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OPTIMIZATION OF SUPERPLASTICISER AND VISCOSITY MODIFYING AGENT IN SELF COMPACTING MORTAR

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ABSTRACT

This paper investigated the use of mini slump cone test along with the graduated glass plate to obtain the optimization of Superplasticiser (SP) and Viscosity Modifying Agent (VMA) in self compacting mortar (SCM). The SCM mixes had 35% replacement of cement with class F fly ash and water/cementitious ratios by weight (w/cm) 0.32 and 0.36. It is observed that for the same cementitious proportions, the optimum dosage of SP was the same for the mixes having w/cm 0.32 and 0.36. Mortar mixes with w/cm 0.36 showed an increase in the rate of flow i.e., lower viscosity at each level of SP dosage as compared to that of mixes with w/cm 0.32. It is also observed that minimum dosage of VMA was required to use in the mortar mixes having w/cm 0.36 in order to arrest the bleeding. Whereas, the use of VMA dosage was not required to use in the mortar mixes having w/cm 0.32 as no bleeding was observed at the optimum dosage of SP. Practically, it is seen that mini slump cone test is the best choice for SCM tests to evaluate the mortar spread and its viscosity (T_{20}). Also, it is seen that percentage of sand in mortar doesn't affect the optimum dosage of SP (saturation point) when the cementitious proportions are kept the same.

Keywords: self compacting mortar; mini slump cone; graduated glass plate; spread; T_{20}; viscosity

1. INTRODUCTION

Rheologically speaking, self compacting concrete (SCC) has a low yield stress and sufficient plastic viscosity to ensure a balance between its fresh properties. A low yield value is needed to improve deformation capacity, while viscosity is essential to maintain a homogeneous system during handling and placing until the start of

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hardening. Sufficient viscosity is required to ensure proper deformation velocity, passing ability and segregation resistance.

Newman and Choo [1] stated the effects of different materials on the rheological properties i.e., yield stress and plastic viscosity (Bingham parameters) of concrete as shown in Figure 1. These will also be applicable to SCC.

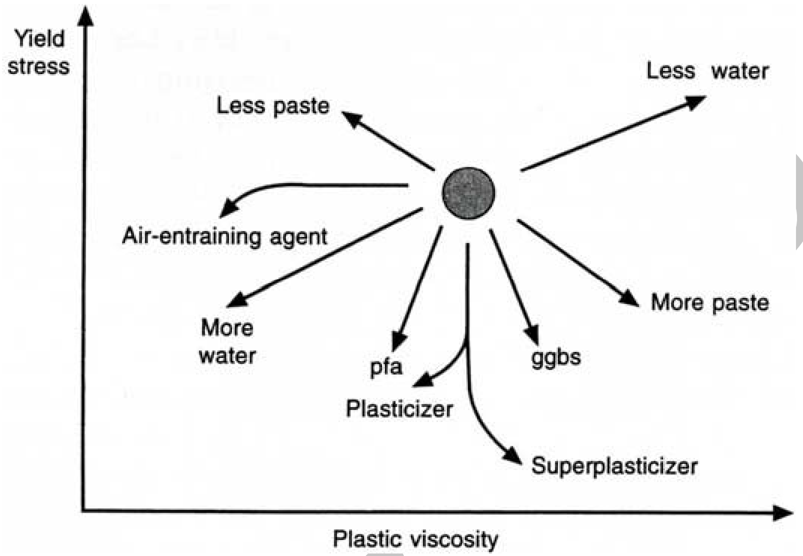

Figure 1. General effects of concrete constituents on the Bingham parameters

Figure 1 clearly indicates that a SCC with low yield stress will be achieved by adding superplasticiser (SP), water, paste or some additives (fly ash or GGBS). Viscosity is controlled by changing water content, paste content or adding some additives (fly ash).

From the Figure 1, it is clearly seen that at some point (i.e., after saturation point), the increase of SP dosage tends to increase the viscosity. Adding more water reduces both yield stress and viscosity, but leads to segregation. So, Viscosity modifying agent (VMA) is generally used to control the segregation. But adding more VMA also increases the yield stress and the plastic viscosity [2]. It is to be considered that if proper optimization of the materials is not done, it leads to adverse effects.

