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The Effect of Retarding Chemical Superplasticizers on the Setting Time of Cement Pastes in Kenya: A Case Study of Ready Mix Concrete in Nairobi

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Abstract

The addition of superplasticizers to concrete confers high strength and workability to it at reduced water/cement ratios. The high workability of superplasticized concrete inevitably permits the use of superplasticizers in ready mix concrete in order to offset the major challenge of slump loss associated with delays in placing concrete or accelerated setting due to hot weather conditions. However, the gains of using superplasticizers are likely to be reversed if the incompatibility issues between the cement and the superplasticizer are not addressed. With the growing number of new cement brands in Kenya, proper guidelines on the use of superplasticizers with the local cement brands need to be developed in order to prevent the problem of incompatibility and obtain the maximum benefit of using superplasticizers. The research seeks to advance proper guidelines on the optimal usage of superplasticizers with local cement paste in ready mix concrete. Major challenges of ready mix concrete in Kenya are as a result of slump loss when the normal setting time of cement is exceeded due to traffic delays prior to concrete placing and also in cases where there is incompatibility between the local cement brands and the superplasticizers. Nairobi City is the most affected, with the longest delays in transportation of ready mix concrete and also with the highest number of cement brands in the market. To compensate for the slump loss in ready mix concrete, additional water is often added at the job site which results in a weaker and less durable concrete.

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There is therefore need to carry out research on the setting time of ready mix concrete in Kenya in order to ensure that the quality is not compromised by redosing with water during transportation or due to incompatibility issues. The research uses the Vicat apparatus test in order to evaluate the initial and final setting times of three types of cement brands widely used in Kenya and the resultant effect when chemical superplasticizers are added. The cement brands tested are Mombasa Portland Pozzolanic Cement, Bamburi Portland Pozzolanic Cement and Blue Triangle Portland Pozzolanic Cement. Two types of chemical superplasticizers have been evaluated and they include Sika Viscocrete 10 and BASF Master Rheobuild RMC 80 (Formerly Rheobuild LD 80). Portland Pozzolanic Cement (PPC) has been adopted in this study due to its wide usage than Ordinary Portland cement (OPC). One of the main advantage of Portland Pozzolanic cement being the lower heat of hydration in concrete and the lower cost of production. The research has indicated that Sika Viscocrete 10 is more suitable for use in ready mix concrete in the City of Nairobi than Master Rheobuild RMC 80. The usage of Master Rheobuild RMC 80 in ready mix concrete in Nairobi requires the addition of a chemical retarder to prevent the quick setting properties of the superplasticizer. It was found that increasing the dosage of Sika Viscocrete 10 in the cement paste leads to a higher retarding effect than Master Rheobuild RMC 80. It was observed that a dosage of 1.1% of Sika Viscocrete 10 extends the initial setting time by more than 100% while the same quantity of Master Rheobuild RMC 80 superplasticizer shortens the initial setting time by up to 32%. It was also noted that over dosage of the superplasticizers reverses the gains of the superplasticizers in concrete. For instance, a higher dosage of Sika Viscocrete 10 produces a high retarding effect leading to significantly high slump retention while Master Rheobuild RMC 80 produces a high accelerating effect at higher dosage leading to significantly high slump loss. The research has also indicated that workable concrete can be achieved at a lower water/cement ratio when superplasticizers are used than when not. Master Rheobuild RMC 80 produces the highest water reducing effect of 23% while SikaViscocrete 10 produces 14%. The lower the water /cement ratio, the higher the concrete strength.

Keywords: Superplasticizer; Portland pozzolanic cements; Water/cement ratio; Ready mix concrete; Setting time; Incompatibility; Traffic delays; Over-dosage; Slump retention.

1. Introduction

1.1 Background

Due to the availability of different types of admixtures and cement in the market, there is flexibility in choosing the right composition of the concrete according to the desired parameters, keeping in mind the overall economy and environmental safety. Admixtures, especially new superplasticizers are being developed regularly in the world, which dramatically change the properties of the concrete. But if there is incompatibility between the cement and the admixtures, it may cause rapid loss of workability, excessive quickening/retardation of setting and low rates of strength gain, in addition to economic loss. In East Africa, Kenya is leading in both cement production and consumption [1, 2, 3]. As per the construction index of August 2013, there were five major cement producing companies in Kenya as indicated in Figure 1. The sixth cement producing company is Savanna cement which joined the market in 2013, Dangote Cement and Lake Cement are slated to enter the market soon.

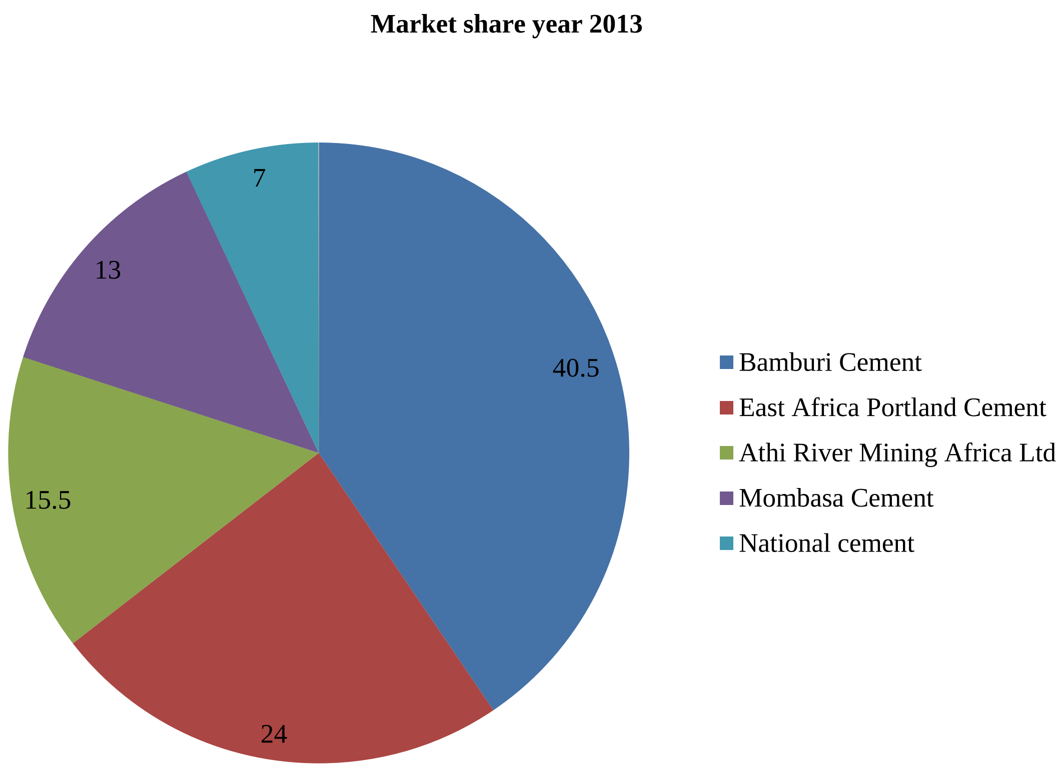

Figure 1: Local market share of the six cement companies in Kenya [1, 2, 3].

With the entrance of many cement brands and different concrete admixtures in the Kenyan market, there is need to carry out a study on the effect of chemical superplasticizers on local cement brands. Three of the six local cement companies have been selected for this research and they include Bamburi Cement (Nguvu), East Africa Portland Cement (Blue Triangle) and Mombasa Cement (Nyumba) [1, 2, 3]. Superplasticizers, also known as high range water reducing admixtures, are synthetic, water-soluble organic chemicals that significantly reduce the amount of water needed to achieve a given consistence in fresh concrete. There are four types of superplasticizers in the Kenyan market. Two are produced by Sika and they include Sika Viscocrete 10 and Sika Viscocrete 3088. The other two types of superplasticizers are produced by BASF and they include Master Glenium and Master Rheobuild RMC 80. The Sika products can be found at the Laxcon Hardware located in Parklands, Nairobi while the BASF products can be found at the BASF head office located off Mombasa road in Syokimau. This research evaluates two commonly used superplasticizers in Kenya which include Master Rheobuild RMC 80 (Formerly known as Rheobuild LD80) and Sika Viscocrete 10. MasterRheobuild RMC 80 is a liquid product manufactured by BASF and is described as a high range water reducing and high performance superplasticizer. It is designed for the production of rheoplastic concrete and is composed of high molecular weight polymers and refined lignosulphonates. Lignosulphonates, which are commonly used as water reducers, have secondary retarding effects [4]. MasterRheobuild RMC 80 disperses and deflocculates cement particles, thereby increasing the workability of concrete mixes. It meets the requirements of EN 934-2 and BS 5075 part 1 and is dark brown in colour [5]. Viscocrete 10 is a product manufactured by Sika and is described as a high performance superplasticizer. It is a third generation superplasticizer for concrete and mortar based on modified polycarboxylate polymer and meets the requirements for set retarding/high range water reducing superplasticizers according to EN 934-2. Sika Viscocrete 10 acts through surface adsorption and sterical effects separating the cementitious binder particles. It is liquid and light brown in colour [6].Carboxylic acids and their salts present in Sika Viscocrete 10 are commonly used as retarders and have secondary water reducing effects [4]. The effect of the superplasticizers can be summarized in two ways:

1) To reduce water content for increased strength and reduced permeability/improved durability
2) As a cement dispersant at the same water content to increase consistence and workability

Superplasticizers are compatible with almost all other admixtures including air-entraining agents, water reducers, retarders and accelerators. The main disadvantage of superplasticizer usage is loss of workability as a result of rapid slump loss due to incompatibility of cement and superplasticizers [7].

