of M20 grade concrete is varied from 28.30 N/mm<sup>2</sup> to 30.10 Mpa up to 15% replacement of Alccofine, but a little decreasing trend after 20% replacement. All the variations are shown in the *Figures 7* to *9*. Similarly, the seven-day compressive strength of M30 grade concrete varies from 24.07 N/mm<sup>2</sup> to 33.57 Mpa up to 15% replacement of Alccofine, but a little decreasing trend after 20% replacement. Similarly, the 28days compressive strength of M30 grade concrete is varied from 39.25 N/mm<sup>2</sup> to 45.40 Mpa up to 15% replacement of Alccofine, but a little decreasing trend after 20% replacement. The seven-day compressive strength of M40 grade concrete varies from 34.70 N/mm<sup>2</sup> to 40.62 Mpa up to 15% replacement of Alccofine but a little decreasing trend after 20% replacement. Similarly, the 28days compressive strength of M40 grade concrete varies from 49.60 N/mm<sup>2</sup> to 57.65 Mpa up to 15% replacement of Alccofine, but a little decreasing trend after 20% replacement

### 4.2 Split tensile strength

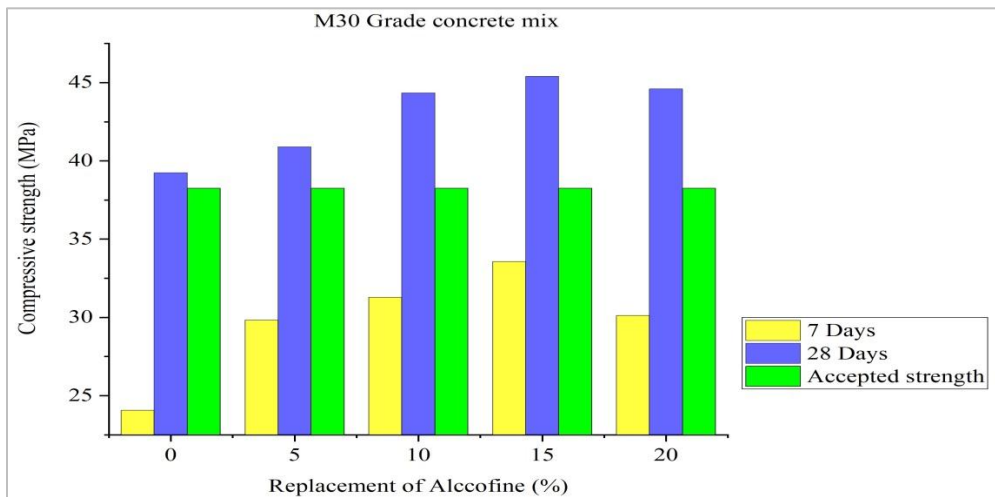
The split tensile strength of M20 grade increased from 4.80 N/mm<sup>2</sup>, to 5.80 N/mm<sup>2</sup> up to 15% Alccofine replacement. The split tensile strength of M30 grade is increased from 5.10 N/mm<sup>2</sup>, to 6.20 N/mm<sup>2</sup> up to 15% Alccofine replacement. The split tensile strength of M40 grade is varied from 5.2 N/mm<sup>2</sup>, to 6.7 N/mm<sup>2</sup> up to 15% Alccofine replacement. The variations are made through *Figures 10* to *12*.

