

ORIGINAL RESEARCH
PAPER



Effect of ultrafine natural steatite powder, super plasticizer and VMA on the fresh and hardened properties of self-compacting cement paste and mortar

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ABSTRACT

For the past few decades innovation in construction material has grown a lot. This leads to special concrete such as self-compacting concrete, geopolymer concrete, self-healing concrete, etc. To prepare a special concrete apart from regular concreting material some sort of special materials was also needed, like mineral and chemical admixtures. Hence it is necessary to study the effect of these admixtures in cement paste and mortar before studying the same in concrete. Hence an attempt is made to study the effect of mineral and chemical admixtures in the fresh and hardened properties of cement paste and mortar. For this study ultrafine natural steatite powder is taken as mineral admixture and polycarboxylic based superplasticizer and Glenium stream 2 were taken as chemical admixtures. Ultrafine natural steatite powder was used as additive to cement in various percentages like 0%, 5%, 10%, 15%, 20% and 25%. Superplasticizer and viscosity modifying admixture were taken as 1.5% and 0.5%, respectively. Then various combinations were worked out. To study the fresh property of cement paste consistency, initial setting time and miniature slump cone test were done based on the results yield stress of cement paste also calculated empirically. To study the hardened property compression test on cement mortar was done. Based on the test results it is clear that the addition of ultrafine natural steatite powder increases the water demand hence reduces the workability. On the other hand, it increases the compressive strength up to a certain limit. Adding superplasticizer increases the workability and reduces the water demand and viscosity modifying admixture reduces the bleeding and segregation effects hence increases the compressive strength.

KEYWORDS

self compacting concrete, yield stress, cement paste, miniature slump cone, steatite

1. INTRODUCTION

In recent years usage of self-compacting concrete and self-levelling mortar has highly increased because of its economical and time benefits [1]. The preparation of self-compacting concrete water plays a vital role in the performance of fresh concrete and it also affects the mechanical and durability properties of concrete. To make the concrete perform better in mechanical and durability aspects the w/c ratio should be less, but it may affect its rheological property [2-5]. To make the concrete perform better in terms of durability and mechanical aspect without losing its rheological nature chemical admixture such as superplasticizer is needed. Adding superplasticizer has its own merits and demerits. On the positive side, it reduces the water needed to produce workable concrete hence increases the strength. From a negative point of view, adding SP is highly sensitive, even if the water content slightly increases it will lead to segregation and bleeding [6, 7]. To produce a workable homogeneous

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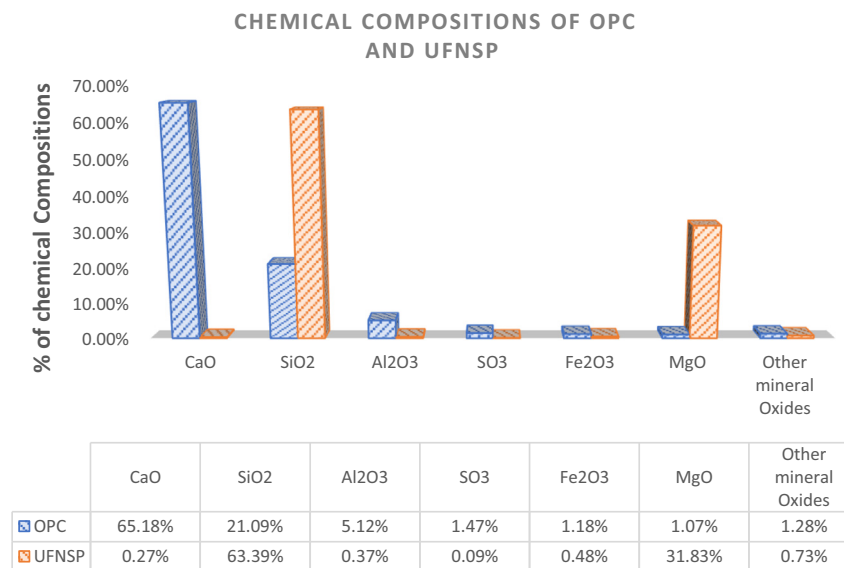