1.2 Statement of the problem

In Kenya, the use of superplasticizers in order to offset the challenges of slump loss due to traffic delays is inevitable. Traffic studies by Gonzales and his colleagues [8] have shown that during peak traffic in Nairobi, more than 40 minutes of delay is experienced at every major intersection alone. This implies that depending on the batching plant location, the cumulative peak delay experienced during transportation of ready mix concrete significantly exceeds the normal setting time of cement and therefore the need for use of superplasticizers. However, the gains of superplasticized concrete are likely to be reversed if incompatibility issues between the local cement pastes and the superplasticizers are not addressed. To compensate for the slump loss in ready mix concrete, additional water is often added at the job site which results in a weaker and less durable concrete. Great investment by the government and foreign companies in the cement manufacturing industry has resulted in production of new brands of cement to meet the increasing local consumption. With the entrance of new brands of cement in the Kenyan market, care need to be exercised when using superplasticizers in ready mix concrete and therefore there is need to carry out research to provide proper guidelines for use when dealing with ready mix concrete.

1.3 Justification

As the use of superplasticizers gains widespread acceptance around the world and especially in Kenya, the need for proper guidelines for its use with local cement brands becomes a necessity. The difficulty in using superplasticizers in ready mix concrete results from the fact that its effects on concrete depend on a number of factors including time of addition, amount of admixture, mixing time, mix proportions, setting time, concrete temperature and ambient temperature [9]. This study seeks to advance useful knowledge on the setting times of the two commonly used chemical superplasticizers (Viscocrete 10 and Rheobuild RMC80) on three types of cement brands in Kenya. The knowledge on the setting times will be essential in dealing with the major challenge of slump loss and prevent the practice of redosing ready mix concrete with water during transportation and hence comprising the quality.

1.4 Objectives

1.4.1 Broad objective

1) To determine the suitability of two retarding chemical superplasticizers (Rheobuild RMC 80 and Viscocrete 10) in ready mix concrete based on the setting times of selected local cement pastes in *Kenya.*

1.4.2 Specific objectives

1) To evaluate the setting times of the three selected cement brands without the chemical superplasticizers
2) To evaluate the setting times of the three selected cement brands mixed with each of the two retarding chemical superplasticizers (Rheobuild RMC 80 and Viscocrete 10)
3) To investigate the water reducing capacity of Sika Viscocrete 10 and Master Rheobuild RMC 80

1.5 Scope and limitations of the research

The research has been limited to three cement brands of Portland Pozzolanic Cement (PPC) produced in Kenya. The cement brands are Bamburi PPC, Mombasa PPC and East Africa Portland PPC. It has also been limited to two types of superplasticizers available and used in the Kenyan market. The superplasticizers used are MasterRheobuild RMC 80 and Sika Viscocrete 10. The research has also not considered the effect of blending the two superplasticizers on the setting time of the cement pastes.

2. Materials and Methods

2.1 Introduction

This chapter contains a detailed description of all the materials used in the experiment, as well as the procedures followed in conducting the various tests. The methodology used for the testing of the superplasticizers is by carrying out laboratory experiments and testing the locally available superplasticizers in different ratios and proportions in order to find out how they behave and what effect they have on the setting of local cement brands.

2.2 Materials

2.2.1 Cements

Three brands of Portland Pozzolanic Cement (32.5N/mm^2) commercially available in Kenya were used. They include:

Mombasa Portland Pozzolanic Cement (Nyumba); This cement corresponds to ASTM Type CEM II cement [10] and meets the requirements of East African Standard KS EAS.18-1 and ISO 9001: 2000 Quality Management System [3].

Bamburi Portland Pozzolanic Cement (Nguvu); This cement corresponds to ASTM Type CEM IV cement [10] and meets the physical and chemical requirements of East African Standard KS EAS.18-1[1].

Blue Triangle Portland Pozzolanic Cement; This cement corresponds to ASTM Type CEM IV cement [10] and meets the physical and chemical requirements of East African Standard KS EAS.18-1 [2].

2.2.2 Water

The water used in all mixes was tap water conforming to ASTM C94 – 1996 [7], Specification for ready mixed concrete.

2.2.3 Superplasticizers

Two types of commercially available chemical superplasticizers in Kenya were investigated. They include:

Master Rheobuild RMC 80 (Formerly Rheobuild LD 80) – This is a high range, high performance and water reducing agent based on high molecular weight polymers and refined lignosulphonates and produced by Master Builders Inc. The manufacturer's recommended dosage is 0.5 to 1litre per 100 kilogram of total cementitious material. It meets the requirements of EN 934-2, Tables 3.1, 3.2, 11.1and 11.2. It also conforms to the requirements of ASTM C-494, Standard Specification for Chemical Admixtures for Concrete, Types A, B, D, F and G [5]. Master Rheobuild RMC 80 is a new product in the Kenyan market.

Sika Viscocrete10 – This is a third generation high performance superplasticizer based on modified polycarboxylate polymer and produced by Sika. The manufacturer's recommended dosage is 0.5 to 1litre per 100 kilogram of total cementitious material. It conforms to the requirements of EN 934-2, Table 11.1/11.2. It also conforms to the requirements of ASTM C-494, Standard Specification for Chemical Admixtures for Concrete, Types A, B, D, F and G [6]. Sika Viscocrete 10 has been used in Kenya for over a decade.

2.3 Equipment

A Vicat apparatus was used for determination of both the standard consistency and setting times of the cement pastes. The apparatus was similar to that recommended by BS EN 196-3 [11].

2.4 Mix proportions

Cement pastes were prepared for determination of consistency and setting time tests. The paste for standard consistency was determined without the addition of the superplasticizers. The determined water content for standard consistence was then applied in the preparation of the other cement pastes.

In order to deduce the water reducing capabilities of the superplasticizers, the w/c ratio of each of the cement paste was gradually reduced from 31.4% to 24.3% (Table 1) while the dosage of the superplasticizer was gradually increased from 0.3% to 1.1% (Table 2) until a non-workable paste was obtained. This was repeated for all the cement pastes and the results compared.

In order to deduce the effect of the superplasticizers on the setting time of the cement pastes, the initial and final setting times were recorded for each of the w/c ratios subjected to incremental superplasticizer dosage (from minimum recommended dosage up to the maximum recommended dosage) as indicated in Table 2. This was repeated for all the cement pastes and the results compared.

Table 1: Amounts of cement and water used for each test

Type of cement	Amount of cement (g)	Water (ml)	w/c ratio (%)
Bamburi PPC	350	110	31.4
		105	30
		100	28.6
		95	27.1
		90	25.7
		85	24.3
Mombasa PPC	350	110	31.4
		105	30
		100	28.6
		95	27.1
		90	25.7
		85	24.3
Blue Triangle PPC	350	110	31.4
		105	30
		100	28.6
		95	27.1
		90	25.7
		85	24.3

Table 2: Amount of chemical superplasticizer used for each test

Type of cement	Amount of cement (g)	Dosage (ml)	Admixture/ cement (%)
Bamburi PPC	350	1	0.3
		2	0.6
		3	0.9
		4	1.1
Mombasa PPC	350	1	0.3
		2	0.6
		3	0.9
		4	1.1
Blue Triangle PPC	350	1	0.3
		2	0.6
		3	0.9
		4	1.1

2.5 Mixing procedure

A digital weighing balance was used to measure 350g of cement. The required quantity of water was measured using a measuring cylinder.

For the control mix, the chemical superplasticizer was not used. The weighed cement was placed into a bowl taking care to avoid loss of cement. Measured water was then added to the cement and mixing commenced immediately using a steel trowel until the paste was uniform.

For the paste with the superplasticizer, the same procedure was repeated except that the required quantity of the admixture and that of water were measured in separate cylinders and then mixed into one solution before being added to the cement.

The time to the nearest minute at which water was added to the cement was recorded as zero time which is the point from which the initial and final setting times were calculated. The procedure was repeated for all the three different cement pastes.