### 4.3 Flexural strength

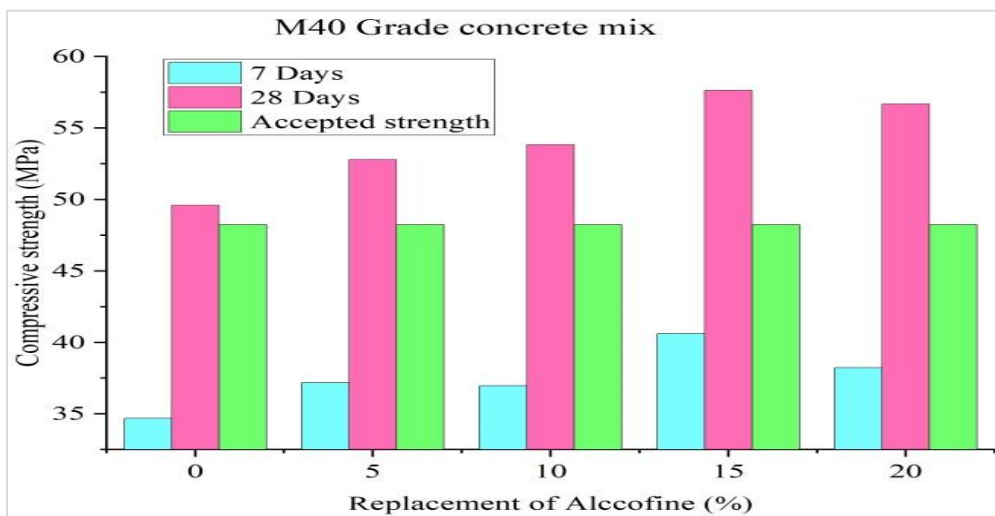
The 28 days flexural tensile strength of M20 grade varied from 3.60 N/mm<sup>2</sup>, to 4.0 N/mm<sup>2</sup> up to 15% Alccofine replacement. Similarly, this strength for M30 grade varied from 3.80 N/mm<sup>2</sup>, to 4.20 N/mm<sup>2</sup>. Finally, in M40 grade concrete it varied from 4.0 N/mm<sup>2</sup>, to 4.50 N/mm<sup>2</sup> up to 15% Alccofine replacement and shown in *Figures 13* to *15*.



