



UNIVERSITY OF NAIROBI

COLLEGE OF ARCHITECTURE AND ENGINEERING

SCHOOL OF ENGINEERING

**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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A Thesis Submitted in Fulfillment for the Degree of Master of Science in Civil  
Engineering (Structures) in the Department of Civil and Construction  
Engineering in the University of Nairobi

*JUNE 2017*

# **DECLARATION**

## **Student's Declaration**

This thesis is my original work and has never been presented for award of a degree in any other University.

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Signature: .....

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## **Supervisor's Approval**

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Dr. Siphila Mumanya

Signature: .....

Date: .....

## **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 subsequently 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 or incompatibility between the superplasticizer and the cement paste. Nairobi City is the most affected, with the longest delays in transportation of ready mix concrete and with the highest variety of cement brands. 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. There is therefore need to carry out research on the setting times of ready mix concrete in Kenya in order to ensure that the quality is not compromised by redosing with water during transportation or at the site.

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 because previous studies have been carried out on Ordinary Portland cement (OPC). Portland Pozzolanic cement is also widely used in Kenya due to its lower cost and the lower heat of hydration that it produces in concrete.

The research has indicated that Sika Viscocrete 10 is most 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 at 1.1% dosage (% of weight of cement), Sika Viscocrete 10 prolongs the initial setting time of the cement paste by 115% (maximum period of 2.5hrs) while Master Rheobuild RMC 80 retards the initial setting time by 35% up to a dosage of 0.5% and thereafter shortens the initial setting time by 35% when the dosage is increased. 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 higher retarding effect leading to significantly high slump retention (unacceptable low early strength) while Master Rheobuild RMC 80 produces a high accelerating effect at higher dosage leading to significantly high slump loss.

The difference in the effect of the two superplasticizers is as a result of their mechanism of action. Master Rheobuild RMC 80 acts by electrostatic repulsion created by negative charge around the cement particles while Viscocrete 10 acts by steric hinderance created by long chains of the polymer preventing attraction of the cement particles.

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 Sika Viscocrete 10 produces 14%. The lower water /cement ratio results in concrete of high compressive strength.

# TABLE OF CONTENTS

DECLARATION.....	i
ABSTRACT .....	ii
TABLE OF CONTENTS .....	iv
LIST OF TABLES.....	vi
LIST OF FIGURES .....	vii
LIST OF ABBREVIATIONS .....	x
DEDICATION.....	XI
ACKNOWLEDGEMENTS.....	xii
CHAPTER ONE.....	1
1.0 INTRODUCTION .....	1
1.1 Background.....	1
1.2 Statement of the problem .....	3
1.3 Justification .....	3
1.4 Objectives .....	4
1.5 Scope and limitations of the research .....	4
CHAPTER TWO.....	5
2.0 LITERATURE REVIEW .....	5
2.1 Introduction .....	5
2.2 Properties of Portland cement in Kenya .....	5
2.3 Hydration of cement .....	9
2.4 Setting time of cement.....	11
2.5 Properties and characteristics of ready mixed concrete.....	13
2.6 Challenges of using ready mix concrete.....	15
2.7 Mechanisms of action of different superplasticizers for high-performance concrete .....	20
2.8 Cement - superplasticizer incompatibility .....	29
2.8.1 Introduction.....	29
2.8.2 Factors affecting compatibility .....	30
2.8.3 Composition and fineness of cement .....	31

2.8.4	Superplasticizer type and dosage .....	35
2.9	Blending of superplasticizers.....	38
CHAPTER THREE .....		40
3.0	MATERIALS AND METHODS .....	40
3.1	Introduction .....	40
3.2	Materials .....	40
3.2.1	Cements.....	40
3.2.2	Water .....	40
3.2.3	Superplasticizers.....	41
3.3	Equipment.....	42
3.4	Mix proportions .....	44
3.5	Mixing procedure .....	46
3.6	Test procedure .....	47
CHAPTER FOUR .....		50
4.0	RESULTS AND DISCUSSIONS .....	50
4.1	Introduction .....	50
4.2	Data collection.....	50
4.3	Data Analysis and discussion .....	56
4.4	Application of the superplasticizers .....	75
CHAPTER FIVE .....		76
5.0	CONCLUSIONS .....	76
CHAPTER SIX.....		78
6.0	RECOMMENDATIONS.....	78
7.0	REFERENCES .....	79
APPENDICES .....		84
APPENDIX A1: DETERMINATION OF CEMENT PASTE OF STANDARD CONSISTENCE.....		85
APPENDIX A2:DETERMINATION OF THE SETTING TIME OF CEMENT PASTE WITH MASTER RHEOBUILD RMC 80 SUPERPLASTICIZER.....		87
APPENDIX A3: DETERMINATION OF THE SETTING TIMES OF CEMENT PASTE WITH SIKA VISCOCRETE 10 SUPERPLASTICIZER.....		95

## LIST OF TABLES

Table 2.1: Main compounds in Portland Cement .....	5
Table 2.2: Main chemical compounds of the three portland Pozzolanic Cements .....	7
Table 2.3: Typical average values of clinker composition of Cem II and Cem IV Type of cement [10] .....	8
Table 2.4: Zeta potential of cement particles in aqueous suspension with superplasticizers [18]. .....	26
Table 3.1: Amounts of cement and water used for each test .....	44
Table 3.2: Amount of chemical superplasticizer used for each test .....	45
Table 4.1: Initial and final setting times of cement paste of standard consistence, w/c=0.314..	50
Table 4.2: Setting times of cement pastes with Master Rheobuild RMC 80, w/c=0.314.....	51
Table 4.3: Setting times of cement paste with RMC 80, w/c = 0.3 .....	51
Table 4.4: Setting times of cement pastes with RMC 80, w/c = 0.286 .....	52
Table 4.5: Setting times of cement pastes with RMC 80, w/c = 0.27 .....	52
Table 4.6: Setting times of cement pastes with RMC 80, w/c = 0.257 .....	52
Table 4.7: Setting times of cement pastes with RMC 80, w/c = 0.243 .....	53
Table 4.8: Setting times of cement pastes with Sika Viscocrete 10, w/c = 0.314.....	54
Table 4.9: Setting times of cement pastes with Sika Viscocrete 10, w/c = 0.3 .....	54
Table 4.10: Setting times of cement pastes with Sika Viscocrete 10, w/c = 0.286.....	55
Table 4.11: Setting times of cement pastes with Sika Viscocrete 10, w/c = 0.271 .....	55
Table 4.12: Rate of change of the initial and final setting times of standard consistence cement paste with Master Rheobuild RMC 80 .....	58
Table 4.13: Rate of change of initial and final setting times of standard consistence cement paste with Sika Viscocrete 10.....	60

## LIST OF FIGURES

Figure 1.1: Local market share of the six cement companies in Kenya [1, 2, 3].	1
Figure 2.1: Chemical Structure of Cross Linked Acrylic Polymers [16].	16
Figure 2.2: CLAP based superplasticizer hydrolyzed by the alkaline water of cement paste [16].	17
Figure 2.3: The chemical structure of PC, PE type and SLCA superplasticizer [17].	18
Figure 2.4: The molecular structure of PC, PE type and SLCA superplasticizer [17].	19
Figure 2.5: The mechanism and the hydrolysis reaction of SLCA in alkaline condition of cement paste [17].	19
Figure 2.6: The slump loss behaviour of different acrylic superplasticizers (PC, SLCA, PE +SLCA) in concrete mixtures with CEM II A/L 32.5R (340kg/m <sup>3</sup> ), w/c = 0.45 [17].	19
Figure 2.7: The effect of superplasticizers on fresh and hardened concrete [18].	23
Figure 2.8: The effect of the superplasticizer on the fluidity of the cement paste [20].	25
Figure 2.9: The chemical structure of Lignosulphonate superplasticizer [20].	25
Figure 2.10: Sulfonated polymer and its electrostatic repulsion effect on the dispersion of cement particles [18].	25
Figure 2.11: Zeta potential of cement pastes with PC or SNF as a function of polymer dosage [18].	26
Figure 2.12: PC type superplasticizer and its steric hindrance effect on the dispersion of cement particles [18].	28
Figure 2.13: Superplasticized cement paste system [30].	30
Figure 3.1: Samples of Master Rheobuild RMC 80 and Sika Viscocrete 10	41
Figure 3.2: Vicat Apparatus fitted with needle for initial setting time test	42
Figure 3.3: Vicat Apparatus fitted with ring attachment for final setting time test	43
Figure 3.4: Weighing of 350g of cement.	46
Figure 4. 1: Effect of Master Rheobuild RMC 80 on the initial setting time of cement pastes of standard consistence.	56
Figure 4. 2: Effect of Master Rheobuild RMC 80 on the final setting time of cement pastes of standard consistence.	57
Figure 4. 3: Effect of Sika Viscocrete 10 on the initial setting time of cement pastes of standard consistence.	59



Figure 4. 4: Effect of Sika Viscocrete 10 on the final setting time of cement pastes of standard consistence.....	59
Figure 4. 5: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.314. ....	61
Figure 4. 6: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.3. ....	61
Figure 4. 7: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.286. ....	62
Figure 4. 8: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.271. ....	62
Figure 4. 9: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.257. ....	63
Figure 4. 10: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.243. ....	63
Figure 4. 11: Effect of RMC 80 on the final setting times of the three cement pastes at w/c = 0.314. ....	65
Figure 4. 12: Effect of RMC 80 on the final setting times of the three cement pastes at w/c = 0.3. ....	65
Figure 4. 13: Effect of RMC 80 on the final setting times of the three cement pastes at w/c = 0.286. ....	66
Figure 4. 14: Effect of RMC 80 on the final setting times of the three cement pastes at w/c = 0.271. ....	66
Figure 4. 15: Effect of RMC 80 on the final setting times of the three cement pastes at w/c = 0.257. ....	67
Figure 4. 16: Effect of RMC 80 on the final setting times of the three cement pastes at w/c = 0.243. ....	67
Figure 4. 17: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.314. ....	69
Figure 4. 18: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.3. ....	69
Figure 4. 19: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.286. ....	70
Figure 4. 20: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.271. ....	70

