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Strength enhancement of concrete incorporating alccofine and SNF based admixture

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Abstract. Cement is the most significant component in concrete. Large scale manufacturing of cement consumes more energy and release harmful products (Carbon dioxide) into the atmosphere that adversely affect the environment and depletes the natural resources. A lot of research is going on in globally concentrating on the recycling and reuse of waste materials from many industries. A major share of research is focused on finding cementitious materials alternatives to ordinary Portland cement. Many industrial waste by-products such as quartz powder, metakaolin, ground granulated blast furnace slag, silica fume, and fly ash etc. are under investigations for replacement of cement in concrete to minimize greenhouse gases and improve the sustainable construction. In current research, the effects of a new generation, ultra-fine material i.e., alccofine which is obtained from ground granulated blast furnace slag are studied as partial replacement by 25% and with varying amounts of sulfonated naphthalene formaldehyde (i.e., 0.3%, 0.35% and 0.40%) on mechanical, water absorption, thermal and microstructural properties of concrete. The results showed moderate improvement in all concrete properties. Addition of SNF with combination of alccofine showed a significant enhancement in fresh, hardened properties and water absorption test as well as thermal and microstructural properties of concrete.

Keywords: alccofine; mechanical properties; thermogravimetric analysis; microanalysis properties

1. Introduction

Ordinary Portland Cement (OPC) is one of the most commonly used building materials globally. The Portland cement production process consumes a significant amount of heat energy and releases a huge amount of carbon dioxide (CO_2) into the atmosphere which further has severe environmental effects (Gopalakrishnan *et al.* 2011). Portland cement production has been reported to be liable for about 3% and 9% of worldwide energy consumption and anthropogenic emission of carbon dioxide, respectively (Worrell *et al.* 2001). Therefore, nowadays more and more interest has drawn to reduce carbon footprints because of cement production and many efforts have been carried out. With the rapid growth in the industrial as well as infrastructural development to cater the needs of ever increasing population, there is an ardent need to focus on sustainable construction materials in construction industries. Earlier practices were to partially replace the ordinary Portland cement with some suitable industrial and agro waste materials such as fly ash, rice husk ash, ground granulated blast furnace slag which are pozzolanic in nature (Noushini *et al.* 2016). As their primary role, slags or Pozzolans are added to cement because they improve properties (durability and mechanical) of concrete as well as concrete structures.

The most significant impacts of pozzolans in the microstructure of concrete or cement paste are changing the interfacial transition zone (ITZ) and reduction of pore structure by pozzolanic reaction (Li *et al.* 2007). The application of newly developed supplementary cementitious materials, nanomaterials or pozzolans has thus become a necessity to improve the strength as well as durability properties of concrete structures, particularly under aggressive environmental conditions (Jindal 2019).

Alccofine is a new generation, ultra-fine supplementary cementitious material (SCM) having ultrafine particle size with specially controlled granulation which has shown significantly better enhancement in the strength as well as durability properties even better than with other SCM's like cement, fly ash, rice husk ash etc., which are generally adopted by construction industry. Alccofine has surprising effects to improve the overall performance of concrete in fresh and hardened states. Alccofine is an ultrafine slag material and glass based SCM obtained from steel or iron industries. Alccofine is one amongst the mineral admixtures of very finely solid glass spheres of non-crystalline polymorph or amorphous of silicon-dioxide. The higher specific surface area of alccofine particles has greater effect on both fresh and hardened state properties of concrete.

Jindal *et al.* (2017a) investigated that alccofine considerably enhances the compressive strength and also

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Table 1 Physical properties of cement

Characteristics	Test Results	Requirements as per BIS:8112
Grade	43	43
Specific gravity	3.10	-
Specific surface area [m^2/kg]	290	225
Standard consistency	30%	-
Initial setting time	94 min	>30 min
Final setting time	280 min	<300 min

Table 2 Chemical properties of cement

Oxide	Percentage
CaO	60.41
SiO_2	20.27
Al_2O_3	5.32
Fe_2O_3	3.56
SO_3	3.17
MgO	2.46
Loss on Ignition	3.55

Table 3 Physical properties of AL-1203

Characteristics	Test Results
Specific gravity	2.90
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

increases the workability of geopolymer concrete (GPC) at ambient temperatures as well as heat curing regime. Sulfonated naphthalene formaldehyde condensates (SNFC) also known as polynapthalene sulphonates (PNS), were first introduced in the year 1930s and initially used in textiles industry and the synthetic rubber development (Aitcin and Flatt 2015). SNFs were used in the construction as concrete admixtures in Japan in late 1960s as the first synthesized high range water reducing admixtures generally known superplasticizers. The plasticizing effect of high range water reducer is depending on the cement grain dispersion. The negatively charged superplasticizer molecules are adsorbed on the positively charged molecules of the cement grains. The electrostatic repulsion between the cement grains (due to negatively charged on surfaces) lower the internal friction in the fresh state of concrete and improves the workability of the concrete.