**Figure 7** Compressive strength for M20 grade mix



**Figure 8** Compressive strength for M30 grade mix



**Figure 9** Compressive strength for M40 grade mix



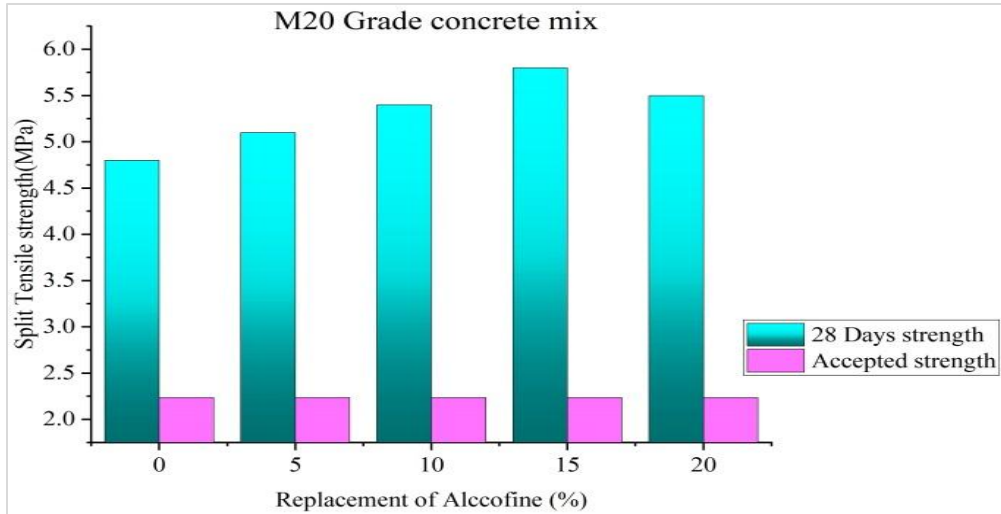


Figure 10 Split tensile strength for M20 grade mix

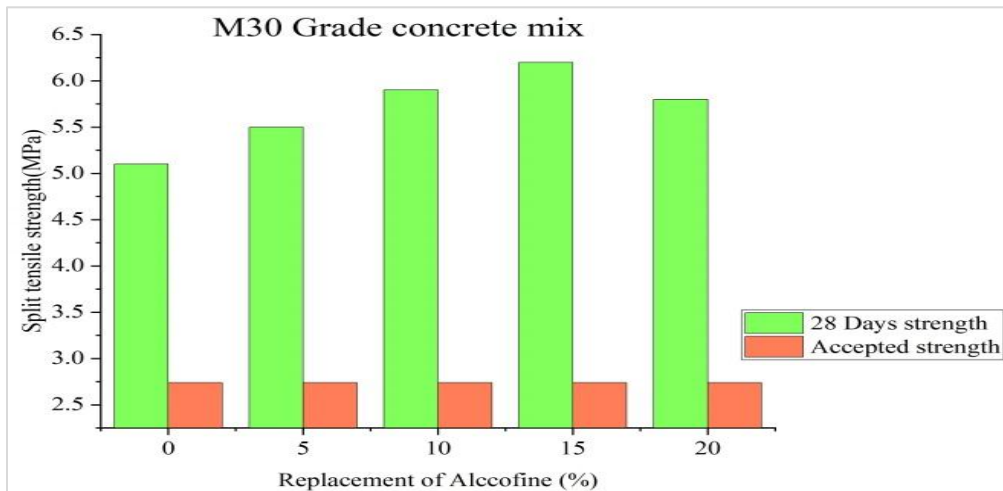


Figure 11 Split tensile strength for M30 grade mix

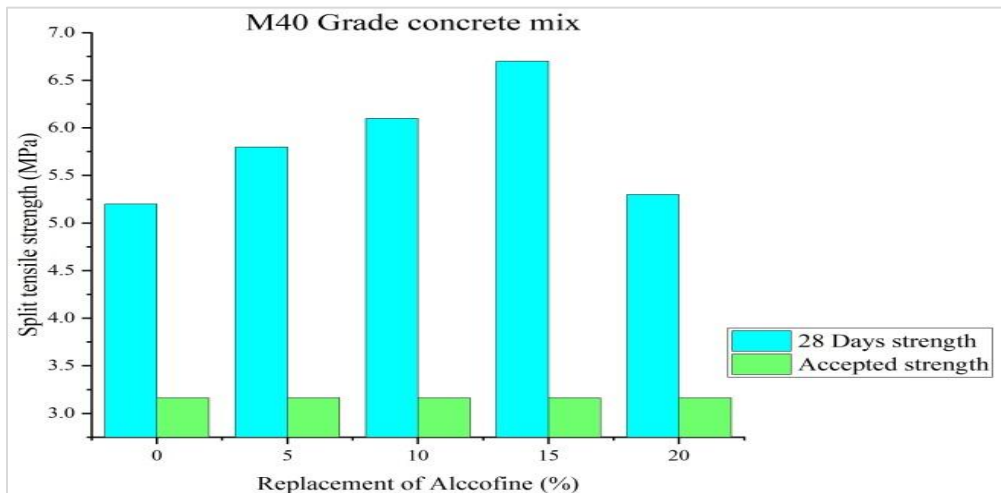


Figure 12 Split tensile strength of M 40 grade mix

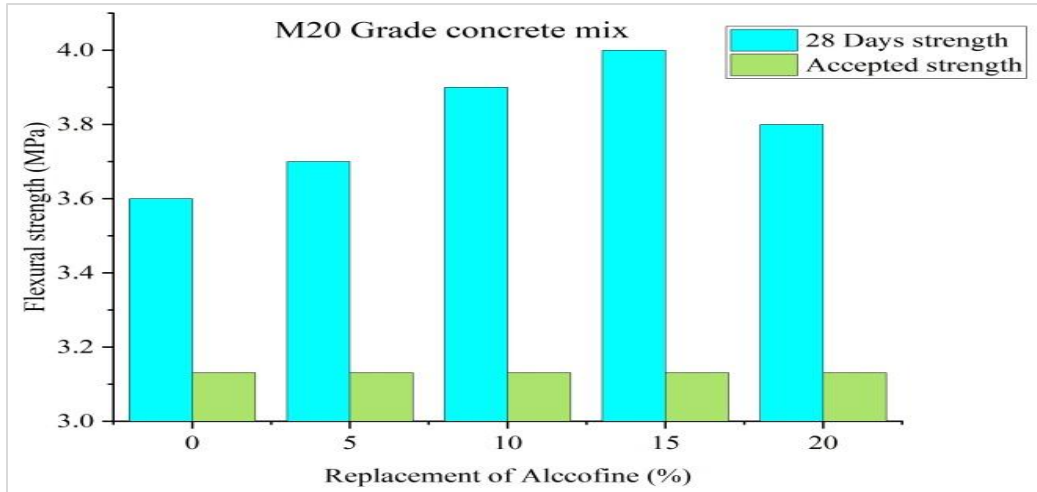