2.6 Test procedure

2.6.1 Standard consistence test

Apparatus

The manual Vicat apparatus and the plunger. The plunger consisted of non – corrodible metal in the form of a right cylinder of at least 45 mm effective length and of 10 mm diameter.

The Vicat mould to contain the paste under test was made of steel. It was 40mm deep and cylindrical with an internal diameter of 75 mm. It was provided with a 2.5 mm thick steel base plate which was larger than the mould.

Filling the mould

The paste was immediately transferred to the lightly oiled mould, placed on the lightly oiled base plate, and filled to excess without undue compaction or vibration.

Any voids in the paste were removed by gently tapping the slightly overfilled mould against the ball of the hand.

The excess was removed by a gentle sawing motion with a straight-edged implement in such a way as to leave the paste filling the mould and having a smooth upper surface.

Determination of standard consistence

The manual Vicat apparatus with the plunger, attached in advance of the test was adjusted by lowering the plunger to rest on the base plate and adjusting the pointer or the scale to zero. The plunger was then raised to the standby position.

Immediately after leveling the paste, the mould and base plate were transferred to the Vicat apparatus and positioned centrally under the plunger. The moving parts were then released quickly and the plunger allowed to penetrate vertically into the centre of the paste. The scale was read at least 5 seconds after penetration had ceased. The scale reading was recorded (which indicates the distance between the bottom face of the plunger and the base plate) together with the water content of the paste expressed as a percentage by mass of the cement. The plunger was immediately cleaned after each penetration.

The test was repeated with pastes for particular water content until one was found to produce a distance between the plunger and base plate of 6 mm. The water content of that paste was recorded to the nearest 0.5% as the water for standard consistence.

2.6.2 Initial setting time test

Apparatus

The plunger was removed and replaced by the steel needle and in the form of a right cylinder of effective length of 45 mm and diameter of 1.13 mm.

The Vicat apparatus with the needle attached in advance of the test was used. The needle was lowered to rest on the base plate and positioned inside the container while adjusting the pointer to read zero. The needle was then raised to the standby position.

Determination of initial setting time

A Vicat mould was filled with a paste of standard consistence. After duration of at least 5 minutes, the mould and base plate were positioned under the needle of the Vicat apparatus. The moving parts were then released quickly and the needle allowed to penetrate vertically into the paste.

The scale was read when penetration had ceased. The scale reading was then recorded, which indicates the distance between the end of the needle and the base plate, together with the time from zero. The penetration on the same specimen was repeated at conveniently spaced positions, not less than 8 mm from the rim of the mould or 5 mm from each other and at least 10 mm from the last penetration position, at conveniently spaced intervals of time of 10minutes intervals. The Vicat needle was cleaned immediately after each penetration.

The elapsed time, measured from zero to the time at which the distance between the needle and the base plate was 6 mm, is the *initial setting time of the cement.*

The specimen was retained for the determination of the final setting time.

The test was repeated for the three different cement pastes when each was mixed with MasterRheobuild RMC 80 and Viscocrete 10.

2.6.3 Final setting time test

Apparatus

The needle fitted with ring attachment of diameter approximately 5 mm to facilitate accurate observation of small penetrations.

Determination of the final setting time

The filled mould used for the initial setting time was inverted on its base plate so that the tests for final set are made on the face of the specimen originally in contact with the base plate. After duration of approximately 5 minutes, the mould and base plate were positioned under the needle of the Vicat apparatus. The moving parts were then released quickly and the needle allowed to penetrate vertically into the paste.

The scale was read when penetration had ceased. The penetrations were then repeated on the same specimen at conveniently spaced positions, not less than 8 mm from the rim of the mould or 5 mm from each other and at least 10 mm from the last penetration position, at conveniently spaced intervals of time of 10 minutes. The Vicat needle was cleaned immediately after each penetration.

The time at which the needle first penetrated only 0.5 mm into the specimen was recorded, together with the time from zero. This is the time at which the ring attachment first fails to mark the specimen and was accurately established by reducing the time interval between penetrations near the final setting time. The final setting time was confirmed by repeating the test in two other positions.

The elapsed time, measured from zero to that at which the needle first penetrated only 0.5 mm into the specimen, is the final setting time of cement, to the nearest 15 min.

The test was repeated for the three different cement pastes when each was mixed with MasterRheobuild RMC 80 and Viscocrete 10.

3. Results

3.1 Introduction

The results of all the experimental tests conducted are presented and discussed in this chapter.

3.2 Data collection

3.2.1 Standard consistence test

The test was conducted at an average temperature of 23◦C.The paste of standard consistence was determined through varying the w/c ratio. The cement paste of standard consistence occurred when the depth of penetration by the plunger resulted in a scale reading of 6 mm on Vicat apparatus. This was obtained at a water/cement ratio of 0.314 (Water content = 110ml, cement =350g). The corresponding initial and final setting times for the paste were recorded as indicated in Appendix A1

3.2.2 Setting times of cement pastes with Master Rheobuild RMC 80

The effect of Master Rheobuild RMC 80 on the setting times of the cement pastes was obtained by increasing the dosage of the admixture from 0.3% to 1.1% of the weight of cement while at the same time monitoring the water reduction capability of the admixture. The w/c was gradually reduced from 0.314 (standard consistence) until a non-workable paste was obtained.

The results of the setting times are indicated in Appendix A2

3.2.3 Setting times of cement pastes with Sika Viscocrete 10

The procedure of determining the effect of Sika Viscocrete 10 on the setting times of the cement pastes was similar to that of Master Rheobuild RMC 80. The dosage of the admixture was increased from 0.3% to 1.1% of the weight of cement while at the same time monitoring the water reduction capability of the admixture.

Reduction of the w/c was done gradually from w/c of 0.314 (standard consistence) until a non-workable paste was obtained.

The results of the setting times are indicated in Appendix A3.

3.3 Data Analysis and discussion

3.3.1 Effect of the superplasticizer on the setting time of the three cement pastes

3.3.1.1 MasterRheobuild RMC 80

(i). Initial setting times

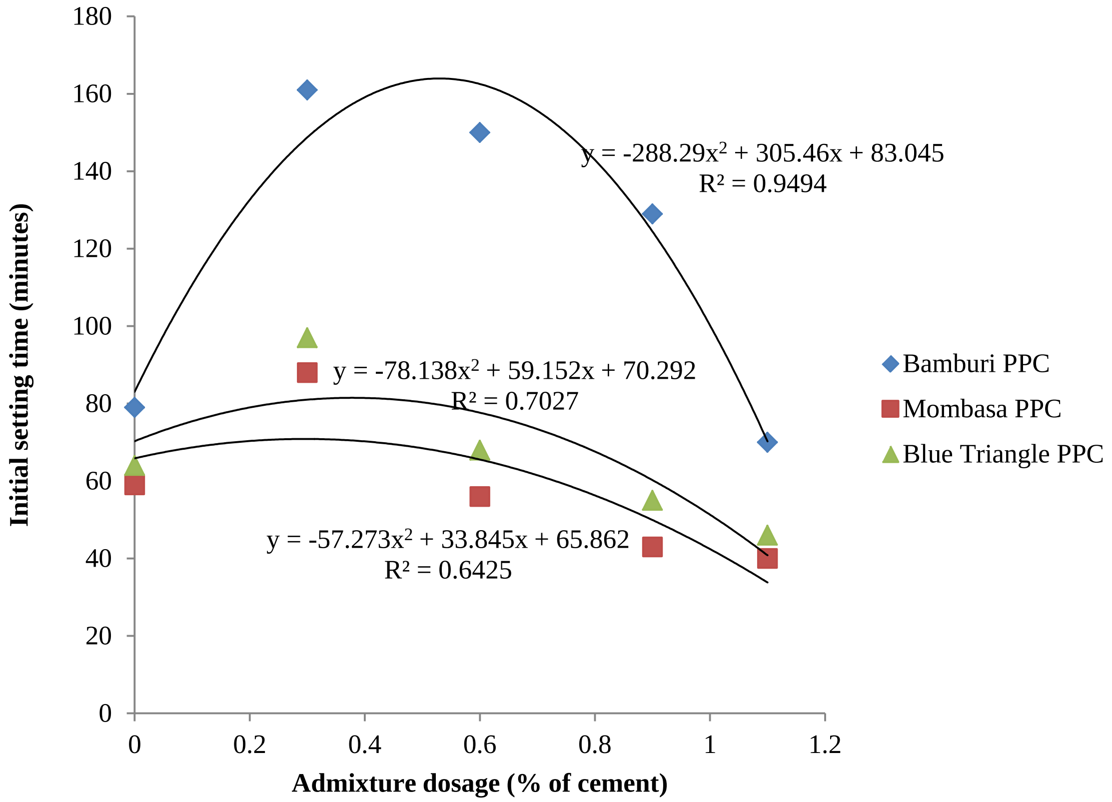

Figure 2: Effect of Master Rheobuild RMC 80 on the initial setting time of cement pastes of standard consistence.