Thus, optimization of SP and VMA in SCM must be done to ensure a stable SCC having low yield stress and adequate viscosity for the given w/cm and mix proportion. And this is best done by self compacting mortar tests.

Studies on the paste [3] or mortar [4] have shown that the rheological properties of the matrix are important to achieve the required fresh properties of SCC.

Due to the lower content of coarse aggregate in SCC, mortar exerts more effects on the fresh properties of SCC than conventional concrete (CC). Mortar not only provides lubrication by wrapping coarse aggregates, it also predominantly influences the fresh properties of SCC with a low yield stress and adequate viscosity so as to ensure the required filling and passing ability without blocking and segregation. Mortar is, thus an integral part of SCC mix design and it has also formed a central part of Jin's research

[4] and [5]. Hence, Self-compacting mortar (SCM) is a precondition of the successful production of SCC.

1.1 Tests on fresh mortar

Mortar tests are widely used to design and evaluate SCC. In fact, assessing the properties of SCM is an integral part of SCC design [6]. EFNARC 2002 (European Federation of National Trade Associations) [6] is the only available standard which is dedicated to special construction chemicals and concrete systems. It describes various tests involved in mortar tests to determine the optimum w/cm and optimum dosage of SP and VMA in mortar. They are mini slump cone test to measure the relative slump of the mortar and mini V-funnel test to measure the rate of flow or viscosity of the mortar.

Here in our study, mini slump cone is used to measure the spread of the mortar as described in EFNARC 2002.

Instead of mini V-funnel test, we have used T_{20} from the mini slump cone test, as an indication of rate of flow or viscosity of the mortar spread as conducted by Shekarchi [7].

As T_{20} indicates the intended viscosity of mortar during this test, it is concluded that it is the best replacement of mini V-funnel test. Practically, it is very much feasible to have a single test apparatus to measure both spread and viscosity of mortar so that rigorous mortar tests can be reduced.

2. Experimental study

2.1 Experimental program

Our objective was to determine the optimum dosage of SP and VMA in SCM with the available materials. In this respect, 53 grade ordinary Portland cement (OPC 53), class F fly ash as an additive, river sand, SP and VMA were used in preparing SCMs having w/cm 0.32 and 0.36. The fresh properties that were determined are the mortar spread, T_{20} and consistence retention.

2.2 Material properties

This section will present the chemical and physical properties of the ingredients. Bureau of Indian Standards (IS) and American Society for Testing and Materials (ASTM) procedures were followed for determining the properties of the ingredients in this investigation.

2.2.1 Cement

Ordinary Portland Cement 53 grade was used corresponding to IS-12269(1987) [8]. The physical and chemical properties of the cement as obtained by the manufacturer are presented in the Table 1.

2.2.2 Chemical admixtures

Sika Viscocrete 10R is used as high range water reducer (HRWR) SP and Sika Stabilizer 4R is used as VMA. The properties of the chemical admixtures as obtained from the manufacturer are presented in the Table 2.

Table 1: Chemical composition and physical properties of cement

Particulars	Test result	Requirement as per IS:12269-1987
Chemical composition		
% Silica (SiO_2)	19.79	
% Alumina (Al_2O^3)	5.67	
% Iron oxide (Fe_2O^3)	4.68	
% Lime (CaO)	61.81	
% Magnesia (MgO)	0.84	Not more than 6.0%
% Sulphuric anhydride (SO_3)	2.48	Max. 3.0% when $C_3A>5.0$ Max. 2.5% when $C_3A<5.0$
% Chloride content	0.003	Max. 0.1%
Lime saturation factor CaO- $0.7SO_3/2.8SiO_2+1.2Al_2O_3+0.65Fe_2O_3$	0.92	0.80 to 1.02
Ratio of Alumina/Iron Oxide	1.21	Min. 0.66
Physical properties		
Specific gravity	3.15	
Fineness (m^2/kg)	311.5	Min.225 m^2/kg
Soundness Lechatlier expansion(mm) Auto Clave expansion (%)	0.8 0.01	Max. 10mm Max. 0.8%
Setting time (minutes) Initial Final	90 220	Min. 30 min Max. 600 min