Figure 4. 21: Effect of Sika Viscocrete 10 on the final setting times of the three cement pastes at w/c = 0.314. ....	72
Figure 4. 22: Effect of Sika Viscocrete 10 on the final setting times of the three cement pastes at w/c = 0.3. ....	72
Figure 4. 23: Effect of Sika Viscocrete 10 on the final setting times of the three cement pastes at w/c = 0.286. ....	73
Figure 4. 24: Effect of Sika Viscocrete 10 on the final setting times of the three cement pastes at w/c = 0.271. ....	73

## **LIST OF ABBREVIATIONS**

OPC	Ordinary Portland Cement
PPC	Portland Pozzolanic Cement
w/c	Water /Cement Ratio
$\bar{y}$	Arithmetic mean
ASTM	American Society for Testing and Materials
CEM	Cement
CLAP	Cross-Linked Acrylic Polymers
SLCA	Slump-Loss Controlling Agent
PC	PolyCarboxylate
SNF	Sulfonated Naphthalene Formaldehyde
SMF	Sulfonated Melamine Formaldehyde
MLS	Modified Lignosulfonate
EO	Ethylene Oxide
PE	Polyether
LS	Lignosulfonate

## **DEDICATION**

This work is dedicated to my family, for whom their sacrifice and great support propelled me to reach this far.

## **ACKNOWLEDGEMENTS**

I would like to thank the Almighty God for the abundant grace and care. I would also like to thank my supervisor, Dr. Siphila Mumanya for her technical guidance and support and not forgetting the Department of Civil Engineering for the opportunity to deliver the project.

My great appreciation to the laboratory team, Mr. Muchina and the laboratory technologist for their assistance and guidance during the tests.

My last regards goes to my family, colleagues and friends for their encouragement and necessary support during the entire period of research.

# CHAPTER ONE

## 1.0 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 slump loss due to quicker setting of concrete or unacceptable low early strength (slump retention) due to excessive retardation of setting time, 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 1.1. 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.

### Market share year 2013

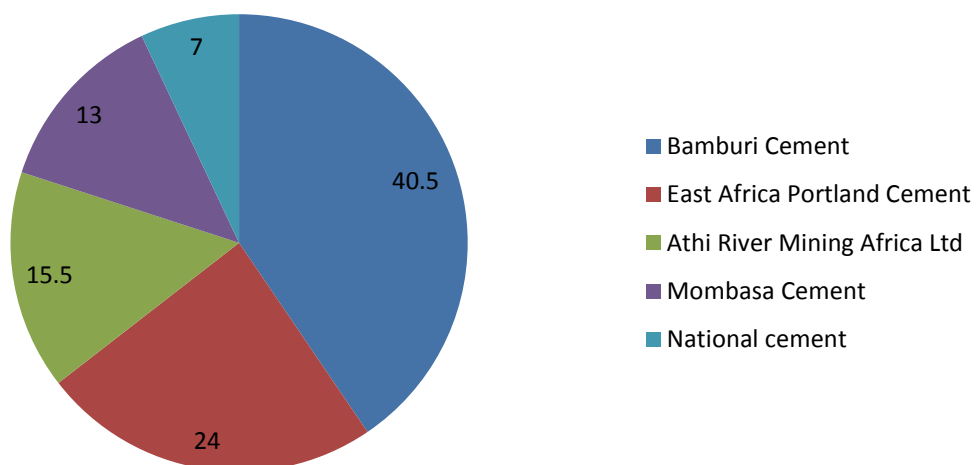


Figure 1.1: Local market share of the six cement companies in Kenya [1, 2, 3].

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 which is liquid and light brown in colour [6]. It is a third generation superplasticizer for concrete and mortar based on modified polycarboxylate polymer and satisfies the physical and chemical requirements for set retarding/high range water reducing according to EN 934-2. 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 drawback of superplasticizer usage is loss of workability as a result of rapid slump loss or abnormal slump retention 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 et al. [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. Normally, contractors adopt the minimum dosage of the superplasticizer specified by the manufacturer to save on cost without considering the setting time in case there are unavoidable traffic delays.

On the other hand, 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 in Kenya 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 re-dosing ready mix concrete with water during transportation and hence compromising 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.

The research has also been limited to two types of superplasticizers which are available and used in the Kenyan market. The superplasticizers are MasterRheobuild RMC 80 and Sika Viscocrete 10.

The research has not considered the effect of blending the two superplasticizers on the setting time of the cement pastes.

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 Introduction

This chapter contains a review of the work conducted by other researchers relating to the subject of this study. It includes a detailed description of the properties of Portland cement and challenges of using ready mix concrete. It also includes the properties and mode of action of superplasticizers.

#### 2.2 Properties of Portland cement in Kenya

Neville et al. [10] defines Portland cement as a type of cement obtained by intimately mixing together limestone and materials bearing Silica, Alumina and Iron Oxide, burning them at a clinkering temperature of 1400 °C and grinding the resulting clinker to a fine powder with some gypsum added.

The major constituents of cement as per Neville et al. [10] are listed in Table 2.1 and they include:

*Table 2.1: Main compounds in Portland Cement*

Name of compound	Oxide composition	Abbreviation
Tricalcium Silicate	3CaO.SiO <sub>2</sub>	C <sub>3</sub> S
Dicalcium Silicate	2CaO.SiO <sub>2</sub>	C <sub>2</sub> S
Tricalcium Aluminate	3CaO.Al <sub>2</sub> O <sub>3</sub>	C <sub>3</sub> A
Tetracalcium aluminoferrite	4CaO.Al <sub>2</sub> O <sub>3</sub> .Fe <sub>2</sub> O <sub>3</sub>	C <sub>4</sub> AF

Two common types of Portland cement in Kenya are outlined below:

##### 2.2.1 Ordinary Portland Cement (OPC)

Different brands of Ordinary Portland cement exist in Kenya and they include Bamburi cement, Mombasa cement, Blue Triangle cement, Savanna cement and Athi River Mining cement.

Neville et al. [10] refers OPC to cement composed of 95-100 per cent of Portland cement clinker and 0-5 percent of minor constituents, which can be of a cementitious nature or a filler to improve workability or water retention. Other requirements are that the ratio of CaO to SiO<sub>2</sub> should not be less than two, and the MgO content is limited to 5 percent. Ordinary Portland cement is by far the most common cement used in general concrete construction in the world.

### **2.2.2 Portland Pozzolan Cement (PPC)**

Neville et al. [10] refers to PPC as cement made by intergrinding or blending pozzolans with Portland cement clinker. According to ASTM C618-06 a pozzolan is described as a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will, in finely ground form and in the presence of water, chemically react with lime (liberated by hydrating Portland cement) at ordinary temperatures to form compounds possessing cementitious properties.

Portland pozzolan cements gain strength slowly and therefore require curing over a comparatively long period of time [1,2,3].

ASTM C595-05 describes Type IP for general construction and Type P for use when high strengths at early ages are not required; Type I (PM) is a Pozzolan-modified Portland cement for use in general construction. The Pozzolan content is limited to between 15 and 40 percent of the total mass of the cementitious material for Type IP and P while Type I (PM) requires less than 15 percent Pozzolan.

Generally, Pozzolan are cheaper than the Portland cement that they replace but their key advantage lies in slow hydration and therefore low rate of heat development. Hence, Portland Pozzolan cement is suitable for mass concrete works [1,2,3].

The research focuses on three brands of Portland Pozzolan cement; Bamburi Pozzolan cement (Nguvu brand), Mombasa cement (Nyumba brand) and East Africa Portland cement (Blue Triangle Pozzolan Cement).

Bamburi Portland Pozzolan Cement (Nguvu 32.5) is produced from Portland clinker and interground with natural Pozzolan as per the physical and chemical requirements of the East African Standard KS EAS 18-1. KS EAS 18-1 is an adoption of the European Norm EN 197-1 Cement Standard. Two types of Nguvu 32.5 are available in Kenya. They include Nguvu CEM II/B-L and Nguvu CEM IV/B-P. The Nguvu cement type that has been used for this study is CEM IV/ B-P 32.5N. CEM IV corresponds to cement of low heat of hydration as per ASTM C595-05.

Mombasa cement manufactures pozzolanic cement by the name Nyumba CEM II/B-P 32.5N. Nyumba cement is standard cement mainly used for general construction purposes. The product satisfies the ISO 9001:2000 for quality management system and complies with the requirements of Kenyan Standard KS EAS-1 2001. CEM II is characterized by high early strengths [3].

East African Portland cement manufactures pozzolanic cement by the name Blue Triangle CEM IV/A 32.5N. This cement is mainly used for general construction purposes [2].

*Table 2.2: Main chemical compounds of the three Portland Pozzolanic Cements [1, 2, 3]*

Raw materials	Bamburi PPC		Mombasa PPC		Blue Triangle PPC	
	%	%	%	%	%	%
	Before Mixing	After Milling	Before Mixing	After Milling	Before Mixing	After Milling
Limestone (CaO)	60	Clinker (65%)	60	Clinker (70%)	60	Clinker (65%)
Kunkur (SiO <sub>2</sub> )	35		35			
Mullscale, Iron ore, (Fe <sub>2</sub> O <sub>3</sub> )	2		2			
Bauxite, Alumina dust (Al <sub>2</sub> O <sub>3</sub> )	3		3			
Pozzolana (SiO <sub>2</sub> )		30%		27%		30%
Gypsum (CaSO <sub>4</sub> )		5%		3%		5%

Table 2.2 shows the average composition of the clinker and the pozzolana that constitute the Portland Pozzolanic Cements used for this study. The clinker is obtained by intimately mixing and heating the raw materials at very high temperatures of 1400°C and then grinding the resultant compound into fine powder before being blended with the pozzolana [10]. The main compounds in the clinker constitute C<sub>3</sub>S, C<sub>2</sub>S, C<sub>3</sub>A and C<sub>4</sub>AF (Table 2.3).