Fig. 1. Chemical compositions of Ordinary Portland Cement and Ultra Fine Natural Steatite Powder as determined by XRF

mix, it is advised to use VMA, since, it reduces the segregation and bleeding in cement concrete [8–10]. Researchers in the past found out that synthetic and semi-synthetic polymers had a significant influence on the rheological properties of cement paste or mortar. The rheological property of concrete or mortar or cement paste is mainly affected by its yield stress and plastic viscosity. At yield stress, the cementitious material will initiate, restrict the flow. Concrete with less yield stress has good flow properties compared with high yield stress concrete. Therefore, at lower yield stress the concrete is much workable and easy to pump [11]. Hence, to design a self-compacting concrete or concrete with greater workability it is essential to find the yield stress of the cementitious material. To find the yield stress of cement paste concrete rheometer and viscometer were commonly used. The major disadvantage with these instruments is that they are costly, cannot be used in the field and require more material for testing. But the yield stress of concrete can also be found using the slump cone test. And the same for cement paste can be found using miniature slump cone test. In this test, the cone is filled with cement paste and lifted slowly. When the cone is lifted with the cement, the paste starts to flow until the shear stress due to the flow reaches the yield stress of the cement paste. Hence the yield stress in this study was calculated based on the equations available from the previous studies by correlating yield stress with the miniature slump test results. [12–15]. Regarding the strength, as the density of concrete increases, the strength of the concrete also increases. To make the concrete much denser we need to use fine particles such as nano-silica, fly ash, ultrafine steatite powder, etc., these finer particles occupy the voids formed between cement paste resulting in denser concrete and a few of these mineral admixtures act as supplementary cementitious material, hence improved CSH gel formed resulting in an increase in

strength and durability aspects [16–20]. Therefore, in this study to reduce the voids present in concrete and to increase the strength ultrafine natural steatite powder was used as additive to cement paste in various percentages. Before studying the effect of these mineral and chemical admixtures in the complex structure such as concrete it is highly recommended to study the same in cement paste and mortar. Adding steatite reduces the heat of hydration as well as makes the mortar stronger and more durable.

2. MATERIALS

To produce the cement paste and mortar, the powder materials used were ordinary Portland cement of 53 grade, conforming to IS 12269:1987 [21] with the specific gravity of 3.14, and the steatite powder was used in various percentages to the weight of the cement as an additive in this study and it was purchased from the locally available distributor (Sri Hariram Chemicals, Madurai) as in ultra-fine nature (i.e) with particle size less than 5 μm . The specific gravity of ultra-fine natural steatite powder (UFNSP) was found to be 2.25. For fine aggregate m-sand with the fineness modulus and specific gravity of 2.623 and 2.65, respectively, was used. And potable tap water conforming to IS: 456 – 2000 [22] was used in this study for producing and curing of cement mortar. For producing good workability and high flowability with less water powder ratio polycarboxylic based superplasticizer (SP) and viscosity modifying agent (VMA) containing polysaccharides were used, and this was purchased from Cera-Chem Private Limited, Chennai, Tamil Nadu. The chemical compositions of cement and UFNSP are mentioned in Fig. 1. These results were obtained by X-ray fluorescence (XRF). The physical properties of cement and steatite are given in Table 1.

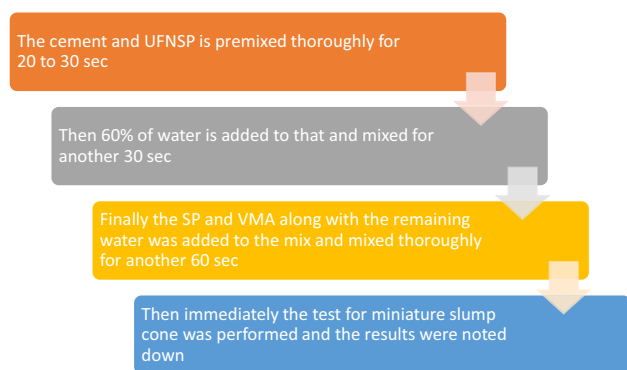


Fig. 2. Mixing method for producing controlled cement paste

Table 1. Physical properties of cement and steatite

Physical Properties	OPC	UFNSP
Mean diameter of particle (μm)	Less than 30	Less than 5
Blaine Surface area (m^2/kg)	360	780
Loss of Ignition	3.12%	3.53%