The main intention of the current study is to evaluate the effect of inclusion of alccofine at a percentage of 25% and various percentages (0.3%, 0.35% and 0.4%) of SNF on the workability in terms of compaction factor value, strength properties (compressive strength, split tensile strength and modulus of rupture), water absorption test, thermal (in terms of thermogravimetric analysis) and microstructural properties (scanning electronic microscopic analysis) of concrete. In this study, an effort has been made to improve the fresh and mechanical properties of concrete with alccofine and SNF based admixture. Water absorption test was performed at 28 days to evaluate percentage of water absorption on cube specimens in accordance with ASTM C642 (ASTM 2013). Also the behavior of concrete under the heating temperature ranging from 24 to 800°C is studied with the help of thermogravimetric analysis. Scanning electron microscopy (SEM) was also performed to study the micro structure of concrete with addition of alccofine and SNF based admixture.

2. Research significance

Ordinary Portland Concrete is a major component in conventional concrete to attain the strength properties. With the emergence of industrialization, industrial solid waste generation had increased in huge amount and the industries are facing difficulty in dumping and disposal of the solid waste generated. Non-engineered industrial waste disposal impacts the atmosphere, which in turns damages the environment. A lot of research is being performed to identify the ways to utilize the industrial solid waste in the construction industry. From the available research, it can be concluded that the industrial solid waste with pozzolanic nature can be used as a supplementary cementitious material. Efforts are being made to reduce the usage of cement by encouraging the use of industrial waste or by-products as admixtures or as a partial replacement of cement. There is no literature available investigating the effects of inclusion of alccofine along with SNF based admixture in concrete and therefore it encouraged the authors to study the effects on various properties of alccofine concrete with the addition of SNF based admixtures. In the current research, an effort has been made to study the effects of alccofine with the addition of Sulfonated naphthalene formaldehyde (SNF) on the mechanical properties, water absorption and thermal properties of concrete so that their scope to address environmental pollution induced by industrial by-products.

3. Materials

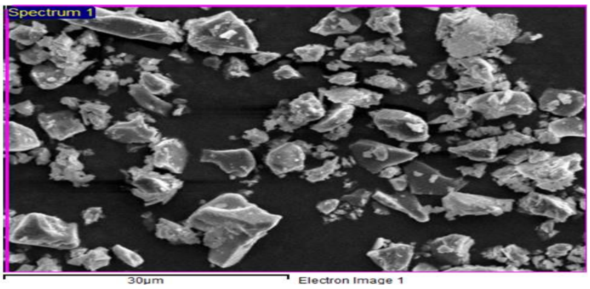
In this study Ordinary Portland cement (OPC) 43 grade is used as a binder. The coarse aggregate and fine aggregate are used as filler materials along with superplasticizers (i.e., Sulfonated naphthalene formaldehyde). OPC is tested as per Indian Specifications BIS 8112 (BIS 2013). The physical and chemical properties of cement are given in Tables 1-2.

The fine and coarse aggregates are tested as per Indian Specifications BIS 383 (BIS 1970). The coarse aggregates of 20 mm downgrade and fine aggregates 4.75 mm downgraded have been used. Alccofine (AL-1203) was obtained from Ambuja Cement Ltd, Goa having the specific gravity of 2.9 confirming to ASTM C989 (ASTM 1999) was used in entire study. The physical and chemical properties of AL-1203 are given in Tables 3-4, respectively.

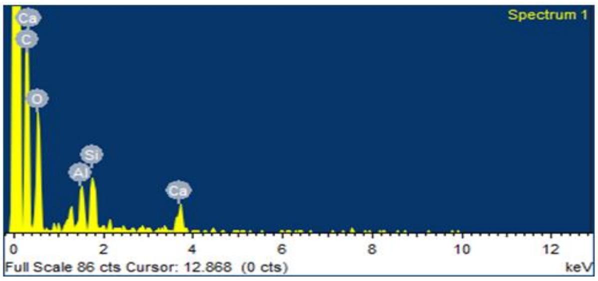
The EDX and SEM analysis of alccofine was performed at 20 keV. From Fig. 1(a) it can be seen that alccofine particles are in angular or irregular shape and size of the

Table 4 Chemical properties of AL-1203 from EDA

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



(a)



(b)

Fig. 1 Microstructural analysis of alccofine using (a) SEM (b) EDX

particles are less than 30µm. Fig. 1(b) shows that AL-1203 consists of Ca K (Wollastonite), Si K (SiO_2), Al K (Al_2O_3), O K (SiO_2), C K ($CaCO_3$) elements with atomic % of 3.27, 3.44, 2.25, 33.39, 57.64 and weight % of 8.66, 6.38, 4.01, 35.26, 45.69 respectively.

In the current research, superplasticizer i.e., Buildplast Super-HR composed primarily of Sulfonated Naphthalene Formaldehyde conforming to ASTM C494 (ASTM 2017) Type F is used. The properties of Buildplast Super-HR are shown in Table 5.

4. Fabrication of concrete

The concrete mix has been designed and prepared in accordance to guidelines laid down in BIS 10262 (BIS

Table 5 Various properties of Buildplast Super-HR (SNF)

Aspect	Relative density	pH	Chloride ion content
Dark brown	1.20	> 6	< 0.2%

2009). The concrete is drenched into steel moulds and left to harden. After 24 hours these cubes are exiled from the moulds for curing. A total of five altered mixes with and without a constant amount of alccofine with varying dosages of SNF at different water-cement ratio have been prepared. Control Mix (NC) i.e., Mix 1, does not contain any amount of alccofine and SNF at water to binder ratio is 0.45. Mix 2 was prepared by replacing 25% of cement content with alccofine without any amount of SNF. Further mixes Mix 3 to Mix 5 were prepared by keeping alccofine as 25% of cement as in Mix 2 with varying dosages of SNF (0.3%, 0.35% and 0.4%) by weight of binder (OPC). In all the mixes the water-binder ratio is kept 0.45. The concrete mix proportion details are given in Table 6.