*Table 2.3: Typical average values of clinker composition of CEM II and CEM IV Type of cement [10]*

<b>Cement Type</b>	<b>Chemical composition, %</b>							
	<b>C<sub>3</sub>S</b>	<b>C<sub>2</sub>S</b>	<b>C<sub>3</sub>A</b>	<b>C<sub>4</sub>AF</b>	<b>CaSO<sub>4</sub></b>	<b>Free CaO</b>	<b>MgO</b>	<b>Loss on ignition</b>
<b>II</b>	46	29	6	12	2.8	0.6	3.0	1.0
<b>IV</b>	30	46	5	13	2.9	0.3	2.7	1.0

## 2.3 Hydration of cement

Baradan et al. [11] refers to hydration as a series of chemical reactions between cement and water to form the binding material. The chemical compounds in the cement react with water to form products of hydration which in turn produce a firm and hard mass – the hydrated cement paste.

The silicates ( $C_3S$  and  $C_2S$ ) react with water to form Calcium Silicate hydrate. This reaction continues even when the solution is saturated with lime and the resulting amounts of lime formed precipitate into crystals. Silicates affect the late stage reactions.

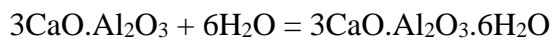
The aluminates ( $C_3A$  and  $C_4AF$ ) react with water to form Tricalcium Aluminate hydrate and affect the rate of the chemical reactions at early periods of hydration.

The main hydrates include:

1. Calcium Silicates hydrate



2. Tricalcium Aluminate hydrate



3.  $C_4AF$  hydrates to Tricalcium Aluminate hydrate and Calcium ferrite  $CaO.Fe_2O_3$  in amorphous form.

Calcium Silicates ( $C_3S$  and  $C_2S$ ) form the main compounds in cement (about 75% of cement weight) and they are ultimately responsible for the final strength of the hardened cement paste.

The proportion of  $C_3A$  present in most cement is comparatively small but its behavior and structural relationship with the other phases of cement make it of interest. The Tricalcium Aluminate hydrate forms a prismatic dark interstitial material in the form of flat plates individually surrounded by the Calcium Silicate hydrate [11].

The reaction of pure  $C_3A$  with water is very violent and produces large amount of heat, forming Calcium Aluminates hydrate in the form of leaf hexagonal crystals. In Portland cement, this reaction leads to immediate stiffening known as “flash setting”[11].

Gypsum, when inter ground with the clinker delays the reaction of  $C_3A$  with water by reacting with  $C_3A$  to form insoluble Calcium Sulfoaluminate ( $3CaO. Al_2O_3. 3CaSO_4.30-32H_2O$ )

ettringite around  $C_3A$  particles, which allows adequate time for the hydration of  $C_3S$  and hence the occurrence of natural setting. Tricalcium Aluminate hydrate is eventually formed, although it is preceded by a metastable  $3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 12H_2O$ , produced at the expense of the original high-sulfate Calcium Sulfoaluminate. The reaction of gypsum with  $C_3A$  continues until one of them is completely eliminated, while the reaction of  $C_3S$  continues to complete hydration [10].

## 2.4 Setting time of cement

The mixing of water and cement produces a paste which gradually stiffens and eventually hardens. Jiang et al. [12] describes setting as the gradual stiffening of cement paste. It is a transformation process from a scattered concentrated suspension to a connected and strengthened system of cement particles. This transformation is produced by cement hydration. Final setting of cement is caused by the hydration and formation of the calcium silicate hydrate (CSH) phase. Determination of the setting time is carried out by gradually measuring the mechanical stiffness of the cement paste using a penetration needle. Two standard methods for determining the setting time are the Vicat needle and the Gilmore needle tests. This study has adopted the Vicat needle test due its availability and use in Kenya.

Setting time of cement is categorized by the initial and final set. These are arbitrary points in time between the initial water – cement contact and the beginning of strength gain. Initial set is the point in time when the cement paste commences to stiffen and mixing of the concrete beyond this point is not recommended. Final set on the other hand, is achieved when the concrete begins to gain strength. Initial set for Portland cement usually takes a minimum of 60 minutes, while final set takes a maximum of 10 hours after initial water-cement contact. Knowledge on the setting time is essential for quality control purposes during preparation and placing of fresh concrete [12].

Standard laboratory conditions at temperature values of 23°C and relative humidity of not less than 90% allow normal setting to occur but outside the laboratory conditions concreting has to be done under the prevailing conditions which adversely affects the setting time.

Hot weather conditions cause loss of water from the surface of fresh concrete/paste through evaporation. The paste/concrete therefore sets rapidly than the normal setting and hence less time is available for concreting operations [9]. Research by Khan et al. [13] has shown that when the temperature of cement paste is increased from 27°C to 45.5°C, at w/c ratio of 0.6, both the initial and final setting times are reduced by half. Challenges of rapid slump loss, cold joints formation and plastic shrinkage cracking may arise due to hot weather.

For ready- mixed concrete, transportation during peak hours of traffic is likely to cause setting of concrete before it is delivered to site. In order to compensate for the setting, water is often



added to the concrete at the job site and this adversely affects the quality of fresh and hardened concrete.

Superplasticizers with retarding and high range water reduction are added into concrete to offset the accelerating effects of high temperatures which increase setting, or to compensate for delays when unavoidable delays between mixing and placing occur [14].

Zakka et al. [9] studied the effect of superplasticizers on the initial and final setting times of Ordinary Portland cements in Texas, U.S.A and found that the addition of superplasticizers delayed both the initial and final setting times. It was noted that the setting time was delayed even further after the second addition of the superplasticizer. The delay in initial and final setting time was generally similar for each addition of the superplasticizer. In general, setting time was related to slump loss, the lower the rate of slump loss, the higher was the delay in setting time. Zakka et al. [9] further noted that the time between the initial and final setting time is reduced at high temperature and that the type of aggregate does not affect the setting time. The study did not consider Portland Pozzolanic cements.

Khan et al. [13] studied the effect of retarding admixtures on the setting time of cement pastes in hot weather. The research focused on the Portland Pozzolanic cements manufactured in Pakistan. The study showed that the effect of retarding admixture on the Pozzolanic cement was not consistent for all the selected cements. The admixture showed accelerating effects on initial set for one type of cement and therefore it was recommended that caution is necessary when using retarders with Pozzolanic type cements. The study did not consider the use of superplasticizers instead of retarders in enhancing concrete performance.

Therefore, research to provide knowledge on the action of superplasticizers on the Portland Pozzolanic cements manufactured in Kenya is necessary.

## 2.5 Properties and characteristics of ready mixed concrete

Neville et al. [10] defines ready mix concrete as a type of concrete delivered for placing from a central plant instead of being batched and mixed on site. It is used extensively in Nairobi as it offers numerous advantages in comparison with other methods. The advantages include:

1. Close quality control of batching which reduces the variability of the desired properties of hardened concrete.
2. Use on congested sites or in highway construction where there is little space for a mixing plant and aggregate stock piles.
3. Use of agitator trucks to ensure care in transportation, thus preventing segregation and maintaining workability.
4. Convenience when small quantities of concrete or intermittent placing is required.

The cost of ready- mix concrete is higher than that of site-mixed concrete, but this is often offset by savings in site organization, in supervisory staff, and in cement content. The latter arises from better control so that a smaller allowance need be made for chance variations [10].

ASTM C94-05 categorizes ready-mixed concrete into two principal categories; central-mixed and transit-mixed or truck-mixed. In the first category, mixing is done at a central plant and then the concrete is transported in an agitator truck. In the second category, the materials are batched at a central plant but are mixed in the truck either in transit or immediately prior to discharging the concrete at the site.

Transit- mixing permits a longer transportation time and is less vulnerable in case of delay, but the truck capacity is smaller than that of the same truck which contains pre-mixed concrete. To overcome the disadvantage of a reduced capacity, sometimes concrete is partially mixed at the central plant and the mixing is completed en-route; This is known as shrink-mixed concrete.

ASTM C94-05 describes the difference between agitating and mixing solely by the speed of rotation of the mixer; the agitating speed is between two and six revolutions per minute, compared with the mixing speed of four to sixteen revolutions per minute. It has been noted that the speed of mixing affects the rate of stiffening of the concrete whilst the number of revolutions controls the uniformity of mixing.

A limit of 300 revolutions for both mixing and agitating is laid down by ASTM C94-05 or alternatively, the concrete must be placed within one and a half hours of mixing. In the case of

transit-mixing, water need not be added until nearer the beginning of mixing, but, according to BS 5328; 1991, the time during which cement and moist aggregate are allowed to remain in contact should be limited to two hours. The effects of prolonged mixing and re-tempering (adding water to restore workability) of ready-mixed concrete are the same as for site-mixed concrete.

British Standards BS 5328;1991 and BS EN 206-1 2000 prescribe methods of specifying concrete, including ready-mixed concrete.

## 2.6 Challenges of using ready mix concrete

The major challenge of ready mix concrete industries is slump loss due to hot weather conditions or unavoidable delays during transportation. Transportation of concrete for a long time during hot weather should not affect its initial slump level as much as possible and prevent the practice of re-dosing (re-tempering) the concrete with water beyond that required in the mix design [7]. Ramachandran et al. [15] has indicated that many properties of hardened concrete (ultimate strength, durability, abrasion resistance) are significantly compromised by re-tempering.

