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Behavior of self-compacting concrete incorporating mineral admixture

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Abstract

The objective of this paper is to investigate the effect that mineral admixtures, different SPs, and different VMAs have on the fresh qualities of SCMs. In this specific instance, the four mineral admixtures that are used are fly ash, limestone powder, brick powder, and kaolinite. Pozzolanic or non-pozzolanic are two possible classifications for these admixtures. One of the SPs had a base consisting of melamine formaldehyde, while the other three included polycarboxylates as their primary component of their bases. On the other hand, the VMAs were an aqueous dispersion of microscopic admixtures based on silica, and they also included a high molecular weight admixture based on hydroxylated polymer. It is possible to make a variety of concrete mixes, each of which has its own unique slump flow, V-funnel, and setting characteristics, which are evaluated in the same way as the fresh properties. At 7, 14, and 28 days of age, respectively, the material is evaluated for its density, ultrasonic pulse velocity, and strength. These are the hardened attributes that are taken into account.

Keywords: Durability; Sustainability; Cement; Material selection; Embodied CO_2

1. Introduction

Self-Compacting Concrete (SCC) was first introduced to the world in the late 1980s in an effort to ease the steel reinforcing shortage. In the case of heavily reinforced structures, such as earthquake-resistant structures, concrete compaction is challenging. Utilizing SCC in construction has a number of benefits, including a decrease in the cost of concrete placement and a reduction in the construction period (as compaction is eliminated). Numerous studies have been conducted on SCC since its invention, since its advantages over conventional concrete have become apparent. Due to the fact that SCC is a unique concrete technology, there are no criteria that outline its requirements. This was mentioned before. IS 10262:2019 primarily covers mix design approaches.

To avoid segregation, SCC is a mixture that is almost fluid but stable at the same time. These two requirements are obviously diametrically opposed. The first criterion is met by employing an effective new generation superplasticizer, while the second is met by incorporating high finer content (cement and filler) as well as viscosity modifying agents (VMA). In order to achieve self-compactibility, it is common practise to limit the amount of coarse aggregate present and to use a mortar that is appropriate for the job. As a consequence of this, mortar serves as the basis for the workability attributes of SCC, which can be evaluated via the study of self-compacting mortars (SCM) [Domone and Jin 1999]. According to EFNARC (2002), one crucial aspect of the design process for SCC is the evaluation of the characteristics of SCM. In order to achieve self-compactibility in SCMs, the amount of sand that is included inside mortar is normally limited to no more than forty percent of the total volume. In addition, lower water-to-cement ratios are used in combination with superplasticizers (SP) [Okamura and Ozawa 1995]. [Citation needed] It is also required to use admixtures that change viscosity in order to generate the most effective mix design possible for SCC or SCM (VMA). [Lachemi et al. 2002] found that VMAs increased the viscosity of SCC and prevented segregation. However, the price of the SCM will be higher since all of these chemical admixtures will be included in it.

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Mineral admixtures, which are components that have been broken up into smaller pieces and added to concrete as separate ingredients either before or during the mixing process [Erdoan 1997], are one option for reducing the cost of SCC. If mineral admixtures are able to replace all or part of the chemical admixtures without having an effect on the fresh properties of SCC, then the cost will be minimised. This will be particularly true if the mineral admixture is a by-product or waste from an industrial operation. In addition, the use of mineral admixtures will increase the product's durability as well as its strength over the long term.

2. Components of concrete

The following component materials were employed in this investigation

- Cement
- Coarse Aggregate
- Fine Aggregate
- Water
- Chemical Admixture
- Mineral Admixture

2.1. Cement

Any type of cement meeting the requirements of the Indian Standard Code (IS) is acceptable. The selection of cement relies on the concrete's overall needs, such as strength, durability, etc. C_3A concentrations over 10% would result in poor workability retention. The recommended cement content for SCC is 350 to 450 kg/m^3; if it exceeds 500 kg/m^3, the shrinkage increases. However, less than 350 kg/m^3 of cement content may be acceptable if additional fine fillers like as fly ash, pozzolana, etc. are included. The utilized cement is OPC (grade 43) with a specific gravity of 3.09. The basic properties of the cement obtained through the testing are mentioned in Table 1.