The results reveal that for each of the three types of cements, the addition of Master Rheobuild RMC 80 caused a retardation of the initial setting time up to 0.5% dosage of the superplasticizer and then further addition of the dosage resulted in the shortening of the initial setting time (Figure 2). Mombasa PPC recorded the highest reduction in the initial setting time by 32%, followed by Bamburi PPC and Blue Triangle PPC at 28% and 11.4% respectively (Table 3).

Table 3: Rate of change of the initial and final setting times of standard consistence paste with Master Rheobuild RMC 80

	Rate of change of initial setting time (%)				Rate of change of final setting time (%)			
Admixture (% cement)	0.3	0.6	0.9	1.1	0.3	0.6	0.9	1.1
Bamburi PPC	+104	+90	+63	-11.4	+5	+2	+4	+4
Mombasa PPC	+49	-5	-27	-32	+4.5	0	+4	+5.5
Blue Triangle PPC	+52	+6.3	-14	-28	+8	+8	+6	+6

The final setting times also followed a similar pattern except for Mombasa PPC that exhibited a gradual increase (Figure 3). An increase in the dosage beyond 0.5% resulted in the shortening of the final setting time of the pastes for Bamburi PPC and Blue Triangle PPC.

(ii). Final setting times

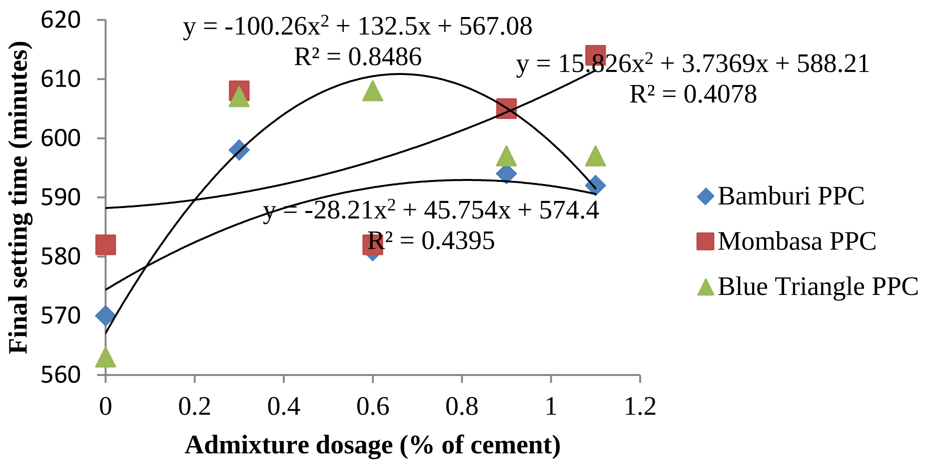

Figure 3: Effect of Master Rheobuild RMC 80 on the final setting time of cement pastes of standard consistence

This trend is in agreement with other published works which have shown that the addition of first generation superplasticizers to concrete will cause quicker setting times [12]. First generation superplasticizers are known not to affect the hydration process of cement. This implies that gypsum is solely responsible for the setting of cement. The results have shown that at a lower dosage of Master Rheobuild RMC 80, the initial setting time of the cement pastes is increased. The optimum dosage required to increase the initial setting time is approximately 0.5%. Beyond 0.5% dosage, the initial setting of the cement pastes is shortened.

The exact cause for this behavior is not known but according to the author, at a lower dosage of the Master Rheobuild RMC 80 superplasticizer (less than 0.5%), there might be some reaction between SO_3- groups of the superplasticizer and the C_3A or its hydration products producing an insoluble ettringite compound around the C_3A particles which in addition to the gypsum reaction concurrently prolong the initial setting time of the cement paste.

Beyond 0.5% dosage, the C_3A in the paste are completely eliminated and therefore there might be some reaction between the excess superplasticizer and Pozzolana to form some compounds giving rigidity to the paste earlier than that obtained by the hydration products of cement. The variation in the initial setting time of the pastes can be attributed to the percentage composition of the C_3A, gypsum and pozzolana in the cement. Mombasa PPC with a lower percentage of gypsum content and high percentage of C_3A produces shorter setting times compared to Bamburi PPC and Blue Triangle PPC.

The variation in the initial setting time between Bamburi PPC and Blue Triangle PPC can be related to different forms of gypsum employed, dehydrate or hemihydrates. Coppola and his colleagues [13] have found that cements manufactured with the same clinker, but with different forms of Calcium Sulfate as set regulators, perform much differently when treated with SNF polymer; in the presence of Calcium Sulfate dihydrate, the fluidizing effect is much more significant than with hemihydrates. These results have been confirmed by Nawa and his colleagues [14] who found that in the presence of SNF superplasticizer cement pastes are much more fluid when dihydrate is used instead of hemihydrates.

From the results, the delay in the final setting time due to the addition of the superplasticizer seem not significant and can be related to the normal hydration of the cement.

Care should however be exercised when using lignosulphonate based superplasticizers with pozzolanic cements. Trial tests should be performed to confirm the behavior of this type of superplasticizers with pozzolanic cements prior to usage.

3.3.1.2 Sika Viscocrete 10

(i). Initial setting times

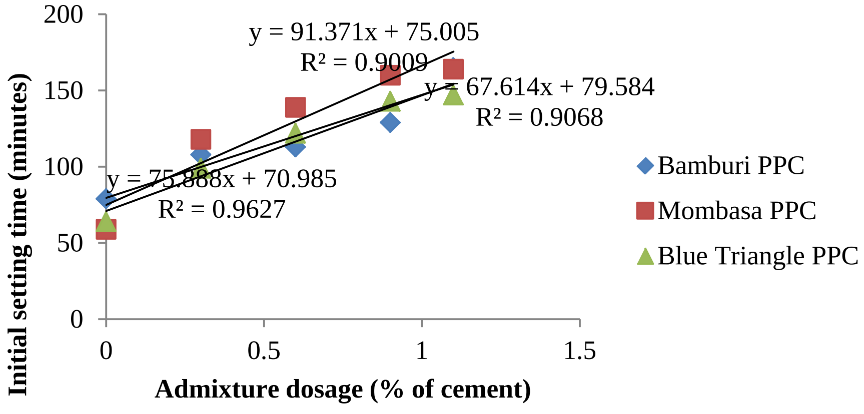

Figure 4: Effect of Sika Viscocrete 10 on the initial setting time of cement pastes of standard consistence

(ii). Final setting times

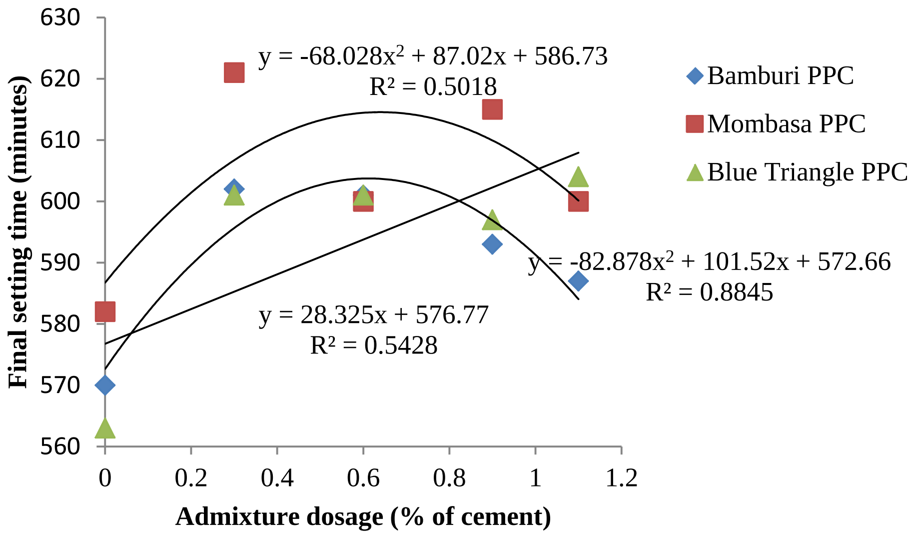

Figure 5: Effect of Sika Viscocrete 10 on the final setting time of cement pastes of standard consistence

The addition of Sika Viscocrete caused marked retardation in the initial setting times for each of the three cements (Figure 4). Mombasa PPC produced the highest retardation of 178%, followed by Blue Triangle PPC and Bamburi PPC at 130% and 109% respectively (Table 4).The delay in the final setting times was however minimal, the highest being exhibited by Blue Triangle PPC at 7.3% followed by Mombasa PPC and Bamburi PPC both at 3%.