However, slump loss is unavoidable because of the intrinsic requirement of cement pastes to set and harden in a relatively short time. Therefore, there is need for a right and proper compromise to ensure zero-slump-loss. The lower w/c in superplasticized concrete produces shorter distance among cement particles and therefore a more significant slump loss when the same quantity of water is lost through evaporation or by reaction with cement during the transportation [7].

Several methods to control the rate of slump loss have been invented. One of the methods involved the addition of the superplasticizer at site prior to placing of concrete but there are practical challenges with this approach. For instance, before the addition of the superplasticizer, the concrete would have stiffened in the truck mixer when high strength concrete (with low w/c) should be produced. Furthermore, dosing the superplasticizer at the site consumes time and does not accurately control the final slump and superplasticizer dosage [7].

The other method used to control slump loss involves the addition of a higher dosage of superplasticizer or adding a retarding admixture in the formulation [9]. However, the limitations of this approach include production of concrete of low early strength or more rapid slump loss. For instance, some retarders (sugar, sucrose, corn syrup or calcium lignosulfonate) may produce slump loss accompanied by a surprisingly quick set. The individual slump loss is dependent on the cement proportion, the chemical and mineralogical composition of cement. Although the detailed mechanism is not clear, the content of  $C_3A$ , gypsum and alkali, as well as the form of calcium sulfate used as set regulator, can affect the rate of slump-loss [9].

The third method that has been suggested to control slump loss involves re-dosing the superplasticizer at different intervals, but this method has been found to have practical challenges and is not easy to be adopted. Furthermore, the relative cost and the total quantity

of superplasticizer cannot be controlled according to a given mix design.

It is therefore important that a superplasticizer which is capable of independently maintaining the slump for a long period of time irrespective of the temperature or the type and proportion of cement is employed. Collepardi et al. [4] studied the effects of a PC-based superplasticizer on the properties of ready-mixed concrete mixtures. This superplasticizer is more effective than SNF and acts as both an immediate superplasticizer and a slump loss reducing agent. Although the contents of the active polymers have been varied for these superplasticizers (0.30% active polymer versus 0.40%), the PC based superplasticizer was more effective than that based on SNF for the water reducing capability ( $w/c = 0.43$  versus  $0.47$ ) and maintaining of the initial slump level.

Tanaka et al. [16] has studied the effect of a CLAP based superplasticizer on the rate of slump loss of concrete mixture. This superplasticizer is a partially cross-linked copolymer of acrylic acid and polyethylene glycol mono-alkyl ether (Figure 2.1) and according to Tanaka and coworkers the cross-linked polymer is hydrolyzed by the alkaline water phase of the cement paste and converted into a PC-based polymer (Figure 2.2).

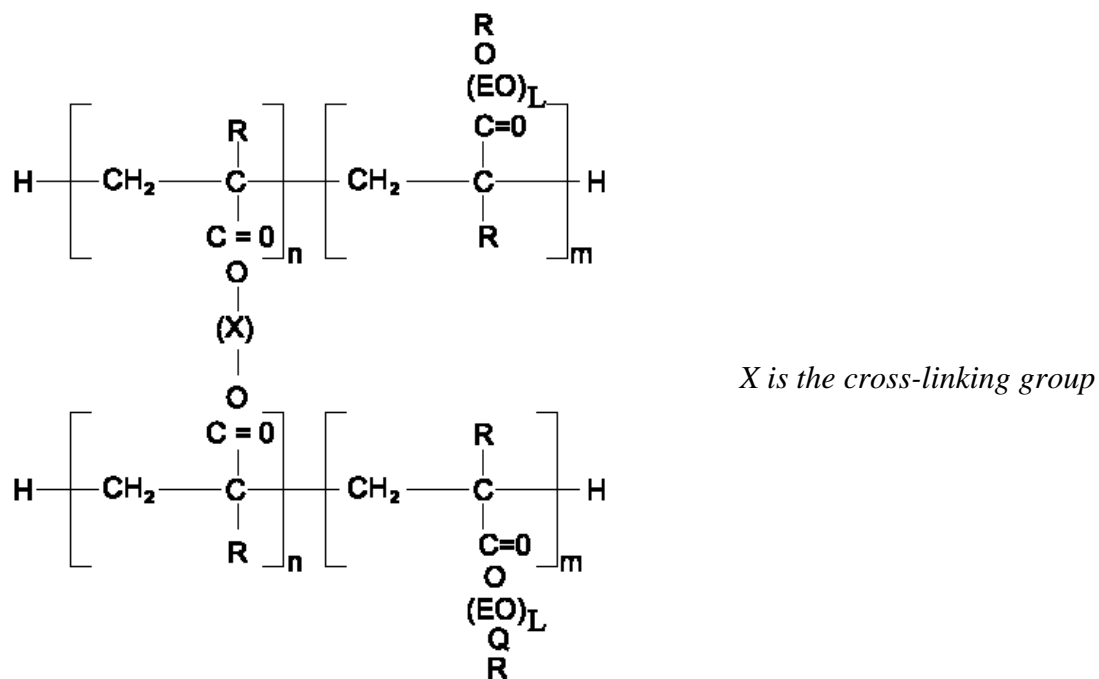


Figure 2.1: Chemical Structure of Cross-Linked Acrylic Polymers [16].

The number of  $\text{COO}^-$  increases progressively with time and is responsible for the low rate of slump loss.

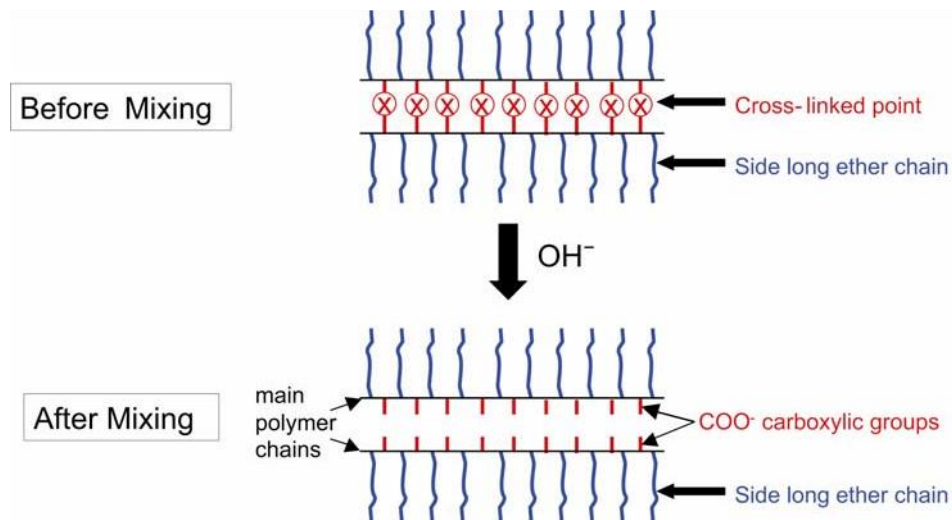


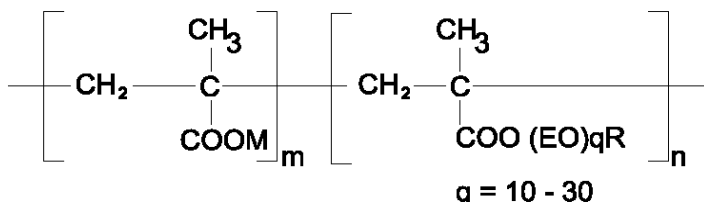
Figure 2.2: CLAP-based superplasticizer hydrolyzed by the alkaline water of cement paste [16].

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

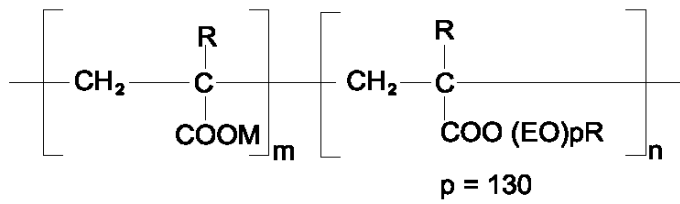
Hamada et al. [17] developed a new family of acrylic polymers based on the following changes with respect to the PC-based superplasticizer:

1. A polyether (PE) based superplasticizer with much longer side chains of ethylene oxide (EO) of 130 moles instead of 10-25 moles in the traditional PC-based superplasticizer (Figure 2.3) produces a lower adsorption speed and reduces the typical retarding effect related to the early adsorption.

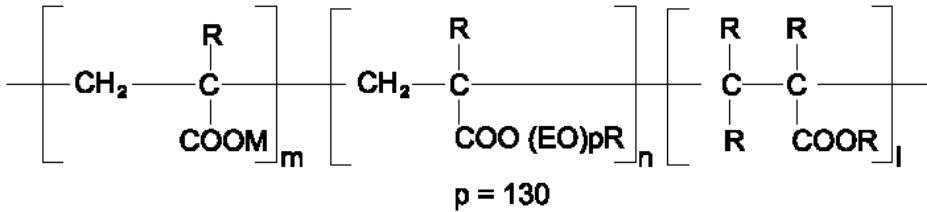
Polycarboxylate based (PC)



Polyether based (PE)



Slump Loss Controlling Agent (SLCA)



q and p are the number of moles of EO in PC and PE or SLCA polymers

Figure 2.3: The chemical structure of PC, PE type and SLCA superplasticizer [17].

2. A modified PE-based superplasticizer where a great number of carboxylic groups are replaced by a slump-loss controlling agent (SLCA) to achieve a higher slump retention with minimal setting retardation. The relatively low number of carboxylic groups in SLCA (Figure 2.4) cause negligible initial adsorption and dispersing effect as well as the setting retardation.
3. Subsequent to the hydrolysis effect which is related with the  $\text{OH}^-$  presence in the aqueous phase of the cement paste, the number of carboxylic units increases (Figure 2.5) and the slump can still increase by prolonging the mixing time due to the increasing adsorption of the polymer on the surface of the cement particles.