2.2. Coarse Aggregate (CA)

The crushed aggregate used in all of the mixes of SCC and conventional vibrated concrete was required to pass through a sieve measuring 12.5 millimetres and be retained on a screen measuring 4.75 millimetres (CVC). The used aggregates were in accordance with the standards established by IS: 383-1970. The amount of CA that was employed had a specific gravity of 2.66, a loose density of 1373 kg/m^3, and a packed density of 1496 kg/m^3. Crushed aggregates have a tendency to increase the strength because of the interlocking of angular particles, but rounder aggregates tend to increase the flow because of lower internal friction. Continuously graded aggregates may have greater internal friction and decreased flow, whereas gap graded aggregates frequently perform better than continuously graded aggregates. On the other hand, the elongated aggregates are not favoured because of the flakiness they exhibit.

Table 1 Test Values of Cement

Property	Test Procedure Used	Value
Standard Consistency of Cement	Vicat's Apparatus with Plunger	31.50%
Initial Setting Time of Cement	Vicat's Apparatus with square annular needle	32 min
Final Setting Time of Cement	Vicat's Apparatus with square annular needle	24 hrs
Fineness	Blaine's Air Apparatus	303 m^2/kg
Soundness	Le-Chatelier's Apparatus	0.18%
Compressive Strength	3 mortar cubes as per IS-4031	46.50 MPa

2.3. Fine Aggregate (FA)

As fine aggregate, locally accessible river sand was utilised and analysed in the laboratory. The following results are obtained, which conform to zone II of IS: 383(1970) and a 4.75 mm sieve. The utilised FA had a S.G of 2.561, a loose density of 1500 kg/m^3, a packed density of 1651 kg/m^3, a fineness modulus of 2.429, and a cleanliness index of 94.15%. The aggregates smaller than 0.125 millimetres must be considered powder. A minimum quantity of penalties must be imposed in order to prevent segregation. The value obtained in sieve analysis is given in Table 2.

Table 2 Test Value of Sieve Analysis

Sieve Size	Cumulative Passing %	
	Fine Aggregate	**Requirement**
10 mm	100.00	100.00
4.75 mm	99.53	95.00-100.00
2.36 mm	88.87	80.00-100.00
1.18 mm	66.05	50.00-85.00
600 um	38.04	25.00-60.00
300 um	15.03	10.00-30.00
150 um	5.09	2.00-10.00

2.4. Water

The mix design made use of potable water from the water supply network system. This water was free of suspended particles and organic components that may have harmed the characteristics of both the fresh and the cured concrete. Potable water that has been filtered to remove potentially dangerous salts was used in both the mixing and curing processes.

2.5. Chemical Admixture

2.5.1. Super-Plasticizer (SP)

The Super-Plasticizer that was used in this study is Glenium B233, which may be purchased from BASF Construction Chemicals (India) Private Limited. In comparison to other SP, Glenium B233 stands out because to its one-of-a-kind carboxylic ether polymer, which has extended lateral chains. This results in a considerable improvement to the cement's dispersion. High range water reducers, also known as HRWRs, are put to use to bring down water concentrations that are higher than 20%. As indicators of the flow characteristics and workability retention, they are readily available on the commercial market. Poly Carboxylated Ethers are the HRWR that are used most often. They are able to satisfy the contradictory requirements of flow and coherence. When compared to conventional plasticizers such as those based on melamine or naphthalene sulphanate, the newest generation of Super-Plasticizers relies far more on cement than its predecessors.