5. Test methods

5.1 Workability of concrete

The effort required to work with concrete is termed as workability of concrete, i.e., if concrete is handled without segregation and without loss of homogeneity; it is known to be workable. It is the property of freshly mixed concrete. In this investigation, concrete is tested for workability before casting. The compaction factor test was conducted to evaluate the workability of concrete as per BIS 1199 (BIS 1959).

5.2 Mechanical properties

The compressive strength test has been performed in a compression testing machine of 2000 kN capacity as per BIS 516 (BIS 1959), for control and reference concrete cubes with addition of SNF in different proportions with a curing period of 3, 7, 28 and 90 days.

Split tensile strength tests were carried out on cylinder specimens of size 150 mm×300 mm as per BIS 5816 (BIS 1999) at 7 and 28 days. The cylindrical specimen was placed longitudinal to the CTM surfaces and the load was applied until the failure occurred along the vertical diameter of the cylinder. The tensile strength of the cylindrical specimens was calculated. Modulus of rupture tests of control and alccofine concrete with addition of SNF in different proportions are found by testing concrete beams of

Table 6 Details of concrete mix proportions per cubic meter of concrete

Mix No	Mix Designation	Cement (kg)	Alccofine (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	W/B Ratio	SNF (%)
Mix 1	NC	438.13	0	614.59	1162.53	0.45	Nil
Mix 2	AM	328.59	109.53	614.59	1162.53	0.45	Nil
Mix 3	AM + 0.30% SNF	328.59	109.53	614.59	1162.53	0.45	0.30
Mix 4	AM + 0.35% SNF	328.59	109.53	614.59	1162.53	0.45	0.35
Mix 5	AM + 0.40% SNF	328.59	109.53	614.59	1162.53	0.45	0.40

size 500 mm×100 mm×100 mm and testing was done by using two-point loading as per BIS 516 (BIS 1959). The testing has been done at an age of 7 and 28 days of curing samples.

5.3 Water absorption

Measurement of water absorption test on cube sample of size 150 mm was carried out at 28 days in accordance with ASTM C642 (ASTM 2013). Initially, the cube specimens had been placed in an oven at a temperature of 105^{0}C for 24 hours. Later, the specimens were taken out from the oven, cooled and were weighted (B). The specimens were immersed in water for two days and weighted (A). The water absorption value of the cube specimen was determined as per Eq. (1) below.

$$\text{Water absorption (\%)} = \frac{A-B}{B} \qquad (1)$$

Where A=Saturated surface dry weight of specimens (grams) and B=Oven dry weight of specimens (grams).

5.4 Electrical resistivity of concrete

Electrical resistivity (ρ) of a material is characterized as its ability to withstand the exchange of ions exposed to an electrical field. It is generally reliant on the microstructure properties of concrete such as pore size and state of the interconnections. Leader RCONTM Concrete Electrical Resistivity Meter has been used to measure the electrical resistance of concrete as per standards guidelines in ASTM C1202 (ASTM 2019). The test was performed on 100 mm size cubical specimens at one pre-determined position on each specimen for reference concrete with and without addition of sodium nitrite at a curing period of 28 days. The electrical resistivity of concrete cubes is expressed as follows

$$\rho = \frac{RA}{L} \qquad (2)$$

Where ρ is electrical resistivity (unit: Ω-m), R is electrical resistance (unit: Ω), L is electrical path length in the specimen (unit: m), and A is the cross-sectional area of the specimen (unit: m^2)

5.5 Thermogravimetric analysis

For TGA analysis, the samples were grounded and sieved through 63 micron sieve. Using acetone, the solvent exchange technique was adopted to remove bound water and to stop the hydration 30 g of the sieved sample with 100 ml of acetone in a bottle was mixed by hand for about 3 minutes. Excess acetone has been drained and the process has been repeated. At 40°C temperature, the samples were dried for 12 hours in oven. Dried samples have been collected and stored in plastic bottles with proper sealed container until the test time. Total ten samples were examined. Small quantities of samples were taken out from concrete cube and heat was applied from 24°C to 800°C in a thermal analyzer with heating rate by 10°C/min. From the experiment, weight decrease corresponding to increasing temperature and also decomposition of hydrates like C-A-S-H, Calcite, Ca $(OH)_2$ and Calcium silicate hydrate were obtained.

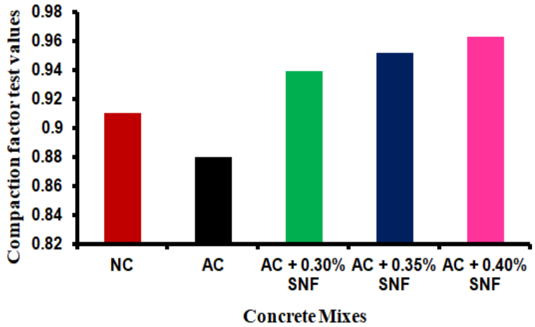


Fig. 2 Compaction factor values with different mixes

5.6 Scanning electronic microscope analysis

The microstructural property of hardened concrete was determined by SEM analysis. A small portion (5 mm) was taken out from concrete samples for SEM analysis.