Figure 13 Flexural tensile strength for m20 grade mix

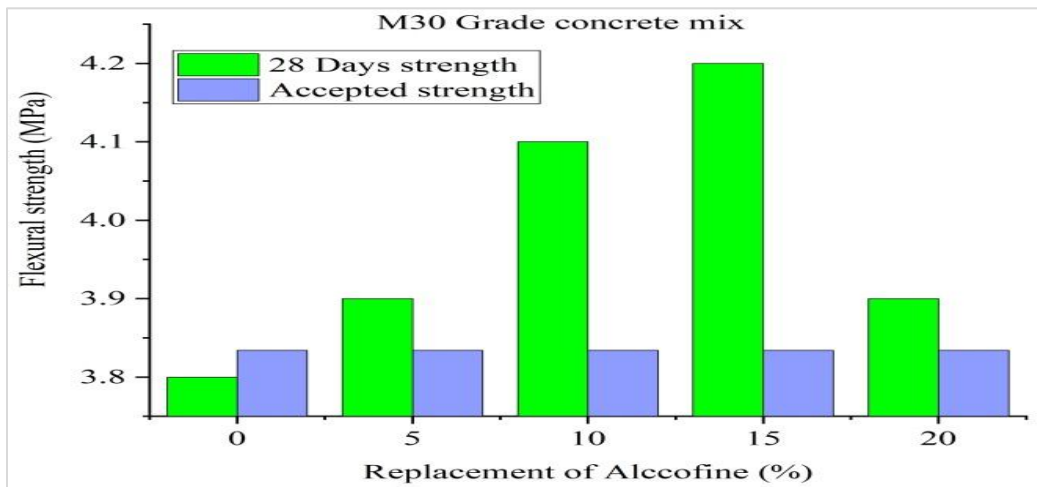


Figure 14 Flexural tensile strength for M30 grade mix

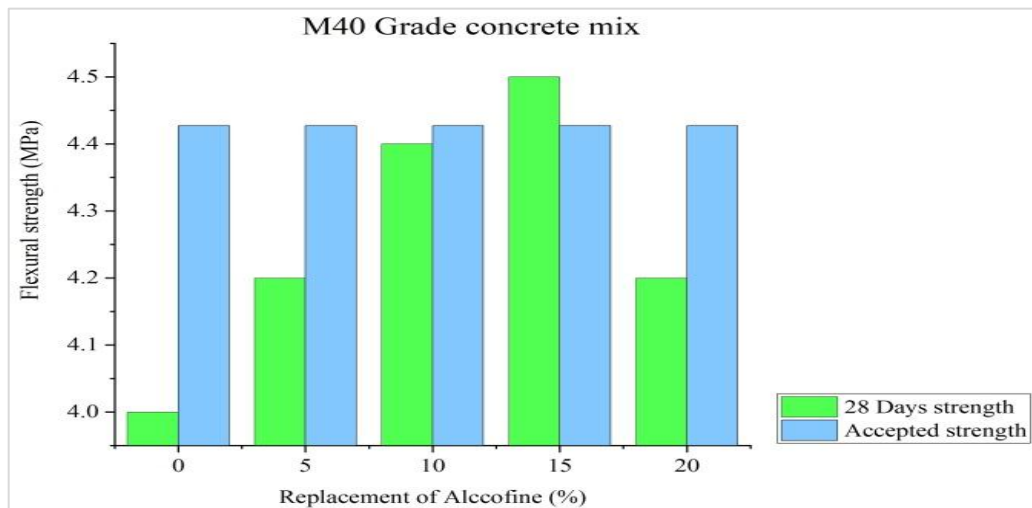


Figure 15 Flexural tensile strength for M40 grade mix

## 5. Discussions of the study

In this part, the discussions of all the strengths viz., Compressive, tensile, and split tensile strengths of all the three grades are discussed as below from the above figures.