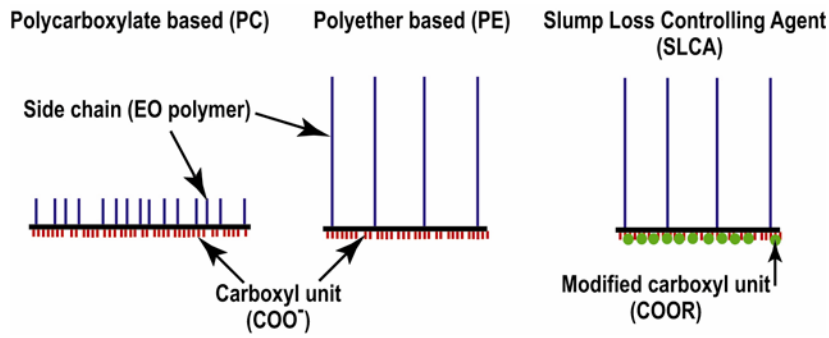


Figure 2.4: The molecular structure of PC, PE type and SLCA superplasticizer [17].

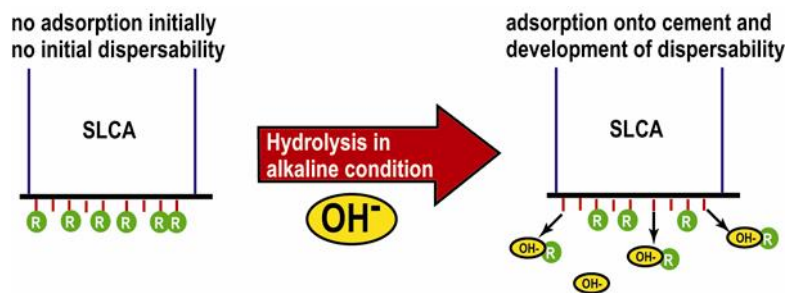


Figure 2.5: The mechanism and the hydrolysis reaction of SLCA in alkaline condition of cement paste [17].

The behavior of fresh concrete in the presence of PC and SLCA-based superplasticizers is schematically indicated in Figure 2.6. Section 2.7.2 and 2.8.3 discusses in detail the chemical action of the superplasticizers on cement pastes.

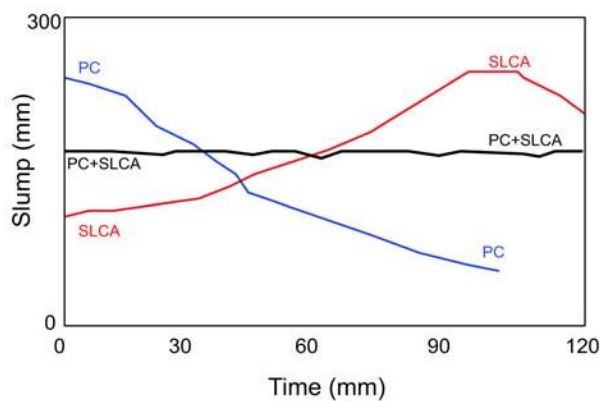


Figure 2.6: The slump loss behavior of different acrylic superplasticizers (PC, SLCA, PE +SLCA) in concrete mixtures with CEM II A/L 32.5R (340kg/m<sup>3</sup>), w/c = 0.45 [17].



## **2.7 Mechanisms of action of different superplasticizers for high-performance concrete**

### **2.7.1 Properties and characteristics of superplasticizers**

Whitney [14] defines superplasticizers as high range water reducers (HRWR), superfluidizers and super water reducers due to their higher efficiency in improving workability and flow of concrete mixes than the conventional water reducing admixtures. They were developed for use where the amount of conventional water reducing admixtures required to reach a desired slump or flow compromised other critical properties of concrete. Researchers used different chemistry methods in order to produce an admixture that allowed contractors to place highly workable concrete with higher strengths and greater durability and less shrinkage when properly designed. ASTM C 494 specifies superplasticizers as Type F for high range water reduction with normal set times or Type G for high range water reduction with retarded setting times. HRWR consist of four chemical groups which include: Sulfonated Melamine – Formaldehyde (SMF), Sulfonated Naphthalene – Formaldehyde condensate (SNF), Modified Lignosulfonate (MLS) and others that may include Sulfonic acid esters or Carbohydrate esters (Carboxylates). HRWR are commonly categorized as first, second and third generation superplasticizers:

1. First generation superplasticizers act by electrostatic repulsion and comprise of anionic materials that create negative charges on the cement particles, resulting in reduced friction due to the same charge particles repelling each other. These superplasticizers do not affect the hydration process and using them to reduce w/c ratios without the addition of retarders makes for quicker setting times. First generation superplasticizers are normally added at site because of the shorter workability times. Their chemistry allows for the reduction in water content by 20% to 30% [14].
2. Second generation superplasticizers are suitable for addition at the batching plant. They coat the cement particles with a thixotropic material; they lubricate the mix, allow lower water/cement ratios and control the hydration process. Second generation superplasticizers can be employed for higher concrete temperatures, thus reducing or eliminating the need of ice. Water content is typically reduced by 20% to 30%, and the higher workability time is extended [14].

3. Third generation superplasticizers coat the cement particles and are suitable for addition at the batching plant. These superplasticizers produce the same advantages as second generation superplasticizers, and have an added advantage of maintaining initial setting characteristics similar to normal concrete while producing a highly plastic mix at an extremely low water/cement ratio. They are effective at deflocculating cement grains due to steric hindrance and their use is being adopted over older sulfonated lignins or melamine based products [14].

Different chemical admixtures when added to the concrete mix chemically react with the components of the concrete and influence its performance in the fresh and hardened state. They can enhance workability of the fresh mixture, strength or durability of the hardened concrete. Ramachandran et al. [15] categorizes chemical admixtures depending on their enhanced property as water reducers, superplasticizers, accelerators, retarders, air-entraining agents, corrosion inhibitors, alkali-aggregate expansion inhibitors, shrinkage reducing admixtures.

Water reducers or plasticizers are added to provide workability in the freshly mixed concrete matrix at significantly lower amounts of mix water, thus producing higher strength and durability. Accelerators are commonly used to offset retardation effects from other admixtures and retardation due to colder temperatures at the job site [14].

Retarders are used to slow down the initial set of the concrete whenever elevated ambient temperatures shorten working times or unavoidable delays beyond the practical limitations of normal placement and finishing operations [13].

Air-entraining admixtures are used to purposely introduce and stabilize microscopic air bubbles in concrete. Air-entrainment will dramatically improve the durability of concrete exposed to cycles of freezing and thawing [14].

Corrosion inhibitors are used in concrete for parking structures, marine structures and bridges where chloride salts are present. The chlorides can cause corrosion of steel reinforcement in concrete and therefore corrosion inhibitors are used to chemically arrest the corrosion reaction .

Shrinkage reducing admixtures, have potential uses in bridge decks, critical floor slabs and buildings where cracks and curling must be minimized for durability or aesthetic reasons.

Alkali-aggregate expansion inhibitors are used to control alkali-silica reaction. Consequently, there has been renewed interest in using lithium compounds (lithium hydroxide, lithium carbonate and lithium nitrate) to combat this deleterious chemical reaction [14].

The invention of superplasticizers is one of the most important breakthroughs that has led to the development of high performance concrete. Figure 2.7 schematically summarizes the benefits of using superplasticizers in concrete.

A superplasticizer can be used as a water reducer at a given workability (I in Figure 2.7), thus increases the strength and durability of concrete due to the lower w/c ratio [18].

A superplasticizer can also be used to reduce both water and cement, so that the workability and strength of the concrete with superplasticizer are matched to those of the control concrete without admixture (II in Figure 2.7). With the reduction in cement, superplasticizers are therefore capable of reducing the amount of hydration heat, a property that is essential for hot weather concreting or mass concrete works. There is also an added benefit of reduction in shrinkage and creep due to the higher aggregate/cement ratio as a result of the reduction in cement content and the increase of aggregate to compensate for the volume decrease of cement and water [18].

Superplasticizers can also be used without modifying the water and cement content, thereby increasing concrete workability (III in Figure 2.7). Highly workable concrete is most suited for placing in areas of congested steel content [18].

Without the use of the superplasticizer, the changes (I) and (II) can be carried out by increasing the cement-content (IV) or both cement and water at a given w/c (V) respectively. However, both changes (IV) and (V) will result in higher shrinkage, creep and heat of hydration for the increased cement content [18].

Great advances in development of superplasticizers containing alternative water soluble synthetic products have been recently proposed [18] in order to reduce the slump loss drawback. More recently in Europe and Japan, these new superplasticizers based on the family of acrylic polymers (AP) have been investigated in depth, and numerous papers presented at the Fifth CANMET-ACI International Conference on “Superplasticizers and Other Chemical Admixtures”[17-19].