6. Results and discussion

6.1 Workability of concrete

The results obtained from compaction factor testing on concrete are shown in Fig. 2. It can be clearly visualized from Fig. 2 that the workability of concrete is greatly influenced by the addition of alccofine and SNF. The value of compacting factor for normal concrete mix (NC) is the lowest, indicating the low workability at constant replacement of alccofine. Since alccofine is much finer than cement, it increases the water demand for workable mix (Ghugal *et al.* 2017). The enhancement of SNF dosage would be effective in improving the workability due to the addition of SNF can induce greater physico- chemical surface interactions through electrostatic interactions (Aitcin *et al.* 2001). From Fig. 2, it can be seen that with the addition of SNF into the concrete mix the workability is improved by 6.7%, 8.1% and 9.43% compared to alccofine added concrete. Beyond the optimum dosage of SNF (i.e., 0.4%) quantity, concrete may get the bleeding as well as segregation.

6.2 Compressive strength

It is noticed that a minor improvement in compressive strength is achieved with alccofine (i.e., 25% cement replacement) at all ages are shown in Fig. 3. The compressive strength is further enhanced significantly with SNF, which is attributed to the reason that the concrete matrix gets densified due to the plugging of pores by alccofine particles (Jamkar *et al.* 2013). The compressive strength of mixture containing 0.3% and 0.35% SNF is increased by 19.29%, 32.18%, 4.44%,3.74% and 46.63%, 43.20%, 10.31%, 12.366%, for the ages of 3,7,28 and 90 days, respectively, in comparison to the mix containing

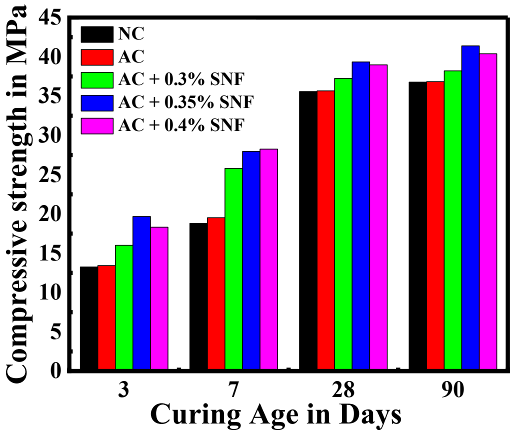


Fig. 3 Compressive strength variation of different mixes with age

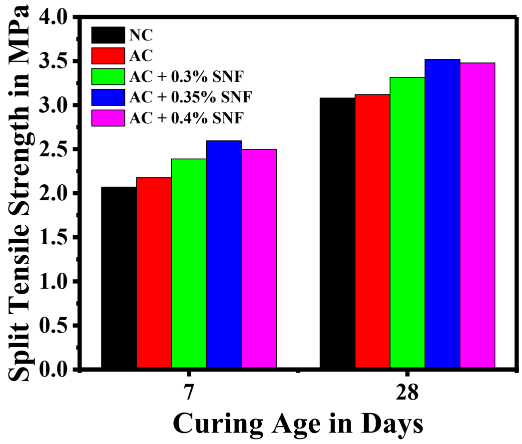


Fig. 4 Split tensile strength variation of concrete mixes

alccofine (AC) only. However, the compressive strength increased in the ranges of 36.43%-9.63% on the addition of 0.4% SNF. The enhancement in the initial ages (3 and 7 days) compressive strength of alccofine added concrete is due to accelerated hydration reaction in concrete on the addition of SNF (Jangra *et al.* 2018, Li *et al.* 2007). SNF mainly forms polymer chains with attached Sulphonate groups (SO_3^-) ions adsorbed onto the surface of cement particles, producing negatively charged particles, and hence the dispersing of particles occurs by electrostatic repulsion between cement and alccofine particles (Aitcin *et al.* 2001). The better dispersion of alccofine and cement particles show enhanced compressive strength. The enhancement of compressive strength continued till the SNF concentration increased up to 0.35% and reduces slightly at 0.4%. The reason for the decrease in compressive strength is observed to be the bleeding and segregation happened at higher dosages of SNF. The later age (i.e., 90 days) compressive strength showed a negligible change for 28 days compressive strength which is because of accelerated heat of hydration process, moreover, the addition of alccofine is responsible for the development of denser microstructure. It is also noticed that most of the hydration process gets completed at 28 days which becomes very slow and will continue over time, thus showing minimum variations in compressive strengths at a curing period of 90 days (Granizo *et al.* 2002, Yip *et al.* 2008).