Conforms to American Society for Testing and Materials (ASTM) C494 Types A and F and IS: 9103-2003. These are its usual properties:

- Color: a liquid with a yellow hue
- Density relative: 1.09 0.01
- pH: 7 ± 1
- Chloride content: Nil to EN 934-2
- Transport: Not categorised as hazardous
- Labelling: Not hazard label necessary

Normal dose for Glenium B233 is between 0.5 and 1.5 litres per 100 kg of cement (cementetious material). Dosages outside the specified range are permitted for testing purposes.

2.5.2. Viscosity Modifying Agent (VMA)

When combined with a superplasticizer, a viscosity modifying admixture (VMA) has the potential to improve the stability of the super-plasticized cement composite (SCC) and/or make it more resilient. This is accomplished by reducing the SCC's sensitivity to shifts in the component ingredients, most notably the aggregate's moisture content.

The VMA that was used for the purpose of this research was Glenium Stream-2, which is offered for sale by BASF Construction Chemicals (India) Private Limited. The Glenium Stream-2 additive is made up of a number of different water-soluble polymers. These polymers are designed to be absorbed on the surface of cement particles, which in turn causes a change in the cement's viscosity.

The rheological properties of the mixture are changing as a result of the presence of the water. The Glenium Stream-2 serves two objectives, which are as follows: During the casting process, it lessens the viscosity of the concrete and maintains its internal cohesiveness. As a result of the agglomeration of polymer chains, it is resistant to segregation, notwithstanding the immobility of the concrete.

Glenium Stream-2 does not include any chloride and is suitable for use with any cement that meets the requirements of the Indian or ASTM reinforced concrete standards. It cannot be used with Super-Plasticizer admixtures that include naphthalene sulphonate because of this incompatibility.

The following is a rundown of the typical qualities of Glenium Stream-2:

- Colour: Colourless liquid
- Specific gravity at 25 °C: 1.01 0.01
- pH: 8 ± 1
- Chloride content: Nil to EN 934-2

The suggested volume range for Glenium Stream-2 is 0.5 to 1.0 litres per cubic metre based on the total amount of particles smaller than 0.1 mm. In exceptional circumstances, other doses may be prescribed based on site-specific requirements.

2.6. Mineral Admixture

In the experimental programme, the types of mineral admixtures that were used were high-lime fly-ash, limestone powder, brick powder, and kaolinite. The results of their the physical attributes they possess are provided in Table 3.

Table 3 Physical Properties of Mineral Admixtures

Physical Properties	Fly Ash	Brick Powder
Specific Gravity	2.05	2.44
Specific Surface Area	0.4651	0.5107
Blaine Fineness	2425	2002
Above 90 µm	26.4	50.7
Above 45 µm	41.8	64.6

3. Methodology

3.1. Mix Design and Proportioning

Table 4 Mix Design of SCC

Concrete Mix	Amount of Ingredient (kg/m^3)						
	C	FA	BP	Sand	Water	SP	VMA
SP	652.00	0.00	0.00	1297.00	260.00	9.76	0.00
SP-FA1	555.00	102.00	0.00	1275.00	260.00	9.76	0.00
SP-FA2	453.00	201.00	0.00	1244.00	260.00	9.76	0.00
SP-BP1	551.00	0.00	101.00	1285.00	260.00	9.76	0.00
SP-BP2	454.00	0.00	203.00	1270.00	260.00	9.76	0.00
SP-FA1-BP1	452.00	101.00	101.00	1266.00	260.00	9.76	0.00
SP-VMA	651.00	0	0.00	1297.00	260.00	9.76	9.76

Table 4 displays the results of the preparation of one control and mixes that include mineral and chemical admixtures. The w/p ratio was decided to be 0.40, and the total powder content was set at 650 kg/m3 throughout the whole process. A portion of the cement was substituted with mineral admixtures in the quantities of 15 to 30 percent of the total weight of the cement. Additionally, there were ternary blends of the mineral admixtures. In Table 4, the letter C represents for Portland cement, while the letters FA, and BP stand for the mineral admixtures fly-ash and brick powder correspondingly. Additionally, the quantities of chemical admixtures, superplasticizers (SP), and viscosity modifying admixtures (VMA) are included in Table 4. The identifiers for the mixes are written in a way that makes the components of the mix evident. For instance, the mix SP-FA2 included SP1 and 30% replacement of FA, the mix VMA-FA1-BP1 contained VMA, 15% replacement of FA, and 15% replacement of BP.