Table 2: Properties of chemical admixtures

Chemical admixture	Specific gravity	pH	Solid content (%)	Quantity (%) by cementitious weight	Main component
Sika viscocrete 10R	1.10	5.0	40	0.6-2.0	Polycarboxylate ether
Sika stabilizer 4R	1.09	7.0	40	0.2-1.0	

2.2.3 Additive or mineral admixture

Class F fly ash produced from Rayalaseema Thermal Power Plant (RTPP), Muddanur, A.P is used as an additive according to ASTM C 618 [9]. As per IS-456(2000) [10], cement is replaced by 35% of fly ash by weight of cementitious material. The physical and chemical properties are presented in the Table 3.

Table 3: Physical and chemical properties of class F fly ash

Particulars	Class F fly ash	ASTM C 618 Class F fly ash
Chemical composition		
% Silica (SiO_2)	65.6	
% Alumina (Al_2O_3)	28.0	
% Iron Oxide (Fe_2O_3)	3.0	SiO_2+ Al_2O_3+ Fe_2O_3>70
% Lime (CaO)	1.0	
% Magnesia (MgO)	1.0	
% Titanium Oxide (TiO_2)	0.5	
% Sulphur Trioxide (SO_3)	0.2	Max. 5.0
Loss on ignition	0.29	Max. 6.0
Physical properties		
Specific gravity	2.12	
Fineness (m^2/kg)	360	Min.225 m^2/kg

2.2.4 Fine aggregate

Natural river sand is used as fine aggregate. The bulk specific gravity in oven dry condition and water absorption of the sand are 2.6 and 1% respectively. The gradation of the sand was determined by sieve analysis as per IS-383(1970) [11] and presented in the Table 4. Fineness modulus of sand is 2.26.

2.2.4 Water

Ordinary tap water is used.

2.3 Experimental procedure

2.3.1 Specimen preparation

Mortars were prepared manually in a container in order to observe its behaviour. Mortar volume of 0.0008 m^3 (8 x 10^{-4} m^3) is sufficient for each mortar test using mini slump cone. It is known that mixing procedures have a significant influence on the fresh properties of SCM. Modified Jin's mixing procedure [4] was carried out throughout this work to achieve maximum efficiency of SP and VMA. The mixing procedures for SCM with SP only shown in Figure 2 and both with SP and VMA shown in Figure 3 are described as follows.

Table 4: Sieve analysis of fine aggregate

Sieve No.	Cumulative percent passing	
	Fine aggregate	IS: 383-1970 – Zone III requirement
3/8" (10mm)	100	100
No.4 (4.75mm)	100	90-100
No.8 (2.36mm)	100	85-100
No.16 (1.18mm)	99.25	75-100
No.30 (600µm)	65.08	60-79
No.50 (300µm)	7.4	12-40
No.100 (150µm)	1.9	0-10

Mixing procedure for mortar with SP only:

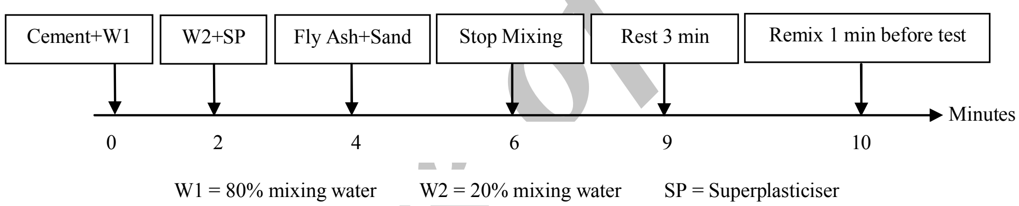

Figure 2. Mixing procedure for mortar with SP only

1. Cement and 1st part (80%) of water was mixed for two minutes.
2. SP along with the 2nd part (20%) of water was added and mixed for two minutes.
3. Fly Ash and sand was added to the mix and mixed thoroughly for two minutes.
4. The mix was stopped and kept rest for 3 minutes.
5. The mix was remixed for one minute and discharged for mortar test.