Table 4: Rate of change of the initial and final setting times of standard consistence paste with Sika Viscocrete 10

	Rate of change of initial setting time (%)				Rate of change of final setting time (%)			
Admixture (% cement)	0.3	0.6	0.9	1.1	0.3	0.6	0.9	1.1
Bamburi PPC	+37	+43	+63	+109	+6	+5.4	+4	+3
Mombasa PPC	+100	+136	+171	+178	+7	+3	+6	+3
Blue Triangle PPC	+55	+91	+123	+130	+7	+7	+6	+7.3

Viscocrete 10 acts by asteric hindrance effect. The cross-linked polymer is hydrolyzed by the alkaline water phase of the cement paste and then converted into a PC-based polymer.

The negative carboxylic groups due to the alkaline hydrolysis are adsorbed on cement surface of cement particles and are responsible for the dispersion of cement particles and the fluidizing action of the admixture. The low slump-loss effect of this superplasticizer can be related with increasing number of the protruding side chains of the acrylic polymer which would prolong the dispersion of hydrated cement particles through asteric hindrance effect.

When the superplasticizer is incorporated into the cement pastes, the rate of hydration slows down. Consequently, the necessary amount of the hydration products giving rigidity to the cement paste will require longer time. Thus, cement pastes having Sika Viscocrete 10 superplasticizer remain plastic for longer time. The retarding effect of the superplasticizer continues until it is eliminated from the solution by reaction with C_3A from the cement [13]. When the higher admixture content is added, apparently more time will be needed for its removal from the solution and that is why the retarding tendency of the superplasticizer increased with higher dosage. The behavior of the polycarboxylate based Sika Viscocrete 10 is similar to other published works [15]

From figure 4 and 5, Sika Viscocrete 10 produces the best compatibility with the selected pozzolanic cements based on the high regression values.