3. PREPARATION OF TEST SAMPLES, MIXING PROCEDURE AND EXPERIMENTAL METHODS

3.1. Preparation of Test samples

In total, 4 sets of cement paste and mortar were prepared. Each set contained 6 ratios of UFNSP. UFNSP was added as additive in the cement paste and mortar. Set 1 consisted of cement and steatite, 2nd set consisted of cement steatite and superplasticizer, 3rd set consisted of cement steatite and viscosity modifying agent, and lastly, the 4th set consisted of cement, steatite, superplasticizer and viscosity modifying agent. In all these 4 sets steatite was added in 0%, 5%, 10%, 15%, 20% and 25%. So, in total, 24 cement pastes and 24 cement mortars were designed. SP and VMA was added to the cement paste and mortar at 1.5% and 0.5% to the weight of cement. For producing the cement mortar, the powder to fine aggregate ratio was maintained as 1:3 with the water-powder ratio of 0.42.

3.2. Mixing proportion

Standard hand mixing was applied for all the tests. The cement pastes for all the tests were produced as mentioned in Fig. 2.

3.3. Experimental methodology

3.3.1. Consistency of cement paste. The main objective of this test is to find the water demand to produce a cement paste of standard consistency as mentioned in IS: 4031, Part 4 -1988 [23]. The test was performed using Vicat's apparatus and as mentioned in IS: 5513-1976 [24]. As for the test, it

was performed with approximately 400g of powder content mixed initially with the water content of 28% to the weight of powder content and the mixed cement paste was kept inside the mould within 3–5 min and levelled with the help of a trowel. A standard plunger of 10 mm diameter and 50 mm depth was attached to the Vicat's apparatus. The plunger was then lowered till it touched the surface of the cement paste then released so the plunger could penetrate the cement paste. The readings were noted down. Again another 1 or 2% weight of water was added to the paste and mixed uniformly, and the test was repeated till the penetration reading was 5–7 mm from the bottom of the Vicat apparatus.

3.3.2. Initial and Final setting time Test. Initial setting time is the time in which cement paste completely loses its plasticity and starts to harden. This is the time available for placing the cement paste or mortar or concrete in position. If delayed, there will be a loss of strength. The initial setting time of the cement paste was found as per IS: 4031, Part 5-1988 [25] using a needle of 1 mm diameter and height of 50 mm attached to the Vicat's apparatus. For this test 400 gm of cement was taken and 0.85 times the water required for standard consistency was used to mix with the cement and bring it to paste form. Then it was filled in the mould and kept over the nonporous plate. Then the needle was lowered carefully till it touched the surface, once it made the contact the needle was allowed to penetrate the sample and the reading was noted down from the bottom. Then the test sample was slightly moved so that the needle penetrated a new place of the test sample; this procedure was repeated at 5 min intervals until the needle failed to penetrate a depth of 35 mm and the corresponding time when it failed to penetrate 35 mm was taken as initial setting time of the cement paste concerned.

The final setting time is the time in which cement paste or cement mortar or cement concrete get hard enough so that it conquers the shape of the mould in which it is kept. Determining the final setting times is very important so that we can remove the scaffolding at the right time. The final setting time of cement paste in this study was found as per IS: 4031, Part 5-1988 using a needle with an annular ring attached to the Vicat's apparatus. For the test, 400 gm of cement was taken and water content of 0.85 times the water required for standard consistency was used to produce the cement paste then the mould was filled with the paste and the surface was smoothened or levelled using a trowel. Then the needle with the annular ring was allowed to freely fall over the cement paste and this was repeated at 5 min intervals at various places of the cement paste kept in the mould till the needle failed to make an impression on the surface of the cement paste.