3.2. Fresh Concrete Properties

The results of the freshness tests conducted on all blends are shown in Table 5. This table contains the measured V-funnel time, t, the measured slump flow diameters, d1 and d2, the calculated average slump flow diameter, d, and the measured V-funnel time. According to Table 5, different mineral and chemical admixtures were used for each of the possible mixes. The quantity of powder (PC plus mineral admixtures), water, and superplasticizers was maintained at the same weight throughout the process. When a VMA was used, the mixture just included PC, sand, water, and SP; there were no minerals added to the mixture at any point. In addition, the control mix was made up of solely PC, sand, and water, with no added chemicals or minerals of any kind. The tests performed are explained in brief below.

3.2.1. Slump Cone Test

This technique is commonly used in concrete technology to determine the fluidity of the concrete mixture. This test facilitates the unrestricted horizontal movement of SCC. In this test, the workability and fluidity of fresh concrete are assessed, and bleeding and segregation can also be observed. The diameter of the cone circle is measured to determine the concrete's filling capacity. The specifications are laid forth in EN 12350-2 [83] and ISO 1920 [84]. Abram's Cone is 300 mm tall with openings that are 200 mm and 100 mm in diameter on the bottom and top, respectively. On a solid steel plate, you'll find two sets of concentric circles, one measuring 200 mm and the other 500 mm in diameter. The concrete spills out of the aperture when the cone is lifted. Maximum diameter across the concrete slab is reported as the mean of two perpendicular measurements. Both the T50 flow time, which measures how long it takes for half of the mixture to spread to a distance of 500 millimetres, and the total flow time from the removal of the cone to the end of flow are recorded. A diameter of 500–600 millimetres is considered enough for a spread. Based on their analysis of highly viscous SSC and standard SSC [5,13], Gezelle and Khayat [5,13] predicted that it would take between 3 and 7 seconds to disperse a 500 mm diameter, and between 2 and 5 seconds for other applications. Spread for a 500 mm diameter should be more than 7 seconds and droop should be between 600 and 650mm for SFRSCC.

3.2.2. V-Funnel Test

Ozawa and his colleagues [76,78,79] from the University of Tokyo in Japan developed the examination (Gomes [36]). Additionally, Japan employed a V-funnel in addition to an odd O-funnel that included a circular component. Concrete with an aggregate size no more than 20 millimetres in diameter may have its filling ability (flowability) evaluated using the V-funnel test. Following the first measurement of the flow rate via the apparatus, the funnel is next loaded with about 12 litres of concrete. Five minutes after the concrete has had a chance to settle, the second flow time is measured. In the event that the concrete displays segregation, the second flow time will be greatly lengthened. The ability of the SCC to flow may be determined by the flow time in the V-funnel. Ozawa et al [4,72,73] have determined that a flow duration of ten seconds is sufficient. The prolonged flow time is indicative of the fact that the combination is prone to blockage.

Hardened Properties

The properties of the hardened concrete mixes are tested at 7 days, 14 days and 28 days. Following Tests were performed and shown in Table 6:

- Compressive Strength Test
- Flexural Strength Test
- Split Tensile Test

Table 5 Properties of Fresh SCC Mixes

Concrete Mix	Diameter	V -Funnel Time
	d (cm)	t (sec)
SP	24	5.05
SP -FA1	24.6	4.14
SP -FA2	26.4	3.29
SP -BP1	17	12.27
SP -BP2	17	21.28
SP -FA1 -BP1	25.7	2.9
SP -VMA	22.4	3.37