6.3 Split tensile strength

The shrinkage and thermal stresses results in the development of tension in concrete due to which early age cracking happens. Generally, these stresses are more than concrete's tensile strength which is very low at initial ages. Therefore, it's very much essential to evaluate the tensile strength of concrete (Aitcin *et al.* 2001). Split tensile strength of cylindrical specimens were recorded at 7 and 28 days for 0.45 *W/B* ratio as shown in Fig. 4. From the results, it is clearly observed that the alccofine added concrete mixes with SNF showed higher tensile strength values than the normal concrete. The early age (7th day) split tensile strength of mixes AC, AC+0.3%SNF, AC+0.35%SNF and AC+0.4%SNF improved by 5.169%, 15.410%, 25.362% and 20.676% respectively, in comparison to normal concrete. At 28th day, tensile strength of concrete mixtures AC, AC+0.3%SNF, AC+0.35%SNF and AC+0.4%SNF was enhanced by 1.29%, 7.66%, 14.25% and 12.92% respectively with comparison to normal concrete. The interfacial transition zone (ITZ) plays an important role in the advancement of tensile strength (Said *et al.* 2012). The ITZ become denser leading in an enhancement of the tensile strength of concrete due to better dispersion of alccofine and cement particles when combined with SNF. It was also noted that the tensile strength of alccofine concrete samples was enhanced with addition of SNF dosage up to 0.35% and declined slightly on increasing the SNF content. The decrease in split tensile strength with greater than 0.35% SNF addition is attributed to the reason that the concrete may get segregation and bleeding that leads to decrease in strength.

6.4 Modulus of rupture

Fig. 5 shows the modulus of rupture test results at 7 and 28 days. It is noticed that there is a slight enhancement in modulus of rupture with the addition of constant dosage of alccofine, like compressive strength and split tensile strength results similar pattern was followed by the modulus of rupture. There is a noticeable development in modulus of rupture results of concrete together with alccofine and SNF. The enhancement of strength is due to plugging of pores with alccofine combination of SNF in concrete matrix. The early age (7 days) modulus of rupture of concrete mixes AC, AC+0.3%SNF, AC+0.35%SNF and AC+0.4%SNF was increased by 2.01%, 15.88%, 24% and 20.89% respectively, in comparison to normal concrete mix. At 28 days, the modulus of rupture for AC, AC+0.3%SNF, AC+0.35%SNF and AC+0.4%SNF mixes improved by 1.37%, 6.29%, 10.51% and 8.34% to normal concrete, respectively. It was also noted that the modulus of rupture of alccofine concrete samples was enhanced when addition of SNF dosage up to 0.35% and declined slightly on increasing the SNF content (Chithra *et al.* 2016). The decrease in modulus of rupture with greater than 0.35% SNF addition is attributed to the reason that the concrete may get segregation and bleeding

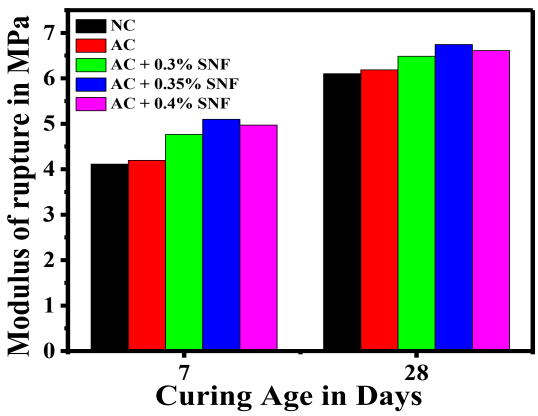


Fig. 5 Modulus of rupture values of concrete mixes

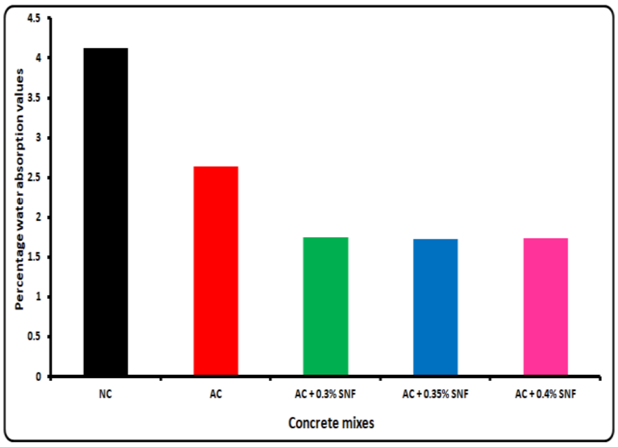


Fig. 6 Water absorption test results different concrete mixes

that leads to decrease in strength.

6.5 Water absorption

Water absorption test is one of the most important parameters for finding the durability index property of concrete. The penetration of ions, water and gases depend on the porosity and microstructure of concrete. From Fig. 6, it can be seen that normal concrete had high water absorption values than that of alccofine added concrete. The mixes with constant alccofine quantity and varying dosage of SNF i.e., AC, AC+0.3%SNF, AC+0.35%SNF and AC+0.4%SNF showed decrease in water absorption percentage values of 2.64%, 1.745%, 1.326% and 1.739%, respectively, with respect to the normal concrete mix at 28th day. From the results, alccofine added concrete mixture showed low water absorption values due to high surface area of alccofine particles which settled in micro spaces in concrete (Reddy 2019). The reason behind that with addition of alccofine and SNF showed better homogeneity in concrete, it helps to improved pore microstructure and also reduce the water absorption values. The reduction in water absorption can be related to the durability of concrete which was illustrated in our earlier investigations (Jindal *et al.* 2017b). So, in may be concluded that with the addition of alccofine and SNF the durability of concrete can be perceived as improved.