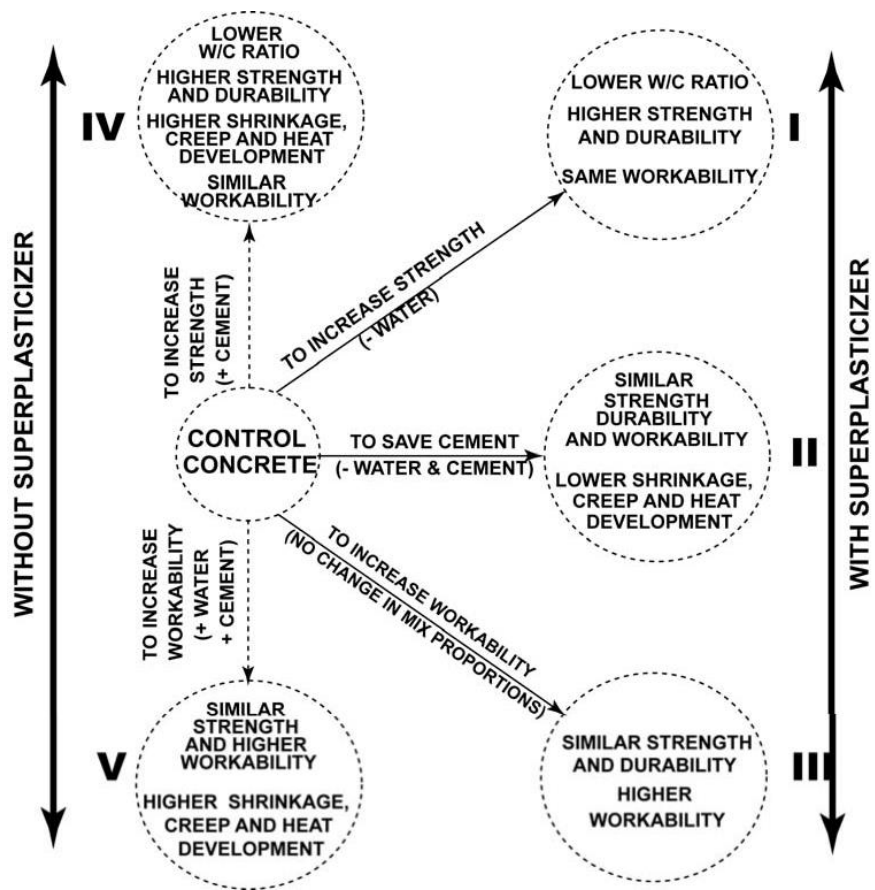


Figure 2.7: The effect of superplasticizers on fresh and hardened concrete [18].

## 2.7.2 Mechanism of action of superplasticizers

Collepari et al. [7] describes the mechanism of action of different superplasticizers. They act by dispersion of smaller cement particles and prevent formation of coarse agglomerates which predominate in the cement paste of the concrete mix. The aim of the dispersion is to prevent the fine particles of cement from flocculating. These dispersants consist of surface active chemicals made up of long chain organic molecules, which have a polar hydrophilic group (water-attracting, such as  $\text{COO}^-$ ,  $-\text{SO}_3^-$ ,  $-\text{NH}_4^+$ ) attached to a non-polar hydrophobic organic chain (water-repelling) with some polar groups ( $-\text{OH}$ ). The polar groups in the chain get adsorbed on the surface of the cement grains, and the non polar hydrophobic end at the tip project outwards from the cement grain. Generally, the molecules of the superplasticizer align themselves around cement particles forming a watery shell. These molecules are attracted to cement particles on one side and water molecules on the other. Thus they create a lubricating film around the cement particles, which reduces both the yield value and the plastic viscosity of the mix (Figure 2.8). These effects are more pronounced for higher concentrations of superplasticizer. Microscopic examination of cement particles suspended in water shows that large irregular agglomerates of cement particles are dispersed into small particles due to the effect of superplasticizers. The admixture forms needle-like hydration products instead of the large fibrous bundles found in normal concrete [20]. There is an increase in fluidity in the cement mixture as a result of the dispersion effect.

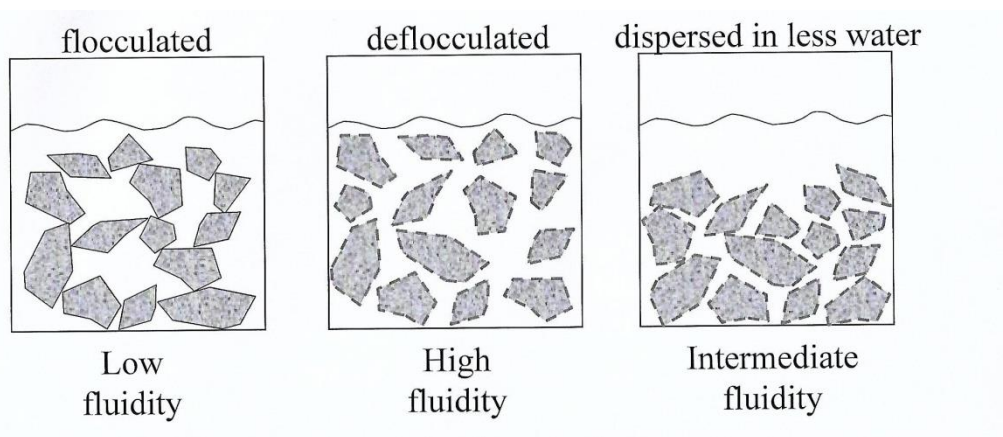


Figure 2.8: The effect of superplasticizer on the fluidity of the cement paste [20].

The dispersion effect by the superplasticizers occurs either by electrostatic repulsion or steric hinderance mechanism [18]. Electrostatic repulsion is caused by the zeta potential, which is a surface charge produced by the grinding of cement during manufacturing. The adsorption of

the superplasticizer leads to a decrease of the zeta potential, and eventually causes like charges (negative) on the cement particles. The electrostatic charge diminishes as the hydration process proceeds and eventually flocculation of the hydrating product occurs.

Electrostatic repulsion is dependent on the composition of the solution phase and the amount of of the superplasticizer adsorbed by the cement. The greater the adsorption of the superplasticizer, the higher the repulsion of the cement particles [21].

LS, SMF and SNF based superplasticizers act by the mechanism of lowering the zeta potential that produces electrostatic repulsion. The dispersion of cement particles is caused by the adsorption of negatively charged groups ( $\text{SO}_3^-$ ) which causes a decrease in the zeta potential and produces like charges on the cement particles (Figure 2.11).

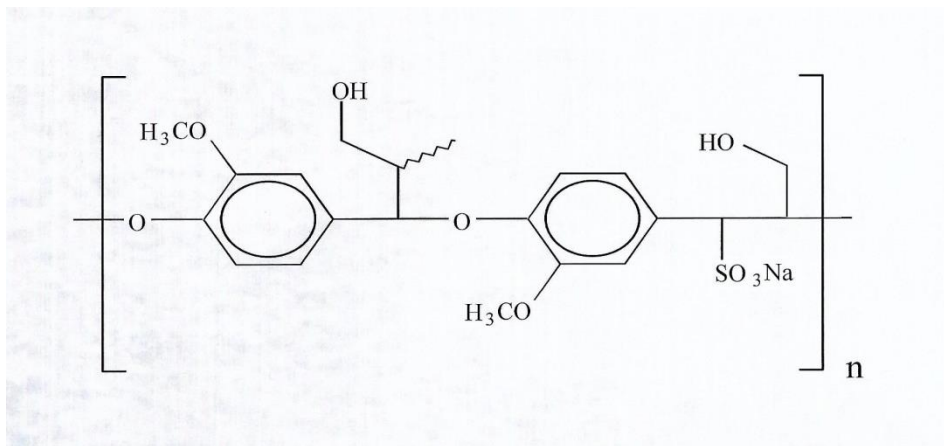


Figure 2.9: The chemical structure of Lignosulphonate superplasticizer[20].

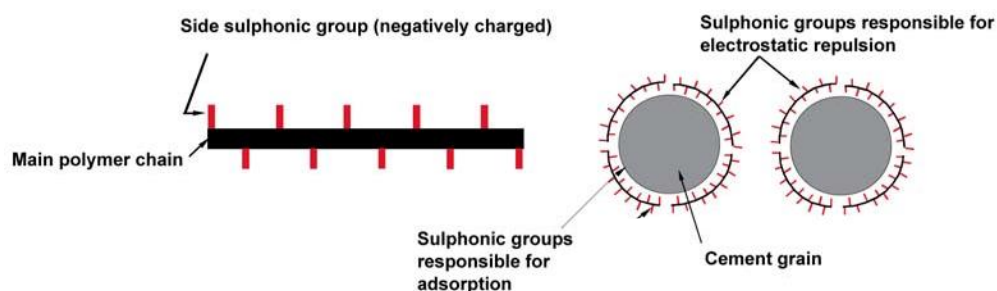


Figure 2.10: Sulfonated polymer and its electrostatic repulsion effect on the dispersion of cement particles [18].

The other dispersion mechanism by the superplasticizers is caused by steric hinderance. Research was carried out on the dispersion mechanism of PC- based superplasticizers and it was found that the zeta potential charge responsible for electrostatic repulsion was much lower and the cement particles appeared almost electrically neutral. The results of the experiments as

shown in Table 2.4, indicated that PC-based superplasticizers produce negligible zeta potential charge (0.3-5 mV), with respect to that caused by SNF-based admixtures (23-28 mV), in aqueous suspensions of cement particles (Figure 2.11). Figure 2.11 indicates that the zeta potential of cement particles treated by PC is much lower than those recorded in the presence of SNF and in particular, when 0.3% of PC by mass of cement was used, the cement particles appeared to be almost electrically neutral.

These results would confirm that the dispersion of cement particles, responsible for the fluidity increase caused by the superplasticizer, is not necessarily related to the electrostatic repulsion associated with zeta potential measurements.

Table 2.4: Zeta potential of cement particles in aqueous suspension with superplasticizers [18].

SUPERPLASTICIZER	MAIN COMPONENT	ZETA-POTENTIAL (-MV)
A	PC	5.0
B	PC	0.3
C	PC	1.0
D	PC	4.0
E	PC	4.0
F	PC	2.0
G	SNF	23.0
H	SNF	28.0

PC = Polycarboxylate - SNF = Sulphonated Naphthalene Formaldehyde Condensate

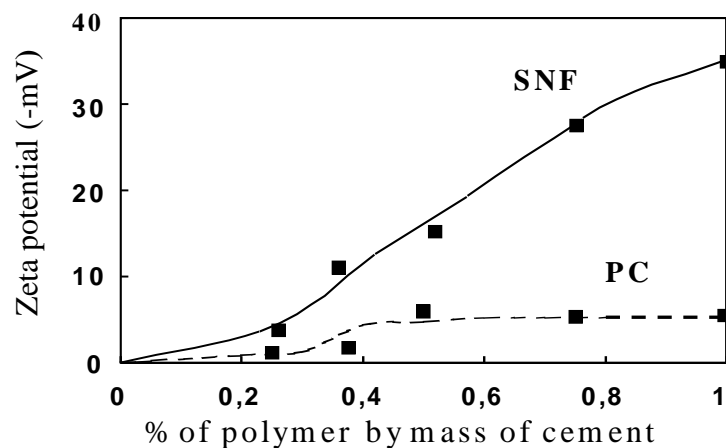


Figure 2.11: Zeta potential of cement pastes with PC or SNF as a function of polymer dosage [18].