Table 6 Properties of Hardened SCC Mixes

Concrete Mix	Compressive Strength (MPa)			Split Tensile Strength (MPa)			Flexural Strength (MPa)		
	7 Days	14 Days	28 Days	7 Days	14 Days	28 Days	7 Days	14 Days	28 Days
SP	24.75	34.32	38.13	1.48	2.08	2.84	2.61	3.27	3.52
SP -FA1	27.02	37.37	41.55	1.81	2.63	3.63	2.75	3.59	3.83
SP -FA2	19.61	27.23	30.26	1.22	1.72	2.39	2.08	2.66	2.80
SP -BP1	22.53	31.12	34.61	1.35	1.86	2.62	2.36	2.97	3.13
SP -BP2	20.44	28.29	31.44	1.28	1.77	2.50	2.146	2.65	2.84
SP -FA1 -BP1	21.42	29.67	32.96	1.31	1.86	2.55	2.08	2.79	2.97
SP -VMA	27.44	38.03	42.24	1.98	2.72	3.74	2.87	3.64	3.88

4. Results and discussion

On the mixtures that do not include any chemical and mineral admixtures, the influence of chemical admixtures on the characteristics of SCC will be researched. Workability characteristics, the slump flow test (in millimetres), the V-funnel test in millimetres, and the setting time were among the fresh attributes that were evaluated and analysed. The compressive strength of the material was measured at 7, 14, and 28 days after its initial preparation.

4.1. Properties of Fresh SCC

When the fresh characteristics are analysed using Fig. 1 and Fig. 2, one of the first things that can be seen is that the use of chemical admixtures in a mix result in an increase in the amount of time it takes to set and in the workability parameters. In the next sections, we will look at these two characteristics in isolation from one another.

Plots showing the results of the two workability tests are shown in Figure 1. As a result of the fact that both Γm and Rm were equal to zero, both of the workability tests demonstrated that the control mix lacked the ability to self-compact. These metrics show a quick rise when the chemical admixtures are added, which indicates that the material has self-compacting properties. According to the findings of the slump flow experiments, mixtures containing SP and 30% BP in combination (SP-BP2) exhibited the least spread, whilst mixtures containing SP and 30% FA (SP-FA2) exhibited the most amount of spread possible. In addition, the results of the slump flow test showed that the addition of a VMA did not have a substantial impact on the diameter of the slump. Similar conclusions may be drawn from the findings of the V-funnel tests as well.

When compared to other combinations, introducing both FA and BP have the greater funnel speed rate. Addition of VMA, resulted in an increase in the relative funnel speed, which indicated improved flowability through the funnel.

These data were consistent with the assumptions that VMAs would improve the cohesiveness of a mixture while having little to no substantial effect on the mixture's capacity to be deformed.

According to EFNARC's recommendations, the minimum relative slump flow diameter should be at least 4.8 millimetres, and the minimum relative V-funnel speed should be at least 1.4 metres per second [EFNARCH 2002]. When these required values are compared to the mixes that have already been discussed, the only mixes that are eligible for an SCC are the mixes that include SP. The suggested values of Γm and Rm are shown by the boundary line in Fig. 1 and 2, respectively. The results of this investigation using SP alone demonstrated a strong agreement with the work carried out by Golasweski et al (2003).