Mixing procedure for mortar with SP and VMA:

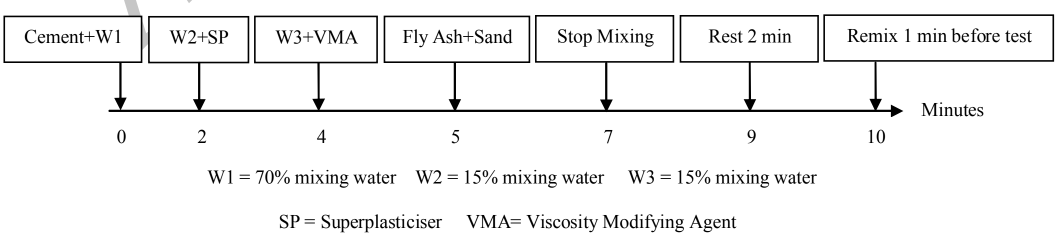

Figure 3. Mixing procedure for mortar with SP and VMA

1. Cement and 1st part (70%) of water was mixed for two minutes.
2. SP along with the 2nd part (15%) of water was added and mixed for two minutes.

3. VMA along with the 3rd part (15%) of water was added and mixed for one minute.
4. Fly Ash and sand was added to the mix and mixed thoroughly for two minutes.
5. The mix was stopped and kept rest for 2 minutes.
6. The mix was remixed for one minute and discharged for mortar test.

2.3.2 Mortar test apparatus

Mini slump cone and graduated glass plate

The test apparatus for measuring the spread and viscosity of mortar comprises a mini frustum (slump) cone and a graduated glass plate. Mini slump cone has top and bottom diameters of 7 cm and 10 cm respectively with a cone height of 6 cm. The graduated glass plate contains two circular graduations of 10 cm and 20 cm in diameter marked at the center of the glass plate as shown in Figure 4. With this test apparatus, both viscosity and spread of the mortar can be measured from a single test.

Figure 4. Mini slump cone and graduated glass plate

2.3.3 Determination of spread

In this test, the truncated cone mould is placed exactly on the 10 cm diameter graduated circle marked on the glass plate, filled with mortar and lifted upwards. The subsequent diameter of the mortar is measured in two perpendicular directions and the average of the diameters is reported as the spread of the mortar.

2.3.4 Determination of T_{20}

T_{20} is the time measured from lifting the cone to the mortar reaching a diameter of 20 cm. The measured T_{20} indicates the deformation rate or viscosity of the mortar. So, during this test, T_{20} can be measured first and average of the spread can be measured subsequently. This procedure is similar to slump cone test conducted on SCC.

2.3.5 Determination of consistence retention

Along with the spread and T_{20}, consistence retention is also an important fresh property of

SCC. It refers to the period of duration during which SCM or SCC retains its properties, which is important for transportation and placing.

Consistence retention was evaluated by measuring the spread and T_{20} of successful SCM at 45 and 60 minutes after adding water. Between measurements, the mortar was stored in the mixing bowl and covered the top to avoid moisture loss. The mortar was remixed for one minute before each test.

3. MIX DESIGN

This paper investigated the effect of SP and VMA dosage on the three SCM mixes (Mix 1, Mix 2 and Mix 3) which had 35% replacement of cement with class F fly ash and water/cementitious ratios by weight (w/cm) 0.32 and 0.36 as shown in Tables 5 and 6. In other words, the cementitious proportion is kept same for all the mixes. The volume of paste content was kept at 359 lit/m^3 for the two mixes Mix 1 and Mix 2 and 388 lit/m^3 for the Mix 3.