The dispersion mechanism performed by the PC-based superplasticizers was found to be more to a steric hindrance effect (produced by the presence of neutral side long ether chains) rather than to the presence of negatively charged anionic groups ( $\text{COO}^-$ ) which are adsorbed on the surface of cement particles. The long ether chains of the polymer molecules on the surface of cement would hinder by themselves from flocculating into large and irregular agglomerates of cement particles (Figure 2.2 and 2.12).

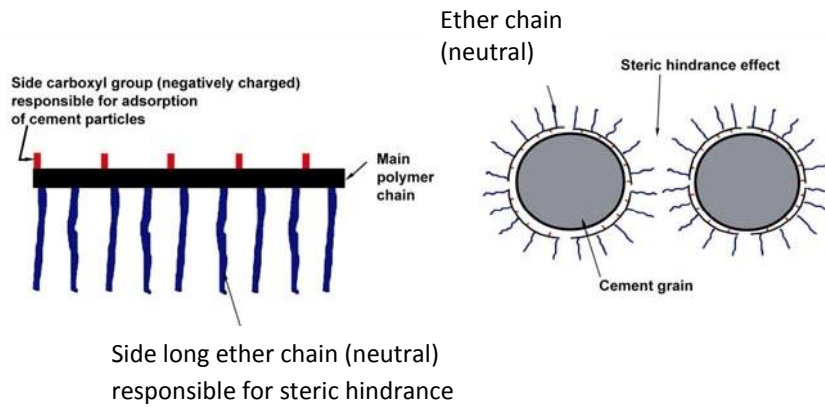
It would seem that polymers with backbone and graft chains, such as PCs, PEs and CLAP cause dispersion of cement grains by steric hindrance [22]. The polymer adsorption itself, rather than the electrostatic repulsion, is responsible for the dispersion of large agglomerates of cement particles into smaller ones resulting in a remarkable increase in the fluidity of cement mixes. Steric hindrance is a more effective mechanism than electrostatic repulsion and is dependent on the size of the main chain and number of attached side chains [23].

The polyethylene oxide side chains extend on the surface of cement particles and migrate in water dispersing the cement particles by the steric hindrance of the chains.

For fluidity retention in PC based admixtures, the main chain should be short with large numbers of long side chains [23]. PCs are generally more effective than the sulphonate based admixtures due to the steric repulsion mechanism and are efficient at low w/c ratios. They are however more sensitive to overdosing and can lead to problems like excessive retardation.

Other mechanisms of action of superplasticizers include dispersion of cement particles by surface tension reduction of mixing water and a decrease in frictional resistance because of the linear polymers lining along the direction of concrete flow and lubrication effect produced by low molecular weight polymers [24].





*Figure 2.12: PC type superplasticizer and its steric hindrance effect on the dispersion of cement particles[18].*

Superplasticizers can also cause some changes in the morphology of hydration products apart from the dispersion effect caused at the early age of concrete. The size of portlandite crystals decreases with addition of superplasticizers [25] and in the presence of high dosage of superplasticizer, ettringite crystallizes in small and massive clusters rather than the conventional needle shaped [26, 27].

## **2.8 Cement – superplasticizer incompatibility**

### **2.8.1 Introduction**

Incompatibility occurs when the performance of fresh and hardened concrete is compromised due to the adverse effects as a result of using a certain combination of the cement and superplasticizer. The adverse effects include flash setting, excessive retardation, rapid slump loss, improper strength gain, high shrinkage cracking etc. These issues ultimately affect the strength and durability of concrete.

The use of superplasticizers with various brands of cement available in Kenya produces different results for each combination. It is therefore not certain that a superplasticizer will manifest all its desired effects with any of the cement brands. Lack of knowledge on compatibility issues causes undue loss to the user when the supply of cement or the superplasticizer is replaced during a project. Most often, compatibility issues are mistaken for problems with the mix design because of the inadequate information on the subject. Therefore, a thorough understanding of the effect and remedies of incompatibility is necessary.

With the expected growth and extensive use of high performance concrete around the world, the problems of incompatibility are likely to increase and there is therefore great need for researchers to develop proper guidelines for use in order to prevent the cement – superplasticizer incompatibility [28].

Incompatibility may also arise due to using multiple chemicals or mineral additives in concrete [29].

## 2.8.2 Factors affecting compatibility

Superplasticizers are adsorbed on the cement particles and most of the time they interfere with the hydration process of cement. Therefore incompatibility problems are independent of the mix design and occur even when the selection and design of materials is proper and are not similar to problems due to poor material selection. For instance, over dosage of the superplasticizer can cause excessive retardation of setting and segregation (due to reduction in paste viscosity and yield stress) which is not a problem of incompatibility but poor design.

There are a number of reasons which affect cement – superplasticizer compatibility and they include the composition of cement, superplasticizer type and dosage, mix proportions etc. Aïtcin [30] describes the interaction of various factors affecting the compatibility in a schematic diagram as shown in Figure 2.13.

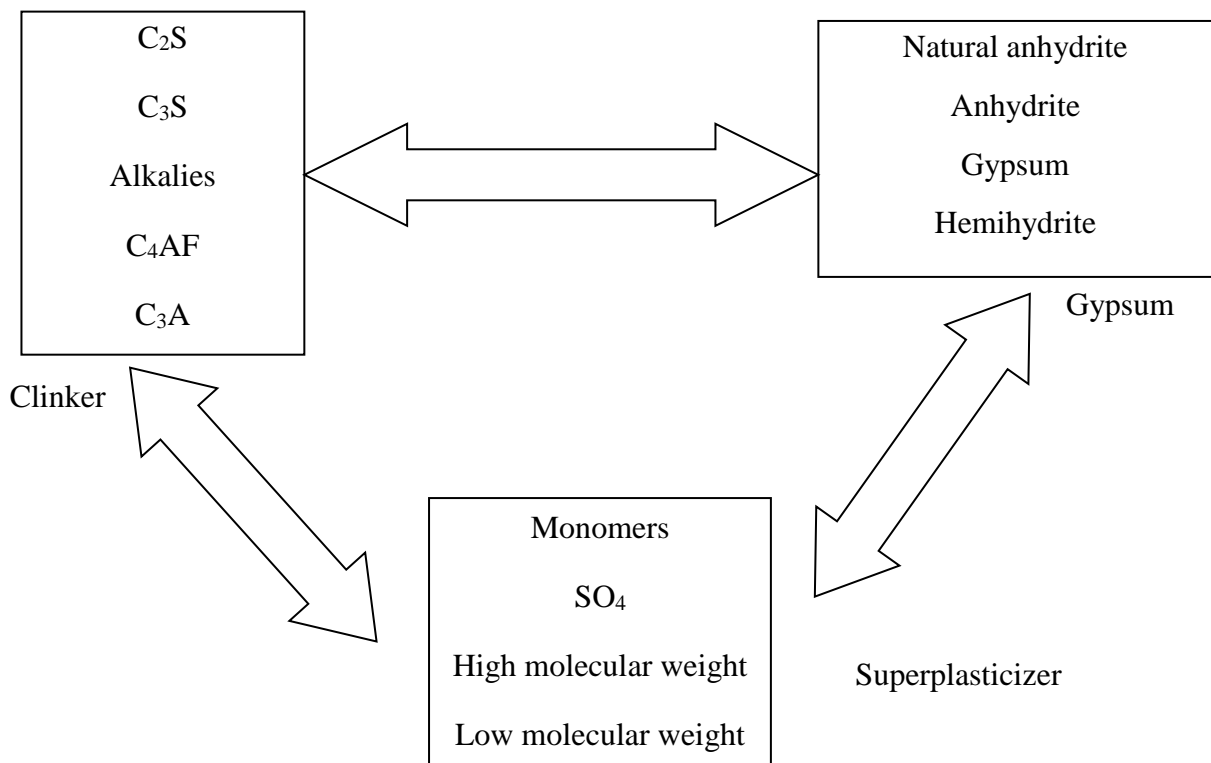


Figure 2.13: Superplasticized cement paste system [30]

The effect of cement composition consists of a variety of factors which are discussed in the subsequent section.

### 2.8.3 Composition and fineness of cement

Cement comprises mainly of four chemical compounds and a number of minor oxides. The main compounds include  $C_3S$ ,  $C_2S$ ,  $C_3A$  and  $C_4AF$  while the minor oxides include alkali oxides ( $K_2O$  and  $Na_2O$ ),  $MgO$  and  $SO_3$  – contributed by gypsum. Gypsum is added in the final stages of cement manufacturing as a set regulator. The particles of cement are usually charged due to the final grinding action of the cement during manufacturing and the surface charge is determined by the Zeta potential. The chemical compounds  $C_3S$  and  $C_2S$  have a negative zeta potential while  $C_3A$  and  $C_4AF$  particles possess a positive charge.

#### 1) $C_3A$ content

The  $C_3A$  content in cement affect the early stages of the cement hydration process.  $C_3A$  react with  $SO_4$  to form an ettringite which prevents flash setting but the end product of aluminate hydration in OPC is monosulphate ( $AF_m$ ). For cement with low content of  $C_3A$  (sulphate resistant) the ettringite remains after the initial hydration.