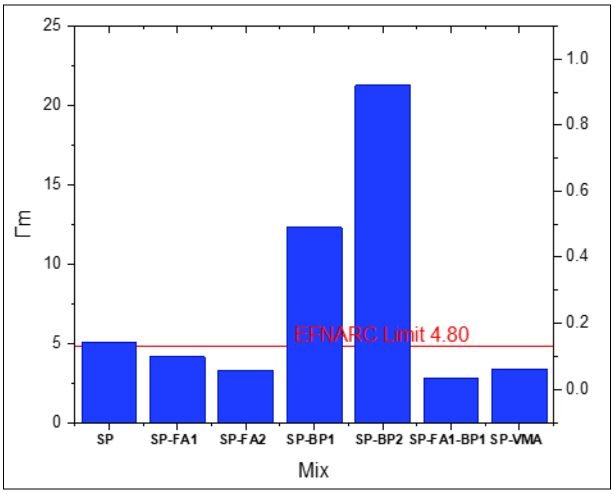

Figure 1 V-Funnel Test Result

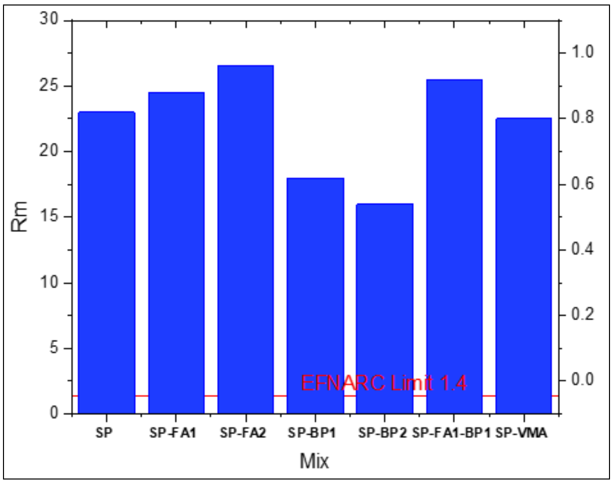

Figure 2 Slump Cone Test Result

The volume of the paste may be increased by the use of mineral admixtures that are less dense than PC. Because of the higher paste volume, there is less friction at the interface between the fine aggregate and the paste, which results in an improvement in workability. In addition, the spherical nature of FA particles and the fineness of their size both have positive impacts on the workability of the material.

4.2. Properties of Hardened SCC

The compressive strength obtained through the lab test at 7days, 14days and 28 days is shown in Fig. 3. It can be concluded from the graph that SCC containing the mineral admixture of fly ash (15% replacement) i.e. SP-FA1 has the highest compressive strength followed by SCC containing SP-VMA.