**Compressive strength:** generally considered as 28 days curing period, However, the early strength of the concrete is ascertained from the 7 days strength. It is generally 75% of the 28 days strength of the respective grade of the concrete. In the same procedure is adopted for the Alccofine concrete also. It is from *Figure 7* the seven-day strength of the M20 grade is in the range of 18.37 N/mm<sup>2</sup> to 25.85 N/mm<sup>2</sup>. However, the required strength is about  $(75/100) \times 23 = 16.5 \text{ N/mm}^2$ . All the mixes have shown higher results because of the fineness of the Alccofine material. But the increasing trend is slightly diminished between 15% and 20 % of the Alccofine replacement in the mixes. Similarly, the required 28 days strength is 24 N/mm<sup>2</sup>. However, the obtained strengths are 28.35 N/mm<sup>2</sup> to a maximum of 30.10 N/mm<sup>2</sup> at 15% Alccofine replacement. The change of trend is similar to the 7 days strength. Hence from the discussion, it is learnt that the strength gained from the 7 days to 28 days is very nominal in this M 20 grade concrete. In *Figure 8* the strengths of the 7 days and the 28 days for the M30 grade is depicted. The trend from 7 days to 28 days is similar to M20 grade concrete, the strengths were also exhibited more than the required strength (i.e., 75% of 28 days strength). However, they have attained full strength at 28 days curing only. Similar to the above two figures the M40 grade concrete also exhibited a similar trend as shown in *Figure 9*. However, the rate of increase of strengths is a lesser rate when compared to the M20 and M30 grades of the concrete. However, the mixes have attained the required strengths for 7 days and 28 days curing period.

**Split Tensile Strength:** determined for ascertaining the tensile strength of Concrete, Though the concrete is very weak in tensile strength, the addition of Alccofine slightly increases the tensile strengths. For M 20, 30 & 40 grades of concrete, the required split strengths are 3.13, 3.83 and 4.43 N/mm<sup>2</sup> respectively. For M20 grade concrete, the split tensile strength was depicted in *Figure 10*. All mixes have higher strengths, and the maximum value was obtained at the 15% replacement of Alccofine. Similarly, the M30 and M 40 grades also have the corresponding trend which is shown in *Figures 11* and *12*.

**Flexural Tensile Strength:** In contrast to the split tensile strength the obtained flexural strengths have lower values. While calculating the results the experimental formula was used to find the strengths. The values are increasing from 0 to 15% alccofine replacement and decreasing to 20%. A similar trend was obtained for the remaining M 30 and M40 grade mixes also. However, all the grades have similar trends also.

### 5.1 Limitations of the study

Alccofine is a totally new and manufactured material with silicon and lime in almost equal proportions. The suitability of Alccofine must be proved in several aspects to that of cement. The behaviour of Alccofine in concrete is yet to be studied for various parameters of concrete-like strength, durability, creep, shrinkage, flexure, permeability. Sufficient studies on the microstructure of Alccofine concrete are not available to explain the behaviour. Systematic operating procedures for mixing, testing and interpretation of results must be established. Indian Standard Code for this concrete has not yet been formulated. Adequate studies of properties like workability, water absorption etc., were found very scanty.

A complete list of abbreviations is shown in *Appendix I*.