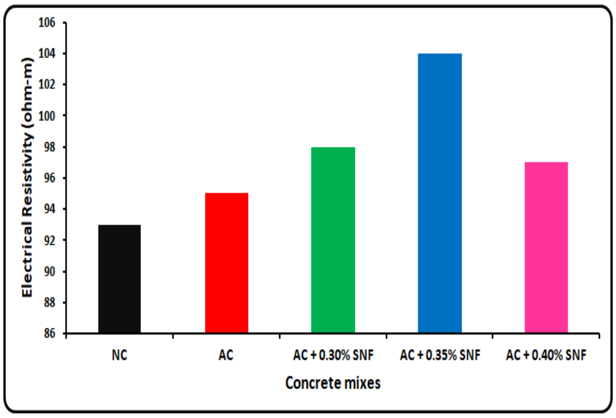


Fig. 7 Graphical representation of electrical resistivity of early strength concrete mixes

6.6 Electrical resistivity of concrete

Fig. 7 shows electrical resistivity results of normal concrete, alccofine added concrete with and without SNF. The mixes with constant alccofine quantity and varying dosage of SNF i.e., AC, AC+0.3%SNF, AC+0.35%SNF and AC+0.4%SNF showed increase in electrical resistivity values of 2.15%, 5.37%, 11.82% and 4.30% respectively with respect to the normal concrete mix at 28th day. It is noticed that concrete cubes with the addition of alccofine (25% by mass) and 0.35% of SNF had high electrical resistivity. It was also noticed that the resistance increases with proportion to increase in SNF up to 0.35%. Alccofine react with cement in the presence of SNF to form additional CSH and ettringite formation in the pores of the concrete and that leads to dense structure formation in the concrete. The reduction in electrical resistivity of concrete at higher dosages of SNF is due to bleeding and segregation.

6.7 Thermogravimetric analysis

The TGA analysis has shown that considerable weight losses occur in many ways. The first effect from 24°C to 100°C was the residual pore water that evaporated from capillary pores (Alessandra *et al.* 2006). At this stage, the weight reduction relied on capillary pores, interlayer water and adsorbed water. Dehydration of C-A-S-H, ettringite and calcium silicate hydrates was occurred at second effect the temperature ranges from 101°C and 460°C. Decomposition of calcium hydroxide was occurred in third effect at 470-760°C during hydration is shown in Eq. (3).

$$Ca(OH)_2 \rightarrow CaO + H_2O \quad (3)$$

At 800°C, the last effect can be attributed to calcium carbonate ($CaCO_3$) decarbonization as shown in Eqs. (4)-(5).

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (4)$$

$$CaCO_3 \rightarrow CaO + CO_2 \quad (5)$$

The hydration compounds decomposition within a temperature range of 24-800°C as shown in Fig. 8. From Fig. 9 shows the weight loss of normal concrete, alccofine

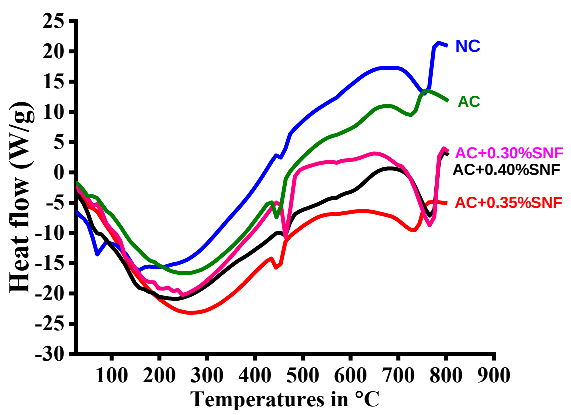


Fig. 8 Differential scanning calorimetry curves of concrete

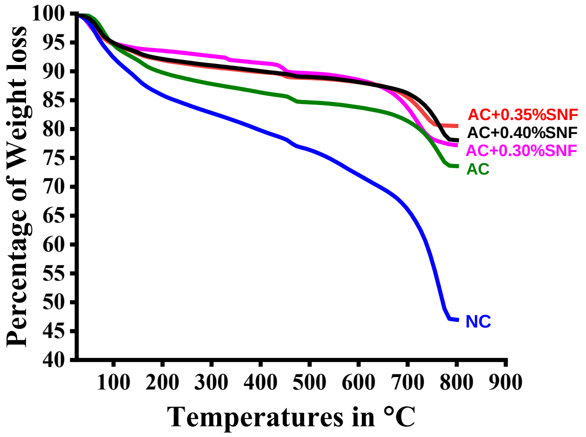


Fig. 9 Percentage of weight loss curves of the concrete

added concrete with varying dosage of SNF admixture for given water to binder ratio i.e., 0.45 corresponding to temperature. From these results, it is clear that concrete with alccofine and SNF present different results from the normal and alccofine concrete which do not contain SNF. All curves showed an endothermic peak of up to 500°C and after 500°C exothermic peak was found from DSC curves. Concrete with alccofine and SNF showed higher heat absorption at 50°C and 100°C, suggesting that alccofine concrete with SNF contains more free water resulting from the hydration being delayed and that these have a higher amount of CSH.