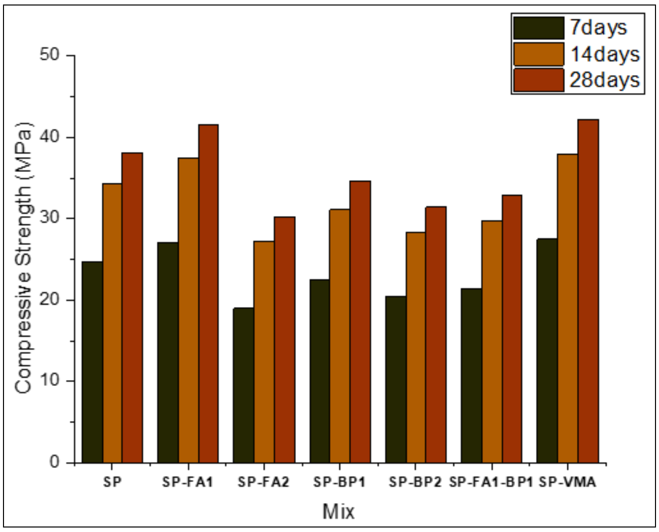

Figure 3 Compressive Strength Test Results

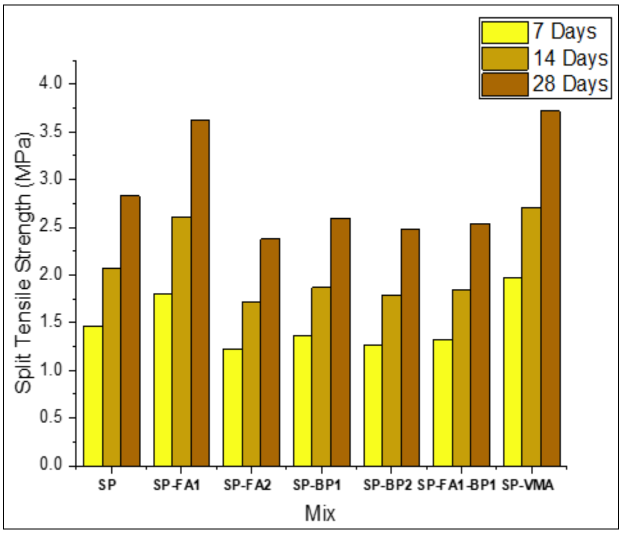

Figure 4 Split Tensile Strength Test Results

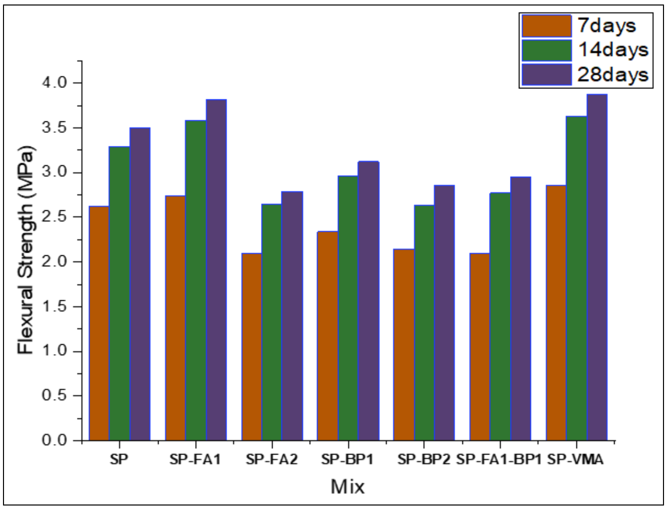

Figure 5 Flexural Strength Test Results

Similarly, the results of the split tensile test, as shown in Figure 4, indicate that the SCC with the highest compressive strength is SP-FA1, which contains fly ash as a mineral admixture (15% replacement). A similar trend is also observed in the results of Flexural strength test as shown in Fig. 5.

5. Conclusion

Following are some of the inferences that can be drawn as a consequence of this experimental research:

- The workability of SCC is mostly determined by the kind of SPs that are used. In this research, polycarboxylate-based SPs exhibited greater results in enhancing the workability of SCCs, as evaluated by both of the workability tests. In particular, SP-FA1 showed the best results in this regard.
- VMAs had a key impact in the characteristics of concrete mixtures both while they were new and after they had hardened. When it came to the fresh characteristics, the use of VMAs in conjunction with SP led to a notable improvement in the cohesion of the mixes. This occurred despite the fact that there was no discernible shift in the mixes' deformability. According to the findings of this research, the workability of SCCs was significantly improved by using FA1, which was a mineral admixture. In addition to this, the SP-FA combinations made the SCMs much more powerful.
- The incorporation of mineral admixtures resulted in an increase in the workability of the SCMs. It was found that FA and BP, two of the minerals that were utilised as admixtures, were superior than VMAs in terms of their capacity to boost the workability qualities of mortars. However, BP cannot be utilised independently since they have a detrimental effect on the workability of the mixture.
- When mineral admixtures are used in lieu of some of the cement, the structure's strength is reduced, which is one of the mineral admixtures' primary drawbacks in comparison to the chemical admixtures. On the other hand, if the mineral admixtures are utilised in lieu of the fine aggregate, then this decrease could not be seen.
- The chemical and mineral admixtures both have a negative impact on the amount of time it takes for mortars to set. However, compared to the other mineral admixtures, FA had the most significant impact on the amount of time required for the mortars to set.
- In order to mitigate the negative effects of using one mineral admixture, it is possible to combine it with a second mineral admixture to create a ternary mix. The FA-BP mixes were shown to boost the workability of the mortars without substantially influencing the setting time when compared to the other ternary mixes that were investigated for this research.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest.

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