Table 5: Mortar mix proportions per 0.0008 m^3 for 40% of sand in mortar

w/cm	%SP	%VMA	Cement (g)	Fly ash (g)	Water (ml)	Sand (g)	SP (ml)	VMA (ml)
	by cementitious weight							
	0.6	0	253	136	128	498	2.3	0
	0.7	0	253	136	128	498	2.7	0
	0.8	0	252	136	127	498	3.1	0
	0.9	0	252	136	127	498	3.5	0
0.32	1	0	251	135	126	498	3.9	0
Mix 1	1.1	0	251	135	126	498	4.3	0
	1.2	0	251	135	126	498	4.6	0
	1.3	0	250	135	125	498	5.0	0
	1.4	0	250	135	125	498	5.4	0
	1.5	0	250	134	124	498	5.8	0
	0.7	0	239	129	136	498	2.6	0
	0.8	0	239	129	135	498	2.9	0
0.36	0.8	0.2	238	128	134	498	2.9	0.7
Mix 2	0.9	0.2	238	128	134	498	3.3	0.7
	1.0	0.2	237	128	134	498	3.6	0.7
	1.1	0.2	237	128	134	498	4.0	0.7

As per the general purpose mix design method developed by Okamura [12], sand content in mortar is kept at 40% of mortar volume in the first two mixes (Mix 1 and Mix 2) as shown in Table 5. For the third mix (Mix 3), sand is kept at 45% of mortar volume in order to evaluate the optimization of SP and VMA as shown in Table 6. These mortar tests conducted to study the interactions among cement, mineral and chemical admixtures and to determine optimum dosages of SP and VMA for the given w/cm.

Table 6: Mortar mix proportions per 0.0008 m^3 for 45% of sand in mortar

w/cm	%SP	%VMA	Cement (g)	Fly ash (g)	Water (ml)	Sand (g)	SP (ml)	VMA (ml)
	by cementitious weight							
0.36 Mix 3	0.7	0	274	148	156	567	3.0	0
	0.8	0	274	147	155	567	3.4	0
	0.8	0.2	273	147	154	567	3.4	0.8
	0.9	0.2	273	147	154	567	3.8	0.8

Mortar tests started with minimum dosage of SP by percentage weight of cementitious and increased the dosage of SP till the maximum spread of the mortar has reached. When the mortar spread shows halo, minimum dosage of VMA by percentage weight of cementitious was used to avoid the bleeding. For each dosage of SP and VMA, fresh mortars were prepared and tested.

3.1 Mortar fresh properties

Mortar fresh properties i.e., mortar spread, T_{20} and consistence retention are presented in the Tables 7, 8, 9 and 10 for all the SCM mixes.

4. RESULTS AND DISCUSSION

4.1 Effect of SP and VMA on spread and T_{20} for the Mix 1

The influence of SP on mortar spread and T_{20} (viscosity) for the Mix 1 is shown in Table 7.

It is observed that as the SP dosage increases, the spread of mortar increases and T_{20} decreases. Spread reaches the maximum value and T_{20} reduces to the minimum at a specific SP dosage. This point is referred as saturation point.

For this mix, maximum spread 301 mm was arrived at 0.9% SP dosage as shown in Figure 5. So, it is the optimum dosage of SP for this mix.

Table 7: Spread and T_{20} for the Mix 1

w/cm	%SP	Time after water mixing (min)		
		Initial		
		Spread (mm)	T_{20} (sec)	Spread + Halo (mm)
0.32 Mix 1	0.6	271	9.67	-
	0.7	287	6.62	-
	0.8	298	5.94	-
	0.9	301	4.68	-
	1.0	300	4.70	-
	1.1	297	4.77	-
	1.2	296	5.6	-
	1.3	296	5.85	305
	1.4	295	6.27	301
	1.5	282	6.9	285

Figure 5. Maximum spread of the Mix 1 at 0.9% SP

Beyond this saturation point, adding SP causes decrease in mortar spread and increase in T_{20}. Adding even more SP leads to segregation of mortar. So, it is practically seen that before reaching the saturation point, the addition of SP increases the spread and decreases T_{20}. After the saturation point, the addition of SP leads to decrease in the spread and increase in T_{20}.

The use of VMA dosage was not used in this mortar Mix 1 as no segregation or bleeding (halo) was observed in the mortar before the saturation point.