The method consisted of calculating the weight loss of normal concrete, alccofine concrete with and without SNF upon heating at 105°C and 580°C. Water removed at 105°C and 580°C is assumed to be free water and bound water, respectively. Free water and bound water can be determined from the following Eqs. (6)-(7), respectively (Amba *et al.* 2010). The calcium hydroxide content can be determined at 580°C as percentage weight by using Eq. (8) (Reddy and Naqash 2019, Roychand *et al.* 2016).

From the results, it can be observed that the free and bound water is more in AC, AC+0.3%SNF, AC+0.35%SNF and AC+0.4%SNF compared to normal concrete as shown in Figs. 10-11, respectively.

$$\text{Free-water (\%)} = \left(\frac{W_{sample} - W_{105^0C}}{W_{sample}}\right) \text{ x } 100 \qquad (6)$$

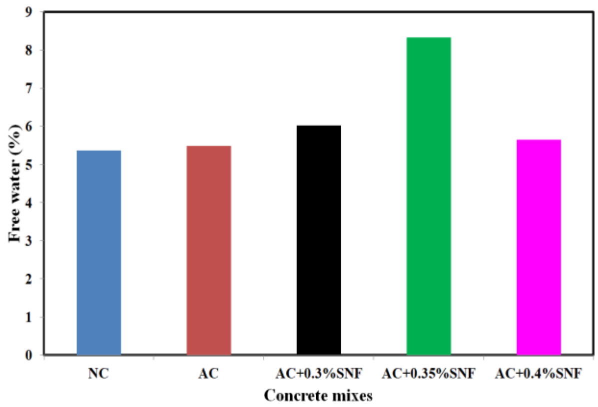


Fig. 10 Free water (%) of different concrete mixes

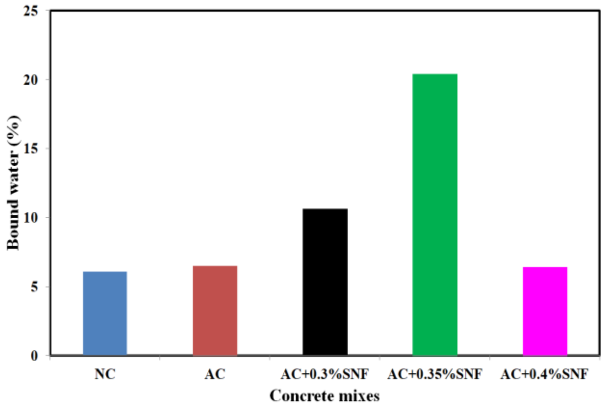


Fig. 11 Bound water (%) of different concrete mixes

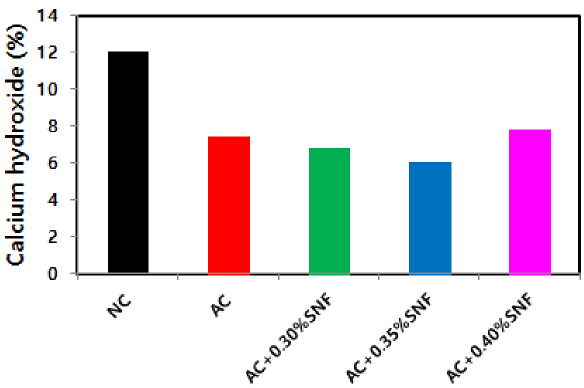
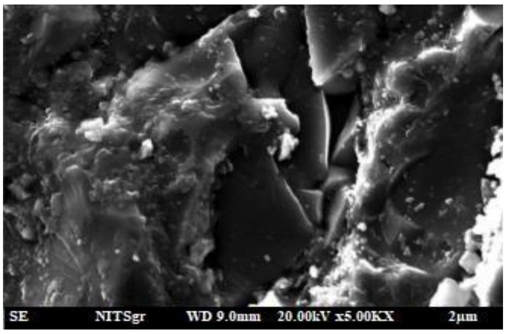


Fig. 12 Calcium hydroxide (%) of various concrete mixes

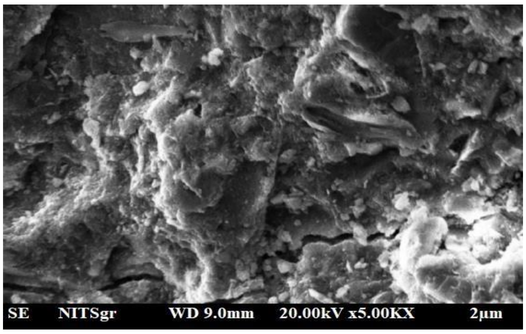
$$\text{Bound-water (\%)} = \left(\frac{W_{105^0C} - W_{580^0C}}{W_{105^0C}}\right) \text{ x } 100 \qquad (7)$$

$$\text{Calcium hydroxide (\%)} = \frac{74.1}{18} \times \frac{\textit{Weight loss due to the dehydroxylation of portland}}{W_{580^0C}} \times 100 \qquad (8)$$