3.3.3. Miniature Slump flow test. For the miniature slump cone test, a miniature version of the Abrams cone was used. The miniature slump cone had a top and bottom diameter of 19 and 38 mm, respectively, and a height of 57 mm was used. The fresh cement paste was filled to the cone and the

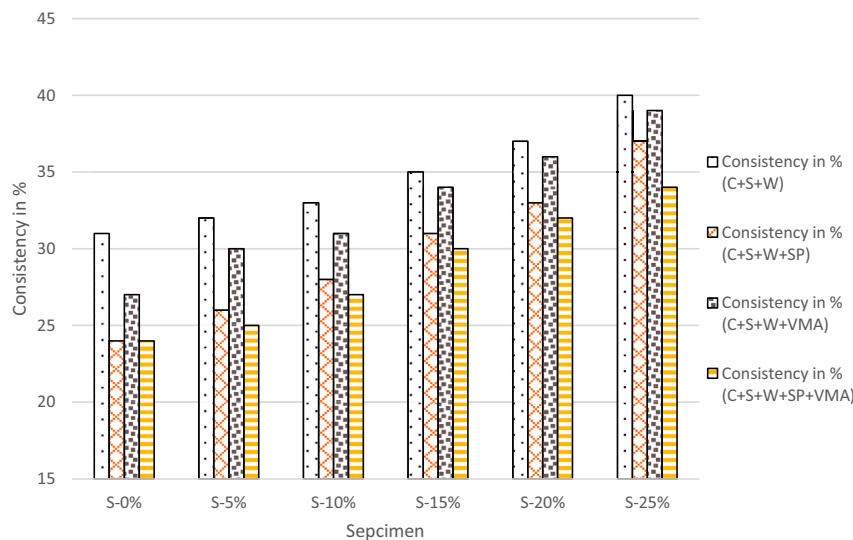


Fig. 3. Results of Standard Consistency test for various set of cement paste

cone was raised as slow as possible so as to reduce the inertial effects. When the cement paste flow stopped, the diameter was measured in two orthogonal directions as shown in Fig. 7 and the average diameter was taken as the spread diameter for the mix.

3.3.4. Compression test on cement mortar. The test sample for compression test on cement mortar was prepared as per IS: 10080-1982 [26]. The cement mould of size 70.6 mm × 70.6 mm × 70.6 mm was used in this study. After casting the specimen, the specimen was kept inside the curing tank for 28 days. After that, the cube was removed from the curing tank and the surface was allowed to dry. Once the surface was completely dried the specimen was kept in a hydraulic compression testing machine of 2000 kN capacity and tested. The load at which it failed and refused to take any more additional load was considered as the failure load of the specimen and noted down. The average of 3 specimens failure load was taken as the load-carrying capacity of the concerned mix and the load divided by the surface area of the specimen gave the compression strength of the mix ID.

3.3.5. Yield stress determination. Based on the work done by N. Roussel [27] the yield stress of the cement paste was calculated based on the miniature slump spread diameter, the volume of the miniature slump cone and based on the density of cement paste.

The formula used to find the yield stress:

$$(\tau_c) = (225\rho g\Omega^2)/(128\pi^2 R^5)$$

where,

ρ - wet density of cement paste

g - acceleration due to gravity

Ω - Volume of the Miniature slump cone

R - Spread diameter.

4. RESULT AND DISCUSSION

4.1. Fresh properties

4.1.1. Consistency of cement paste. From Fig. 3 it is clear that the addition of steatite increases the water in all 4 sets of cement paste and it is also evident that this water demand could be minimised to a smaller extent by the addition of VAM with water during mixing and it could be minimised to a larger extent by adding superplasticizer or by adding both superplasticizer and VMA together with water during mixing. The rationality behind this is that the UFNSP is very fine in nature hence it absorbs more amount of water than cement does, thus, it increases the water needed to bring it to standard paste [28]. The maximum amount of water need is for the mix that contains cement with 25% of steatite and water alone and the min water required for bringing it to the standard paste was obtained with the mix that contains cement with 0% steatite and water with the addition of SP and VMA. The difference in water consistency between these two mixes was found to be 16%.