3.3.2 Comparative setting times of the three cement pastes with the admixtures

3.3.2.1 Master Rheobuild RMC 80

(i). Initial setting times

a) At w/c = 0.314, 0% water reduction

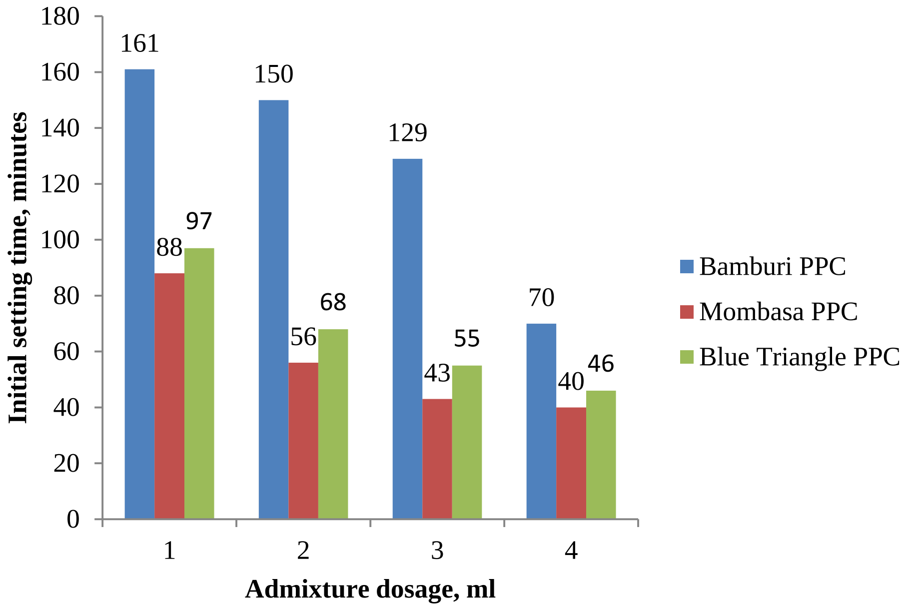

Figure 6: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.314

b) At w/c = 0.3, 4.5% water reduction

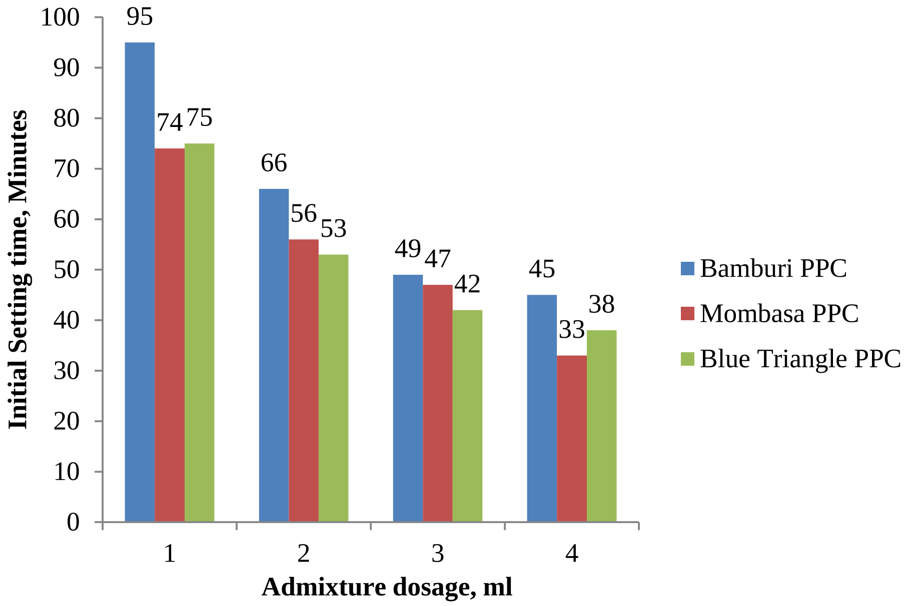

Figure 7: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.3

c) At w/c = 0.286, 9% water reduction

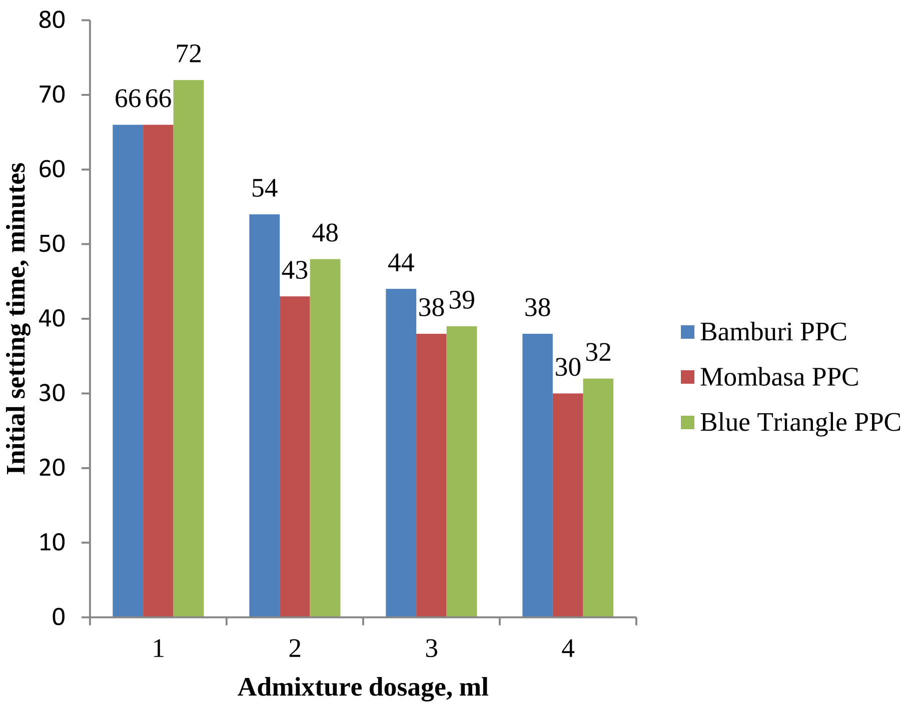

Figure 8: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.286

d) At w/c = 0.271, 14% water reduction

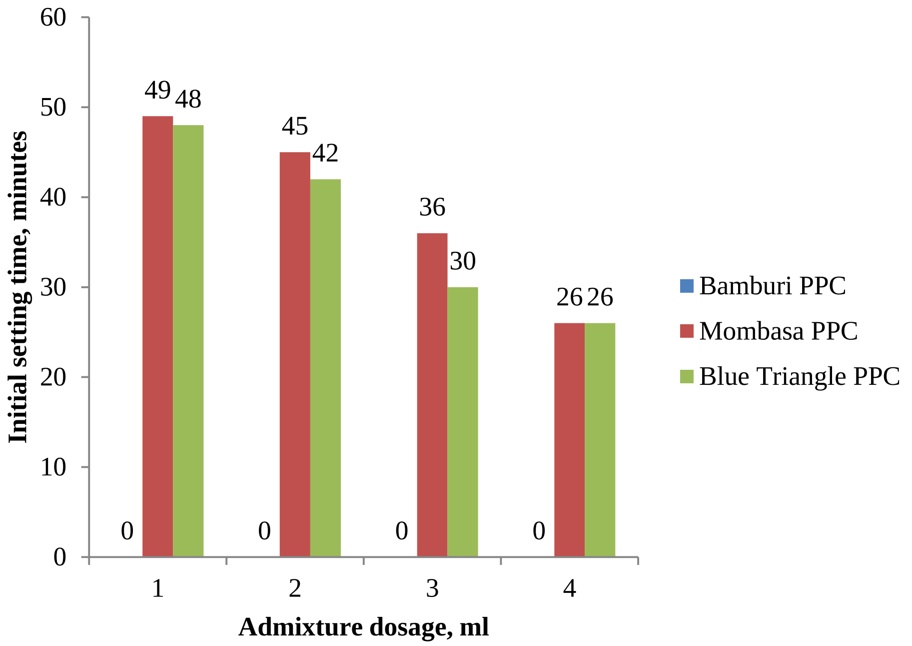

Figure 9: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.271

e) At w/c = 0.257, 18% water reduction

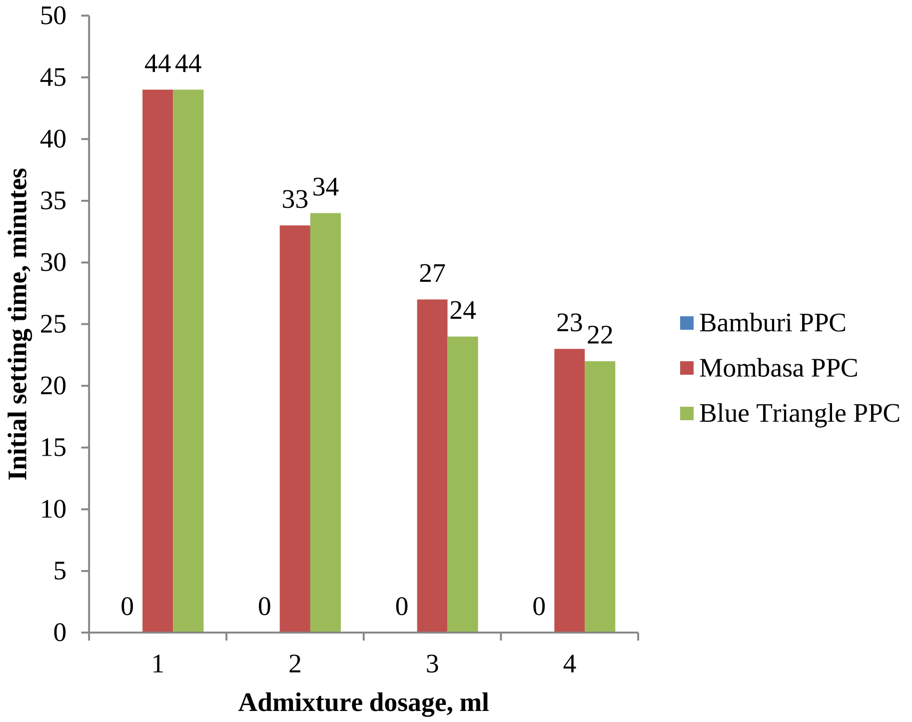

Figure 10: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.257

f) At w/c = 0.243, 23% water reduction

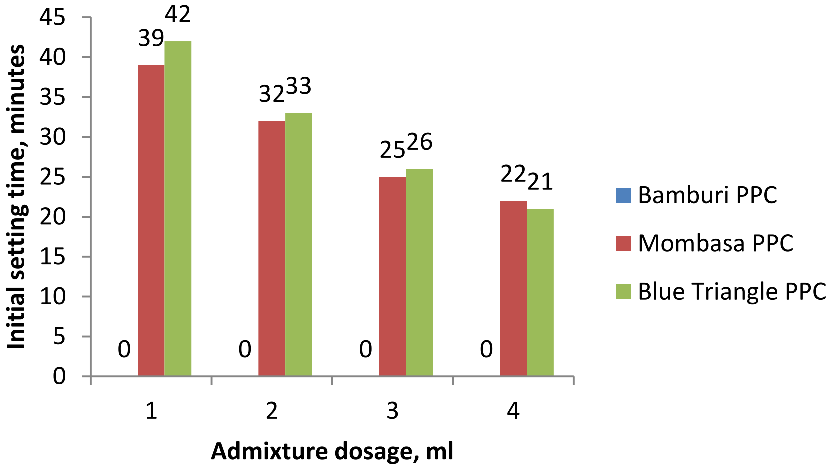

Figure 1: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.243

From the comparative results (Figure 6 to 11), it can be noted that when the cement pastes are mixed with Master Rheobuild RMC 80, the mix is workable at a relatively lower water cement ratio than when no admixture was used.

The high workability effect of Master Rheobuild RMC is as a result of the dispersion mechanism of the superplastizer. RMC 80 is a chemical based on lignosulphonate polymers which act by dispersing and deflocculating pre-dominant coarse agglomerates in the cement paste into smaller cement particles and therefore causing an increase in fluidity of the cement paste. Therefore, at high dosage of the admixture the fluidity effect is significant and can allow a reduction of the w/c ratio without compromising the workability [9, 16].

Master Rheobuild RMC 80 has a water reducing capacity of up to 23%. This is within the range obtained by other researchers [12] for lignosulfonate based superplasticizers.

Bamburi PPC is workable up to a w/c ratio of 0.286 which is lower than w/c ratio for the standard consistence paste. Mombasa PPC and Blue Triangle PPC are workable up to w/c ratio of 0.243 with the admixture.

The results also reveal that at lower w/c ratio and higher dosage of Master Rheobuild RMC 80, the setting time of the cement paste is decreased. This confirms that some reaction exists between excess quantities of the superplasticizer and the hydration products causing rigidity of the paste.