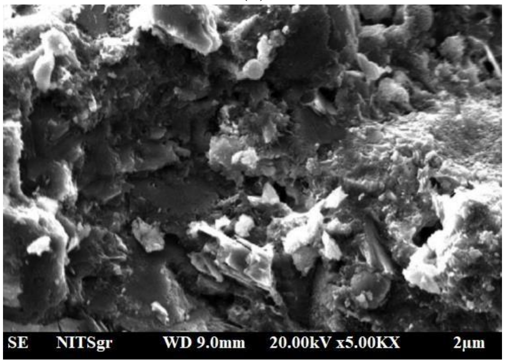
From Fig. 12 shows the percentage of calcium hydroxide of normal concrete, alccofine added concrete with varying dosage of SNF admixture for given water to binder ratio i.e., 0.45 corresponding to temperature. The reason behind that alccofine react with calcium hydroxide in the presence of water to form additional calcium silicate hydrate in the concrete (Zhang and Guang 2011).



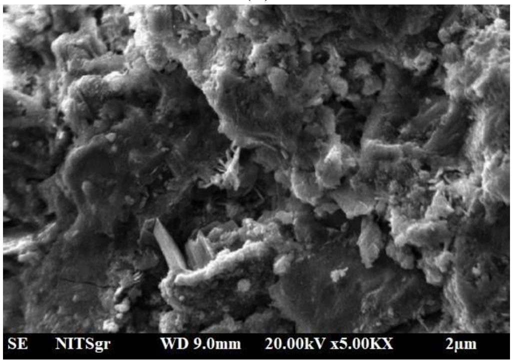
(a)



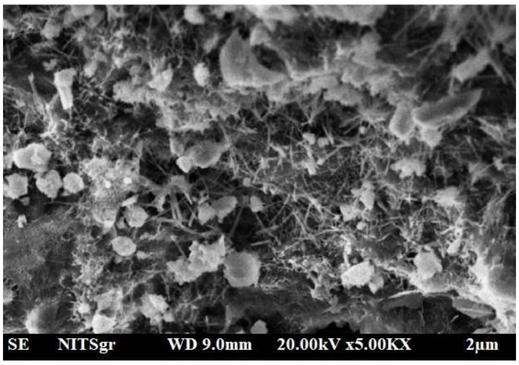
(b)



(c)



(d)



(e)

Fig. 13 SEM analysis of (a) Normal concrete, (b) Alccofine concrete, (c) Alccofine + 0.30% SNF (d) Alccofine + 0.35% SNF and (e) Alccofine + 0.40% SNF

6.8 SEM analysis

The distribution and formation of hydration products of hydrated cement paste of five different mix proportions are pictured below. The microstructure of the five mixes were examined and compared with the nominal mix. The microstructure and strength properties of all the five mixes were correlated based on the hydration products formed after 28 days. The reason behind the strength of the concrete was analysed and explained based on the growth of hydration products in the microstructure of concrete mixes. SEM can provide both compositional and topographic analysis of the material. Fig. 13 shows the SEM analysis of normal and alccofine added concrete with addition of 0%, 0.30%, 0.35% and 0.4% of SNF. SEM image in Fig. 13(a) shows that the normal concrete without alccofine and SNF is highly porous and least compact, whereas Fig. 13(b) image clearly indicates that the alccofine added concrete microstructure is more dense which may be due to the formation of additional C-S-H gel (white precipitates) because alccofine is highly rich source of calcium and silica (Jindal *et al.* 2017c). Similarly, in Figs. 13(c-e) the effect of SNF is clearly visible. Fig. 13(d) show a more compact microstructure when 0.35% SNF is added whereas with higher percentage of SNF some needle type structures are visible which may be the reason of diminishing the strength of the concrete.

Comparing of normal and alccofine added concrete samples after curing age of 28 days, alccofine added concrete with 0.35% SNF has a compact and dense structure which may be due to formation of more hydrated products such as CSH, CAH and CASH which enhances the compressive strength (Aziz *et al.* 2014).

7. Conclusions

• Total five different combinations of mixtures were investigated for fresh properties, mechanical properties, water absorption, thermal and microanalysis properties.

• With addition of constant alccofine quantity showed moderate enhancement in compressive strength of concrete at all ages as the addition of alccofine results in the enhanced hydrated products. The additional hydrated gel leads to denser microstructure and improved mechanical strength and durability.

• With constant dosage of alccofine and 0.35% SNF showed better enhancement in compressive strength, split tensile strength and modulus of rupture of concrete at all ages.

• From the water absorption test results, the concrete with addition of alccofine and SNF showed reduction of water absorption values compared to normal concrete due to filling of pores by alccofine particles. The decrease in water absorption may indicate the improvement in the durability of concrete.

• The resistivity of concrete was increased with addition of alccofine and SNF due to homogeneity mixture up to 0.35% of SNF and further increment of SNF dosage electrical resistivity was decreased due to over precipitation of calcite at the surface region.

• From thermogravimetric analysis, concrete with alccofine showed less mass loss reduction and more decomposition of hydrates occurred while applying temperatures from 24 to 800°C. From TGA results, Combination of alccofine with varying dosage of SNF was found to have less calcium hydroxide and more bound water compared to normal concrete.

• From SEM analysis, alccofine and combination of alccofine with SNF was improved the microstructure and formation of calcium silicate aluminum hydrate and calcium silicate hydrate in the concrete.

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