4.1.2. Initial and Final setting time. Based on the test results obtained from the Vicat's apparatus, it is noted that the addition of steatite up to 20% decreases the initial and final setting of cement paste in all the 4 sets but at 25% replacement it suddenly increases the initial and final setting time; this increase in setting time is due to the formation of the excess percentage of MgO content [29]. Whereas up to 20 percentage steatite, due to higher water absorption rate it makes the cement paste to get dry earlier hence it reduces the initial and final setting time and the effect of chemical admixture is that both VMA and SP increase the setting time due to the chemical reaction they form with the cement.

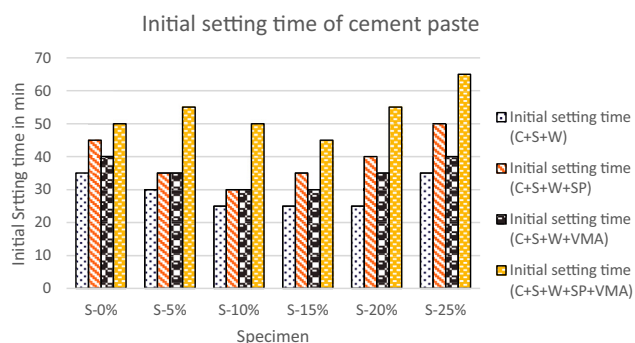


Fig. 4. Test results of Initial setting time for various sets of cement paste

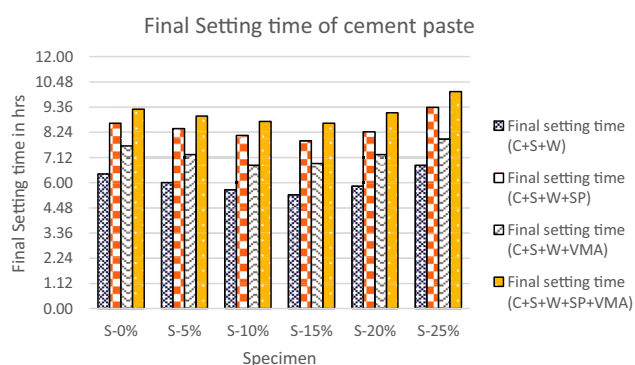


Fig. 5. Test results of final setting time for various sets of cement paste

Hence the max value of initial and final setting time was found with the mix that contains 25% of steatite and with the addition of VMA and SP along with water. And the lowest setting time was found with the mix that contains 15% of steatite and without the addition of both VMA and SP. And the difference between these two mixes was found to be 40 min in the initial setting time and 4 hrs 55 min in the final setting time. The test results for initial and final setting time for all mix combinations of cement paste are shown in Figs 4 and 5.

4.1.3. Miniature Slump Test. The spread diameter of the slump of cement paste was found using a miniature version of Abram's cone. The results were plotted in Fig. 6. Based on the results it can be stated that the addition of steatite and the addition of VMA reduces the flow, whereas the addition of SP increases the flow. Furthermore, it is noted that without the addition of SP we could not produce the spread itself (i.e) the results were like true slump, hence their spread is taken as the bottom diameter of the miniature slump cone. Out of the 2 sets that contain SP the maximum spread was obtained in 0% addition of steatite and incorporation of SP during the mixing. And the lowest spread was found at 25% addition of steatite and with the combined effect of VMA and SP. The reason for the reduction in the spread is mainly due to the addition of steatite. Since steatite absorbs more water content (proven from standard consistency test), the