4.2 Effect of SP and VMA on spread and T_{20} for the Mix 2

But for the Mix 2 with w/cm 0.36, it is seen that bleeding (halo) was observed at the SP dosage of 0.7% by cementitious weight itself i.e., before the saturation point as shown in Table 8 and Figure 6. As we know that increase of water reduces the yield stress and viscosity and some times leads to segregation. This behaviour is clearly seen in the mixes Mix 1 and Mix 2 when w/cm is increased from 0.32 to 0.36. T_{20} value of Mix 2 is significantly low i.e., rate of flow has been increased as compared to that of Mix 1.

Table 8: Spread and T_{20} for the Mix 2

w/cm	%SP	%VMA	Time after water mixing (min)		
			Initial		
			Spread (mm)	T_{20} (sec)	Spread + Halo (mm)
0.36 Mix 2	0.7	0	295	3.25	300
	0.8	0	295	3.03	304.5
	0.8	0.2	237	6	-
	0.9	0.2	296	3.15	-
	1.0	0.2	231	5.78	-
	1.1	0.2	290	3.03	-

Figure 6. Spread with halo of the Mix 2 at 0.7% SP

At 0.8% SP dosage, spread does not change, but T_{20} is decreased from 3.25 sec to 3.03 sec and the thickness of halo is increased as shown in Figure 7(a). It clearly indicates the requirement of VMA in order to resist segregation.

Then, fresh mortar mix was prepared both with 0.8% SP dosage and minimum VMA dosage of 0.2% by cementitious weight and mortar test was conducted. It is observed that the minimum dosage of VMA stopped the bleeding, but the spread has decreased from 295 mm to 237 mm as shown in Figure 7(b) and T_{20} increased from 3.03 sec to 6 sec i.e., viscosity is increased.

(a) Spread with halo without VMA (b) Spread without halo with 0.2% VMA

Figure 7. Spread of the Mix 2 at 0.8% SP

This may be the reason as Khayat [2] stated that VMA can imbibe some free water and increase the viscosity, thus reducing the risk of segregation or bleeding. From the result, it indicates that maximum spread has not been arrived at 0.8% SP dosage and 0.2% VMA dosage. It leads to increase in SP dosage.

Hereafter, 0.2% VMA dosage was maintained for all the mixes of Mix 2 category. Now, fresh mortar mix was prepared with 0.9% SP dosage and 0.2% VMA dosage and tested. It is seen that spread was increased from 237 mm to 296 mm without any bleeding as shown in Figure 8 and T_{20} decreased from 6 sec to 3.15 sec i.e., rate of flow has been increased satisfactorily.

Figure 8. Maximum spread of the Mix 2 at 0.9% SP and 0.2% VMA

After this point, mix prepared with 1% SP and 0.2% VMA dosage and tested. Mortar spread again decreased from 296 mm to 231 mm which is less than the spread 237 mm that has been arrived at 0.8% SP dosage and 0.2% VMA dosage. At this stage, T_{20} increased from 3.15 sec to 5.78 sec. This result was not satisfactory.

Again, a fresh mix with 1.1% SP and 0.2% VMA was prepared and tested. Spread has increased from 231 mm to 290 mm, but it is less than 296 mm which was maximum spread at 0.9% SP dosage. When comparing the mixes with 0.9% and 1% SP dosage, maximum spread 296 mm was observed for the mix with 0.9% SP dosage. So, it is referred as the saturation point. Thereby, it is noted that for the Mix 2 having w/cm 0.36, the optimum dosages of SP and VMA were 0.9% and 0.2% respectively.

Interestingly, it is observed that VMA dosage didn't affect the saturation point of SP dosage which is 0.9%.

In our study, saturation point is arrived at the same SP dosage of 0.9% by cementitious weight for the two mixes Mix 1 and Mix 2 with w/cm 0.32 and 0.36 respectively. It is inline with the statement that for mortars with the same powder (binder) proportions, the dosage of SP expressed in terms of percentage by cementitious weight, doesn't change significantly with the variation of w/cm [13].