3.3.2.2 Sika Viscocrete 10

(i). Initial setting times

a) At w/c = 0.314, 0% water reduction

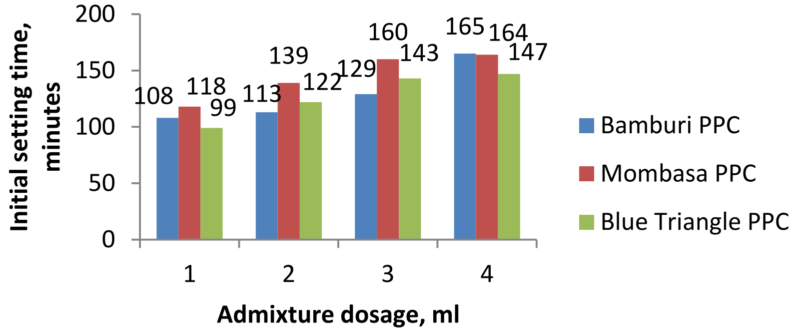

Figure 12: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.314

b) **At w/c = 0.3, 4.5% water reduction**

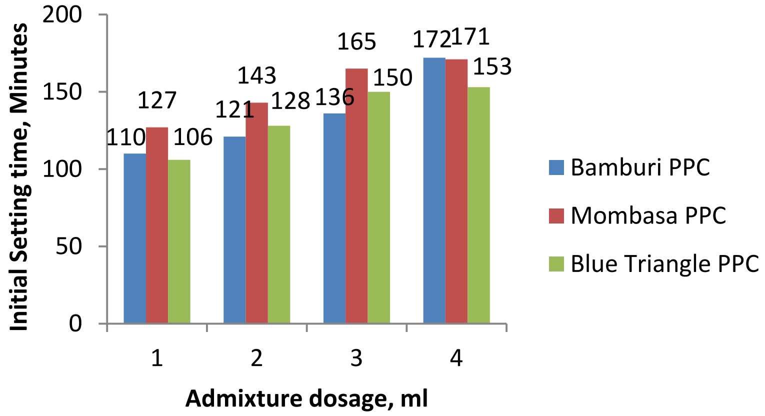

Figure 2: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.3

c) **At w/c = 0.286, 9% water reduction**

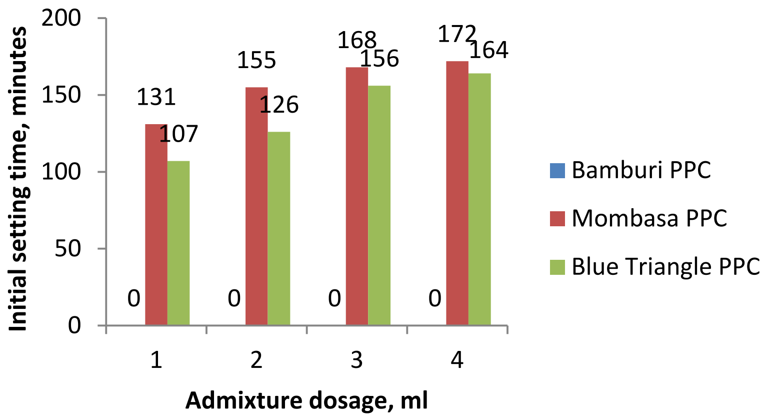

Figure 14: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.286

d) At w/c = 0.271, 14% water reduction

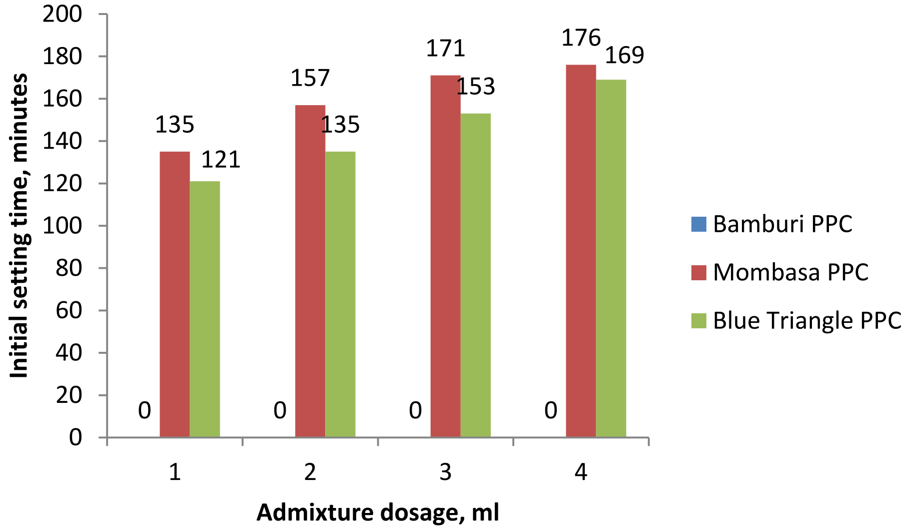

Figure 15: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.271

The bar charts in Figure 12 to 15 reveal that the addition of SikaViscocrete 10 superplasticizer significantly extends the initial setting time of the three pastes by at least 100%.This therefore implies that with the addition of 1.1% of Sika Viscocrete 10 to any of the three cement pates, traffic delays during transportation of ready mix concrete in Nairobi can be completely compensated. It was found that a higher dosage of Sika Viscocrete 10 to cement paste results to a higher retarding effect. This has been confirmed by other researchers who have carried out studies on polycarboxylate based superplasticizers [7, 9].

It can be noted that the workability effect of Sika Viscocrete 10 is less than Master Rheobuild RMC 80.The cement pastes for Mombasa PPC and Blue Triangle PPC are workable at a relatively higher water cement ratio of 0.271 compared to 0.243 by RMC 80.

Sika Viscocrete 10 was found to have a water reducing capacity of 14% which is lower than the expected water reducing capacity for third generation superplasticizers. Third generation superplasticizers produce a water reducing capacity of between 20% and 30% [12]. The cause of this difference can be related to the high percentage of sulfur compounds from the clinker phase and from added gypsum which is more than 4% in pozzolanic cements.

Portland cement contains sulfur compounds from the clinker phase and from added Calcium Sulfate (e.g. gypsum) which acts as a set regulator; Coppola and his colleagues [13] studied the influence of the sulfate content in the clinker phase on the performance of superplasticized concrete mixtures in terms of initial slump level at a given water-cement ratio, slump- loss rate, and compressive strength at early and later ages. Moreover, the lower the clinker sulfur content, the lower is the slump loss rate of the superplasticized concrete mixture. At higher sulfate content in Portland cement (4%), the differences in the slump and slump loss behaviors related to the clinker sulfur content were significantly reduced. These results indicate that the superplasticizing effect depends on the sulfur content of the clinker phase as well as the total sulfate content determined by gypsum addition as set regulator.

3.4 Application of the superplasticizers

3.4.1 Effect on the construction cost

In terms of cost, Sika Viscocrete 10 is more expensive than Master Rheobuild RMC 80. Based on the maximum recommended dosage, an additional amount of Ksh. 200 for every 50kg of cement is required for Sika Viscocrete 10 while Master Rheobuild RMC 80 requires an additional amount of Ksh.165.

However, in terms of effectiveness to achieve a specific workability of the concrete, the amount of Sika Viscocrete 10 required is much lesser than Master Rheobuild RMC 80. On the other hand, in terms of durability, the amount of Master Rheobuild RMC 80 required to achieve a specific strength of concrete is less than Sika Viscocrete 10.

Despite the cost associated with the use of superplasticizers, overall cost savings in terms of manpower and accelerated construction time is possible. Sika Viscocrete 10 is suitable for long haul applications, and more particularly for ready mixed concrete. Master Rheobuild RMC 80 quick setting properties make it ideal for use in precast industry applications or insitu concrete works, where the concreting time is short.

Nevertheless, Sika Viscocrete 10 and Master Rheobuild RMC 80 allow for the production of a high strength and durable concrete having a reduced permeability and shrinkage, and an improved surface finish.

3.4.2 Effective w/c ratio

The research has based on the w/c ratio obtained for the paste of standard consistence. This w/c ratio is the minimum amount required for complete hydration of the cement to occur.

However, this w/c ratio cannot be effectively employed in the field because it is difficult to determine how much of the mixing water in concrete will be absorbed by the aggregate.

The difficulty is caused not only by the large amounts (10 to 20%) of water absorption by porous aggregated, but also by the fact that some aggregates continue to absorb water for several weeks. Therefore, reliable estimates of moisture deviation from the saturated – surface dry (SSD) condition and of the SSD bulk specific gravity are very difficult. Also, unlike normal weight aggregates, the bulk specific gravity of the light weight aggregates can vary widely with grading.

Therefore, trial batch mixes are necessary to ascertain the field w/c ratio.

4. Conclusions

The test results and observations reveal that loss of setting time due to traffic delays when transporting ready mix concrete in Nairobi can be completely compensated by use of Sika Viscocrete 10. Sika Viscocrete 10 has a high retarding effect and is capable of extending the initial setting of cement by more than 100% (maximum period of 2.5 hours) when 1.1% (% of weight of cement) of the admixture is incorporated in the cement paste. Sika Viscocrete 10 can therefore be classified as a third generation superplasticizer based on these properties.

The results further indicate that BASF Master Rheobuild RMC 80 has a higher water reducing effect and can be useful for in-situ concrete or precast concrete requiring very high strengths. The superplasticizer causes a water reduction of up to 23% while Sika Viscocrete 10 is capable of producing 14%. Master Rheobuild RMC 80 however, does not retard the initial setting times of cement and therefore for purposes of ready mix concrete, the addition of a retarder to prolong the initial setting of concrete is necessary. It was found that the superplasticizer can cause quicker setting of cement paste by up to 32% and therefore delays in placing of concrete should be minimized when using it with pozzolanic cements. Trial tests are necessary to confirm the behavior of the superplasticizer with pozzolanic cements prior to usage. BASF Master Rheobuild RMC 80 can be classified as a first generation superplasticizer based on ASTM classification of superplasticizers.

Master Rheobuild RMC 80 and Sika Viscocrete 10 were found to be compatible with the three brands of cements tested. It was also found that the final setting times of the cement pastes are not significantly affected when the two superplasticizers are used.

It is however critical that the correct amount of dosage is administered for both RMC 80 and Sika Viscocrete 10 to prevent instances of rapid slump loss or an abnormal slump retention by any of the superplasticizers. Sika Viscocrete 10 is capable of producing abnormal slump retention when used in excess due to its high retarding effect while Master Rheobuild RMC 80 on the other hand is capable of producing a rapid slump loss due to its quick setting properties.

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Appendices

APPENDIX A 1: DETERMINATION OF CEMENT PASTE OF STANDARD CONSISTENCE

Water cement ratio = 115/350 = 0.329								
	Initial setting time (Mins)				Final setting time (Mins)			
Test	t1	t2	t3	Mean	t1	t2	t3	Mean

				ȳ				ȳ
Bamburi PPC	90	83	76	83	531	523	519	524
Mombasa PPC	73	64	69	69	525	531	529	528
Blue Triangle PPC	66	61	73	67	536	528	514	526

Water cement ratio = 110/350 = 0.314								
	Initial setting time (Mins)				Final setting time (Mins)			
Test	t1	t2	t3	Mean ȳ	t1	t2	t3	Mean ȳ
Bamburi PPC	88	79	70	79	535	591	583	570
Mombasa PPC	68	50	60	59	586	559	600	582
Blue Triangle PPC	63	58	71	64	543	596	550	563

Water cement ratio = 105/350 = 0.3								
	Initial setting time (Mins)				Final setting time (Mins)			
Test	t1	t2	t3	Mean ȳ	t1	t2	t3	Mean ȳ
Bamburi PPC	90	103	99	97	593	601	589	594
Mombasa PPC	64	71	68	68	614	609	621	615
Blue Triangle PPC	70	66	59	65	560	600	533	564