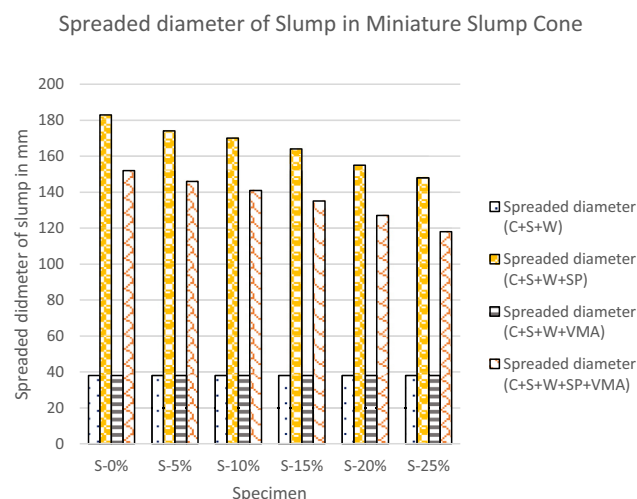


Fig. 6. Test results of Spread diameter of Various sets of cement paste

mix with high steatite content could not find sufficient fluidity so the spread is reduced, but the addition of SP makes the water available for the flow hence there is visible spread in the mix having SP in it. The increase in the spread between the above-mentioned two mixes was about 55%.

4.1.4. Yield stress of cement paste. Based on the test results obtained by the miniature slump cone test the yield stress was calculated using the formula mentioned in under 3.3.5. and plotted as shown in Fig. 8. Since there is no spread obtained in cement paste without the addition of SP, yield stress could not be found. Hence the yield stress was found for the other two sets of cement paste. Based on that the yield stress was found to be less than 10 Pa for all the mixes except the cement paste with 15% 20% and 25% and with the addition of VMA and SP. Yield stress of cement paste was lower than 10Pa and this is the typical range of self-compacting concrete and paste [30, 31].

4.2. Test on harden concrete

4.2.1. Compressive strength of cement mortar. The compressive strength of cement mortar was found to be high in 15% addition of steatite in all 4 combinations. And the ultimate strength was found in the cement paste with 15% steatite and with the addition of SP. The lowest compressive strength was obtained with 25% addition of steatite and without the use of SP and VMA. The increase in compressive strength between the lowest and the ultimate was found to be around 46%. At 15% addition of steatite, it could fill all the pores in the cement mortar hence produce the denser mix, which contributes to the increase in the strength of cement mortar [29]. The addition of steatite also produces the formation of M-S-H gel along with the C-S-H gel, which contributes a reasonable increase in strength [32]. Further increasing the steatite content there are no excess pores to be