## 6. Conclusion and future work

Even though the IS 10262-2019 code explicitly does not recommend the Alccofine as a partial replacement of cement in concrete mix proportions, the instructed guidelines are similar to other Supplementary cementitious materials viz., GGBS, FA is adopted in Alccofine replacement concrete mixes also. With the above procedure, the following conclusions have been drawn for asserting the suitability of the Alccofine in the concrete mixes. The 28 days compressive strength benchmark criteria satisfied the acceptance criteria laid down in IS 456-2000 code requirement.

The seven-day compressive strengths for all the three-grade concrete mixes have gained more than 70% of the 28-day compressive strength. The 28 days strengths have also achieved the respective target mean strengths of M20, M30, and M40 grades. The split tensile strength is the direct tensile strength generally used for the deformation characteristics of concrete, but the closed-form solution was not recommended in IS 456-2000 code. Hence ACI 381-2019 code formula was adopted. With this formula,

0.5√ft. All the concrete mixes were satisfied with the procedure. Similar to compressive strength, 15 % replacement shows a higher value. The flexural strength of the 100x100x500mm prisms was tested for all mixes with all percentages of replacements. The tested results were compared with the code recommended equation of IS456-2000. The tested values satisfied the code recommendations.

The 15% Alccofine replacement concrete shows a higher value when compared to other replacements of Alccofine. 15% replacement of Alccofine has shown the higher strengths in all the three-grades of concrete. More particularly, the 7-day compressive strength of M20 grade for 15% replacement of Alccofine achieved the 28 days strength. This 15 % replacement was the optimum dosage of Alccofine replacement for the hydration process and strength gain satisfying the codal provisions. However, the partial replacements of 10 and 20 % act as filler material in the bonding phase in the concrete. All the above results pertain to ordinary Portland cement with severe exposure conditions only.

- The optimum % level of Alccofine can be considered to experiment on concrete subjected to elevated temperatures.
- Microstructural analysis can be carried for each grade of Alccofine concrete compared to nominal mix.
- Various durability and NDT tests can be conducted on various grades of Alccofine concrete compared to nominal concrete.
- Reinforced concrete beams and columns can be cast made of Alccofine concrete and can be studied for various strength characteristics.

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#### Conflicts of interest

The authors have no conflicts of interest to declare.

#### Author contribution statement

**BLN Sai Srinath:** Data collection, conceptualization, writing – original draft. **Chandan Kumar Patnaikuni:** overall review and supervision. **Santhosh Kumar B:** Investigation on challenges and draft manuscript preparation. **Balaji K.V.G.D:** Analysis and interpretation of results. **Kode Venkata Ramesh:** Data interpretation.

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### Appendix I

S. No.	Abbreviations	Description	
1	Al	Alccofine	
2	Al <sub>2</sub> O <sub>3</sub>	Aluminium Oxide	
3	CaO	Calcium Oxide	
4	C.A.	Coarse Aggregate	
5	CO <sub>2</sub>	Carbon-di-Oxide	
6	CTM	Compression Testing Machine	
7	FA	Fly Ash	
8	Fe <sub>2</sub> O <sub>3</sub>	Ferric Oxide	
9	GGBS	Ground Granulated Blast Slag	
10	GHG	Green House Gases	
11	HSC	High Strength Concrete	
12	M20	M20 Grade Concrete Mix	
13	M30	M30 Grade Concrete Mix	
14	M35	M35 Grade Concrete Mix	
15	M40	M40 Grade Concrete Mix	
16	M50	M50 Grade Concrete Mix	
17	MgO	Magnesium Oxide	
18	MSA	Maximum Size of Aggregate	
19	NDT	Non Destructive Tests	
20	SCGC	Self-Consolidating Concrete	Geopolymer
21	SCM	Supplementary Materials	Cementitious
22	SiO <sub>2</sub>	Silicon Dioxide	
23	SO <sub>3</sub>	Sulphur Trioxide	
24	S.P	Super Plasticizer	
25	pH	Potential of Hydrogen	
26	UTM	Universal Testing Machine	
27	IS 2389		
28	IS 10262	Indian Standard Codes	
29	IS 456		
30	IS 516		