Water cement ratio = 100/350 = 0.286								
	Initial setting time (Mins)				Final setting time (Mins)			
Test	t1	t2	t3	Mean ȳ	t1	t2	t3	Mean ȳ
Bamburi PPC	-	-	-	-	-	-	-	-

Mombasa PPC	68	50	60	59	614	603	624	614
Blue Triangle PPC	58	62	51	57	595	602	583	593

Appendix a 2: determination of the setting times of cement paste with master rheobuild rmc 80 superplasticizer

Test 1

Water cement ratio = 110/350 = 0.314								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	155	143	127	55	593	552	581	600
Mombasa PPC	80	47	37	30	613	588	607	619
Blue Triangle PPC	93	62	49	40	605	616	571	598

Water cement ratio = 105/350 = 0.3								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	82	57	36	32	633	592	613	569
Mombasa PPC	60	45	30	23	609	586	594	612
Blue Triangle PPC	67	42	33	31	617	602	580	593

Water cement ratio = 100/350 = 0.286								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	44	40	30	26	602	571	621	603
Mombasa PPC	57	33	26	20	600	591	610	589
Blue Triangle PPC	60	36	28	25	612	603	586	578

Water cement ratio = 95/350 = 0.271								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	35	30	22	18	611	597	601	583
Blue Triangle PPC	39	33	23	20	606	600	605	603

Water cement ratio = 90/350 = 0.257								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	35	25	21	15	602	591	621	588
Blue Triangle PPC	34	30	19	16	605	611	606	599

Water cement ratio = 85/350 = 0.243								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	24	21	20	20	593	612	597	603
Blue Triangle PPC	30	29	23	22	603	590	617	586

Test 2

Water cement ratio = 110/350 = 0.314								
	Initial setting time (Mins)				Final setting time			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	161	160	131	70	601	591	603	570
Mombasa PPC	86	61	43	40	592	567	604	611
Blue Triangle PPC	99	73	62	53	606	599	600	601

Water cement ratio = 105/350 = 0.3								
	Initial setting time(Mins)				Final setting time(Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	104	72	50	43	598	600	617	583
Mombasa PPC	74	59	50	36	619	589	590	611
Blue Triangle PPC	69	50	41	36	599	600	613	609

Water cement ratio = 100/350 = 0.286								
	Initial setting time(Mins)				Final setting time(Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	73	55	49	37	591	603	601	586
Mombasa PPC	68	44	39	33	613	603	580	617
Blue Triangle PPC	69	46	37	30	603	599	600	621

Water cement ratio = 95/350 = 0.271								
	Initial setting time(Mins)				Final setting time(Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	51	44	34	29	599	604	601	614
Blue Triangle PPC	49	37	26	26	600	595	602	606

Water cement ratio = 90/350 = 0.257								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	47	38	31	26	578	612	602	600
Blue Triangle PPC	41	33	20	21	603	600	601	586

Water cement ratio = 85/350 = 0.243								
	Initial setting time(Mins)				Final setting time(Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	47	34	28	20	603	606	599	604
Blue Triangle PPC	45	30	19	19	600	600	610	594

Test 3

Water cement ratio = 110/350 = 0.314								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	166	147	130	85	600	600	597	605
Mombasa PPC	98	61	50	49	620	592	605	613
Blue Triangle PPC	99	70	53	46	609	609	621	591

Water cement ratio = 105/350 = 0.3								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	99	69	60	60	598	598	601	616
Mombasa PPC	87	63	60	41	603	603	599	606
Blue Triangle PPC	90	67	51	48	611	608	595	600

Water cement ratio = 100/350 = 0.286		
	Initial setting time (Mins)	Final setting time (Mins)

Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	80	68	53	50	601	600	601	603
Mombasa PPC	73	51	49	37	586	599	599	600
Blue Triangle PPC	86	61	53	41	611	611	605	608

Water cement ratio = 95/350 = 0.271								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	61	60	52	31	609	605	600	600
Blue Triangle PPC	56	56	40	33	602	602	607	581

Water cement ratio = 90/350 = 0.257								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	50	35	30	28	621	600	608	603
Blue Triangle PPC	58	40	33	29	605	605	600	615

Water cement ratio = 85/350 = 0.243								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	46	40	27	26	603	603	599	600
Blue Triangle PPC	50	39	35	22	616	601	608	607

Arithmetic mean, $\bar{y}$ = <u>Test 1 + Test 2 +Test</u> 3

Water cement ratio = 110/350 = 0.314								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	161	150	129	70	598	581	594	592
Mombasa PPC	88	56	43	40	608	582	605	614
Blue Triangle PPC	97	68	55	46	607	608	597	597

Water cement ratio = 105/350 = 0.3								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	95	66	49	45	610	597	610	589
Mombasa PPC	74	56	47	33	610	593	594	610
Blue Triangle PPC	75	53	42	38	609	603	596	601

Water cement ratio = 100/350 = 0.286								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	66	54	44	38	598	591	608	597
Mombasa PPC	66	43	38	30	600	598	596	602
Blue Triangle PPC	72	48	39	32	609	604	597	602

Water cement ratio = 95/350 = 0.271								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	49	45	36	26	606	602	601	599
Blue Triangle PPC	48	42	30	26	603	599	605	597

Water cement ratio = 90/350 = 0.257								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	44	33	27	23	600	601	610	597
Blue Triangle PPC	44	34	24	22	604	605	602	600

Water cement ratio = 85/350 = 0.243								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	39	32	25	22	600	607	598	602
Blue Triangle PPC	42	33	26	21	606	597	612	596

Appendix a 3: determination of the setting times of cement paste with sika viscocrete 10 superplasticizer

Test 1

Water cement ratio = 110/350 = 0.314								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	93	93	120	161	588	601	579	590
Mombasa PPC	123	150	166	166	619	600	611	597
Blue Triangle PPC	100	123	146	150	603	603	599	600

Water cement ratio = 105/350 = 0.3		
	Initial setting time (Mins)	Final setting time (Mins)

Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	100	111	132	172	603	603	599	600
Mombasa PPC	125	148	168	169	600	607	580	592
Blue Triangle PPC	102	129	151	151	596	600	600	588

Water cement ratio = 100/350 = 0.286								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	130	150	170	170	601	601	600	600
Blue Triangle PPC	111	122	160	167	614	598	601	604

Water cement ratio = 95/350 = 0.271								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	130	148	168	173	600	620	587	602
Blue Triangle PPC	119	130	153	160	589	607	613	617

Test 2

Water cement ratio = 110/350 = 0.314								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	117	121	132	169	598	601	601	575
Mombasa PPC	109	130	153	160	630	590	617	603
Blue Triangle PPC	98	120	142	144	605	601	596	600

Water cement ratio = 105/350 = 0.3								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	108	123	137	175	612	609	610	613
Mombasa PPC	130	141	160	170	610	631	599	607
Blue Triangle PPC	105	124	149	150	613	617	600	600

Water cement ratio = 100/350 = 0.286								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	128	154	165	175	607	607	614	621
Blue Triangle PPC	110	125	148	160	616	604	603	609

Water cement ratio = 95/350 = 0.271								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	135	156	170	179	618	607	607	600
Blue Triangle PPC	120	136	157	176	599	605	613	610

Test 3

Water cement ratio = 110/350 = 0.314								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	115	126	135	164	619	600	600	597

Mombasa PPC	123	137	160	166	613	610	618	601
Blue Triangle PPC	100	124	142	148	595	600	595	613

Water cement ratio = 105/350 = 0.3								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	121	130	139	170	599	599	607	627
Mombasa PPC	127	140	168	174	622	619	606	630
Blue Triangle PPC	110	131	151	159	587	603	610	603

Water cement ratio = 100/350 = 0.286								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	134	160	169	170	606	606	600	599
Blue Triangle PPC	101	131	159	166	611	605	605	608

Water cement ratio = 95/350 = 0.271								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	140	167	175	176	631	611	607	604
Blue Triangle PPC	123	140	150	172	600	609	617	580

Arithmetic mean, $\bar{y}$ = <u>Test 1 + Test 2 +Test 3</u>

Water cement ratio = 110/350 = 0.314

	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	108	113	129	165	602	601	593	587
Mombasa PPC	118	139	160	164	621	600	615	600
Blue Triangle PPC	99	122	143	147	601	601	597	604

Water cement ratio = 105/350 = 0.3								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	110	121	136	172	605	604	605	613
Mombasa PPC	127	143	165	171	611	619	595	610
Blue Triangle PPC	106	128	150	153	599	607	603	597

Water cement ratio = 100/350 = 0.286								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	131	155	168	172	605	605	605	607
Blue Triangle PPC	107	126	156	164	614	602	603	607

Water cement ratio = 95/350 = 0.271								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	-	-	-	-	-	-	-	-
Mombasa PPC	135	157	171	176	616	613	600	602
Blue Triangle PPC	121	135	153	169	596	607	614	602