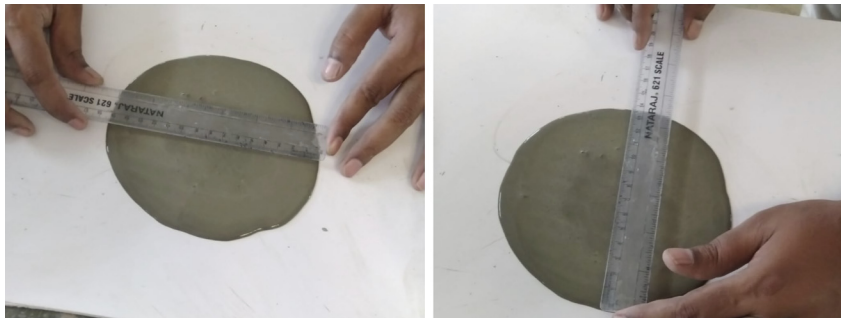


Fig. 7. Measurement of Spread diameter of cement paste

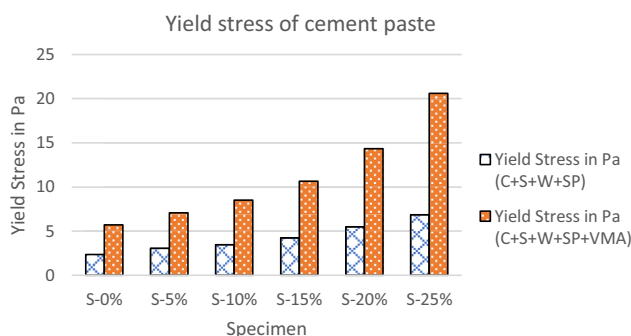


Fig. 8. Yield stress value based on the miniature slump spread diameter

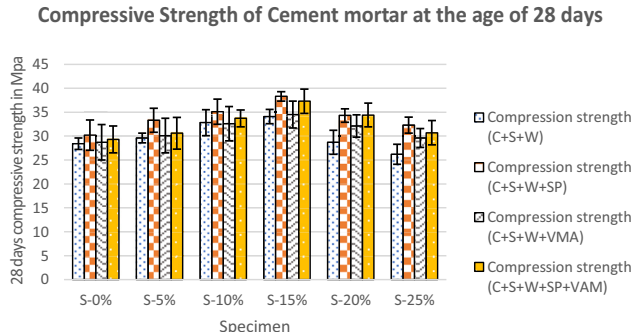


Fig. 9. Compressive strength of cement mortar at the age of 28 days

filled hence it becomes a residual content, hence the strength is diminishing [32]. The 28 days compressive strength of cement mortar was calculated along with standard deviation of test samples and plotted in Fig. 9.

5. CONCLUSION

The effect of ultra-fine natural steatite powder, SP and VMA in the fresh and hardened properties of the cement paste and mortar was studied to understand how the same minerals and chemicals will behave in a complex structure like concrete. Based on the results, the following conclusions were drawn.

Effect of Steatite

- The presence of steatite in cement paste, mortar or concrete will increase the water demand due to the finer particle size and high-water absorption. Hence it is recommended to use a water-reducing admixture to compensate for this effect so that all the cement particles will get hydrated and produce the required strength.
- The inclusion of steatite up to 20% to the weight of the cement reduces the setting time. When compared with the control specimen there is a reduction of 10 min in the initial setting time and one hour in the final setting time. Therefore, the addition of steatite up to 20% is recommended to use for quick removal of formwork during concreting. Also, it advised not to use the steatite beyond 20% since it increases the setting time of cement to a greater extent.
- The addition of steatite diminishes the flow of cement paste. Hence the same is expected in cement mortar and concrete. This is mainly due to the formation of denser paste and absorption of more water when the steatite is added. Thus it is recommended to use steatite if there are visible segregation or bleeding effects in concrete.
- The incorporation of steatite increases the strength of cement mortar as expected. This is mainly due to the production of denser composition. Since the particle size of steatite is smaller than the particle size of cement, it occupies the voids present in mortar, thus it increases the strength so in concrete also we could expect this same kind of results. The optimum increase in the strength was found at 15% addition of steatite. The reason behind this is that up to 15% steatite contributes to pores filling. Above this ratio there become lesser voids and the residual steatite becomes an inert material in the cement paste, hence reducing the strength.

Effect of SP and VMA

- The addition of SP and VMA reduces the water demand. On the other hand, the addition of these two chemical admixtures increases the initial and final setting time.
- The inclusion of SP increases the flow properties whereas the incorporation of VMA reduces flow. At the same time, VMA produces much denser paste, hence the

addition of VMA in concrete could reduce the segregation effects. Therefore it is recommended to use SP along with VMA to produce better self-compacting concrete.

- Based on the test results of the yield stress it is concluded that we could produce self-compacting concrete for all sets of mix containing SP except for the mix with 15% 20% and 25% with VMA. Even this could be brought to SCC if we use mineral admixtures like fly ash or GGBS additionally.

Finally, it is concluded that the addition of steatite, SP, and VMA could be a better combination in producing high-performance concrete hence the negative effect of water demand caused by steatite has been nullified by the incorporation of steatite and the positive effects could result in producing denser concrete. The addition of SP will result in better workable concrete and the addition of VMA will make the concrete flow uniformly without segregation.

Future scope

The effect of steatite, SP and VMA has been successfully studied at the micro level. Thus, we could study the effect of these minerals and chemicals in a complex structure like concrete and we could try producing high performance or self-compacting concrete.

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