4.3 Effect of SP and VMA on spread and T_{20} for the Mix 3

The influence of SP and VMA on mortar spread and T_{20} (viscosity) for the Mix 3 is shown in Table 9. This mix has 45% of sand in mortar volume. As it can be seen from the Table 9, spread has decreased and T_{20} has increased when compared to that of Mix 2. This is because of increase in percentage of sand in mortar from 40% (Mix 2) to 45% (Mix 3). But, the behaviour of the Mix 3 is almost similar to that of the Mix 2. Interestingly, maximum spread 293mm was observed at 0.9% SP dosage which was saturation point.

Table 9: Spread and T_{20} for the Mix 3

w/cm	%SP	%VMA	Time after water mixing (min)		
			Initial		
			Spread (mm)	T_{20} (sec)	Spread + Halo (mm)
0.36 Mix 3	0.7	0	285	5.56	290
	0.8	0	290	4.12	301
	0.8	0.2	245	5.78	-
	0.9	0.2	293	3.31	-
	1.0	0.2	243	5.66	-
	1.1	0.2	290	3.23	-

It is to be noted that irrespective of sand content in mortar volume, if cementitious proportions are kept the same for the mixes, the dosage of SP (i.e., saturation point) tends to be the same for those mixes.

4.4 Consistence retention

As it can be seen from Table 10, all these three mixes attained good consistence retention in the spread and T_{20} at 45 and 60 minutes after adding water. So, it can be stated that the used chemical admixtures had good compatibility with the cement and mineral admixture.

Table 10: Spread and T_{20} at 45 and 60 minutes after adding water

w/cm	%SP	%VMA	Time after water mixing (min)					
			Initial		45 min		60 min	
			Spread (mm)	T_{20} (sec)	Spread (mm)	T_{20} (sec)	Spread (mm)	T_{20} (sec)
0.32 Mix 1	0.9	0	301	4.68	301	4.76	292	5.24
0.36 Mix 2	0.9	0.2	296	3.15	285	4.78	284	6.25
0.36 Mix 3	0.9	0.2	293	3.31	283	4.92	282	6.31

Thus, polycarboxylate-type superplasticiser can provide higher consistence retention [14].

Hence, during transporting and placing, the fresh properties of SCC after mixing should be maintained close to their initial level, usually for 60 to 90 minutes [15], [16] and [17].

5. CONCLUSIONS

The following conclusions can be drawn based on the results of this experimental investigation for the mortar mixtures and procedures used:

1. Mini slump cone and graduated glass plate is the best choice for SCM tests to evaluate the mortar spread and its viscosity (T_{20}) respectively in order to get the optimization of SP and VMA in SCM. T_{20} is the best alternative for mini V-Funnel test for determining the viscosity of the spread.
2. Polycarboxylate ether based SP (Sika Viscocrete 10R) and Polycarboxylate ether based VMA (Sika Stabilizer 4R) showed better performance in SCM in view of good mortar spread, adequate viscosity (T_{20}) and consistence retention.
3. Maximum spread observed at the optimum dosage of SP so called saturation point of

SP dosage.

4. Before the saturation point, the increase of SP dosage increases the spread and decreases the viscosity (T20) of the mortar.
5. After the saturation point, the increase of SP dosage doesn't show any improvement of the mortar rather it decreased the spread and increased the viscosity (T20).
6. Even adding more SP causes segregation of the mortar.
7. VMA was required to use when the mortar spread shows halo (bleeding) before the saturation point of SP.
8. The use of VMA can imbibe the water so as to resist bleeding and makes the mortar so cohesive.
9. VMA dosage doesn't affect the saturation point of SP dosage.
10. For mortars with the same cementitious proportions, the dosage of SP expressed in terms of percentage weight of cementitious, holds the same value even with the variation of w/cm.
11. For mortars with the same cementitious proportions, the dosage of SP expressed in terms of percentage weight of cementitious, holds the same value even with the variation of percentage of sand in mortar.
12. The increase of sand in mortar decreases the spread and increases the viscosity (T20).

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