Flash setting occurs when the ratio of  $C_3A$  to  $SO_4$  is very high or when the amount of  $SO_4$  in the solution is negligible causing rapid hydration of  $C_3A$ . False setting on the other hand occurs when the ratio of  $C_3A$  to  $SO_4$  is very low causing a high possibility of the formed calcium sulphate being converted to gypsum.

Superplasticized concrete is exposed to high rates of slump loss when the content of  $C_3A$  is high while the sulphate available is low. Cements consisting of moderate to high content of  $C_3A$ , up to 9%, experience an increase in slump loss when compared to that of control concrete. In cases where the content of  $C_3A$  is lesser, higher amounts of the superplasticizers get adsorbed on  $C_3S$  and  $C_2S$  leading to reduced rate of strength gain [31]. Cements consisting of less than 10% of interstitial phase (3.6%  $C_3A$  and 6.9%  $C_4AF$ ) required less superplasticizer dosage to produce high fluidity at low w/c ratio.

#### 2) Calcium Sulphates content

During the early phase of cement hydration, the main reactions that occur include the reaction of  $C_3A$  with gypsum to form the ettringite and that of  $C_3S$  with water to produce Calcium Silicate Hydrate and Calcium Hydroxide. Superplasticizers interact with cement during this phase of hydration and it has been shown by researchers that superplasticizer molecules with sulphonated functional groups have a higher affinity for the positively charged aluminates.

They therefore compete with the sulphate released from gypsum for the aluminates [32, 33]. In cases where the solubility of the calcium sulphate released from gypsum is low, the superplasticizer molecules are adsorbed first on the aluminate compounds and therefore preventing the normal setting reaction involving the formation of ettringite. The calcium sulphate present in the cement is dependent on the raw material and the attained temperatures during the final grinding process, and can be a mixture of dihydrate (gypsum), hemihydrates or anhydrite. It is therefore critical that the  $\text{SO}_4$  molecules are readily available in the solution in order to prevent the superplasticizer molecules from interfering with the aluminate hydration process. Thus, high solubility of the calcium sulphate released from gypsum is key. The hemihydrate and synthetic anhydrite possess greater solubility properties than gypsum but the solubility of the natural anhydrite is very slow. It has been shown that the presence of natural anhydrite in the cement causes compatibility problems. In the presence of the sulphonate based superplasticizers, it has been found that the solubility of sulphates decrease and this ultimately affect the normal setting process of the cement [26]. Therefore, adequate amounts of soluble alkali sulphates are usually presented in cements in order to improve the availability of sulphates in the solution.

### **3) Content of Alkalis**

The content of alkalis in cement is necessary in accelerating  $\text{C}_3\text{S}$  hydration process. It is however critical that the amount of alkalis in the cement is regulated since in excess amounts the alkalis could react with the aggregates in the concrete. Cements with high alkali content cause workability problems when used without any admixtures while those with low alkali content produce concrete of poor rheology when used with sulphonate based superplasticizers [34]. The poor rheology is related to the availability of soluble sulphates which has been discussed in the earlier section. The challenges posed by low alkali cements can be solved by the addition of an optimum amount of soluble alkalis in the form of the metasilicate or sulphate compounds [33]. Jiang et al. [34] has researched and found that the optimum soluble alkali content necessary to maximize fluidity and reduce the rate of slump loss is 0.4 – 0.5%. Higher contents of alkali promote the solubility and availability of sulphate ions in the solution and therefore decreases the loss of fluidity with SNF [35, 36]. However, in the presence of high amount of alkali sulphates other than calcium sulphate, it may be difficult for the crystallization of the ettringite to occur in order to allow for rapid stiffening [27].

Different forms of alkalis exist, alkalis in the form of  $K_2O$  increase reactivity of  $C_3A$  whereas  $Na_2O$  reduces the reactivity of  $C_3A$  [37]. Furthermore, problems of efflorescence occur when naphthalene and melamine based superplasticizers are used with cements comprising high alkali oxide content ( $Na_2O + K_2O > 0.75\%$ ).

#### 4) **Fineness of cement**

Finer cement particles require a higher water demand for a particular workability due to the high specific surface area. Consequently, they require a higher amount of the superplasticizers to be used for a certain workability [33].

Ramachandran et al. [37] have examined the properties of cement grouts with SNF superplasticizer and have confirmed that the content of  $C_3A$  and the fineness of cement are among the most important factors: the higher the content of  $C_3A$  and the cement fineness, the lower the fluidizing effect.

Coppola et al. [19] 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 et al. [38] who found that in the presence of SNF superplasticizer cement pastes are much more fluid when dihydrate is used instead of hemihydrates. However, for cement with very low alkali content the difference in fluidity caused by the two Calcium Sulfate forms is negligible.

Nawa et al. [38] have found that with Calcium Sulfate in the form of anhydrite as a set regulator, the fluidity of superplasticized cement paste lies between the values obtained with dihydrate and hemihydrates except that in cement with very low alkali content the fluidity is much lower.

Nawa et al. [38] have examined the complex influence of the water soluble alkali Sulfate of the cement on the fluidizing effect of the SNF-based superplasticizer. They have confirmed that SNF, as well as SMF as found by Ramachandran et al. [37], absorb on  $C_3A$  and  $C_4AF$  more quickly and selectively than on  $C_3S$  and  $C_2S$ . The adsorption of superplasticizer on  $C_3A$  and  $C_4AF$  is inhibited in the presence of alkali sulphate, leading to increased adsorption of the superplasticizer on  $C_3S$  and  $C_2S$ . An increase in the content of alkali of cement causes a reduction in the total amount of superplasticizer adsorbed on the cement and therefore there is

a higher amount of polymer in the aqueous phase to cause dispersion and reduction of the viscosity of the cement paste.

However, according to Nawa et al. [39], excessive amount of alkali Sulfate compresses the electric double layer causing a small increase in viscosity of the cement paste. These results would indicate that there is an optimum alkali Sulfate content with respect to the fluidity of superplasticized cement paste [39, 40].

#### **2.8.4 Superplasticizer type and dosage**

The type and amount of superplasticizer dosage have an effect on the cement – superplasticizer compatibility issues.

It has been found that most superplasticizers increase the setting time and slow down the hydration process [33]. Primarily, superplasticizers prolong the reaction of  $\text{Ca}^{2+}$  and prevent the ettringite crystallisation [27, 32].

##### **1) Adsorption effects**

The adsorption of the superplasticizer on the surface of cement particles causes a reduction in the amount of the polymer available in the solution. Thus, a higher amount of the superplasticizer is required to obtain a specific fluidity when adsorption levels are higher.

Superplasticizers when in contact with  $\text{C}_3\text{S}$  form organo- mineral compounds and slow down the precipitation and growth of C-S-H and C-H [33, 41]. This formation of organo-mineral phases causes a reduction in the amount of superplasticizer available in solution leading to loss of slump.

High molecular weight of the polymer and the presence of calcium ions causes an increase in the surface adsorption of the superplasticizer. This shows that the manufacturing process can largely determine the performance of the chemical superplasticizer. Therefore, the manufacturing process need to be monitored in order to produce high molecular weight polymers.

##### **2) Molecular weight of polymer**

The presence of low molecular weight polymers in the lignosulphonate based superplasticizers has been shown to cause excessive air entrainment which leads to loss of concrete strength [42, 43]. At high dosages, these superplasticizers can cause unnecessary retardation due to their high content of sugar which in some instances is modified or removed in order make them chemical effective. Research has shown that depending on whether the chemical is a sodium salt or a calcium salt, the issues of compatibility are unpredictable since neither type of the chemical is compatible with all cements. Lignosulphonate (LS) based admixtures produce a complex salt when in contact with  $\text{Ca}^{2+}$  thus decreasing its concentration in the liquid phase. This delays the hydration of the aluminates and causes retardation of the setting period.



Compared to LS, the adsorption of SNF depends more on the type of cement thus necessitating its addition in higher quantities. Chandra and Bjornstrom [44] researched and found that due to the difference in the degree of adsorption of LS and SNF/SMF, the rate of slump loss is lower for mortars composed of LS than with SMF or SNF.

### **3) Time of addition of the superplasticizer**

Delayed addition has been proposed as a means of reducing the rate of slump loss in the case of SMF and SNF based admixtures [45, 46]. The rate of adsorption of the superplasticizer reduces when the cement hydrates and is greater on un-hydrated compounds than the hydrated phases [47]. There is therefore more admixture available in the solution to maintain the fluidity when delayed addition is carried out. Aiad [48] found out that the optimum delaying time of the admixture is 10 – 15 min and it is not dependent on the type of superplasticizer and cement.

Uchikawa et al. [24] linked the improvement in fluidity of concrete due to later addition of the superplasticizers to the increased availability of the admixture in solution. They also found that SNF based chemicals were more responsive to delayed addition compared to PC and lino-sulphonates.

The SMF or SNF based superplasticizers are able to transform a no-slump concrete into a self-leveling mix with a slump increase of about 200mm. However, the method of addition of these superplasticizers affects the rate of slump increase effect. An immediate addition procedure (superplasticizer with gauging water) produces a less workable mix in comparison to a delayed addition of the same superplasticizers (after an initial mixing period of 1 minute) [7].

The influence of the method of addition on the effect of superplasticizers has been related to the different capability of SMF or SNF polymer molecules to be adsorbed on anhydrous or hydrated cement particles [19]. For instance, a preliminary treatment of cement even with a small amount of water (1-2%) produces superplasticized concrete mixes which, independently of the method of addition of the superplasticizer, always perform as well as the best concrete produced by delayed addition [15]. This effect seems to be related with the production of an ettringite coating on the surface of cement particles during the preliminary water treatment. It seems that addition of superplasticizers with mixing water causes a strong incorporation of the polymer molecules into the C<sub>3</sub>A-gypsum system, leaving only small amounts of polymer for dispersion of C<sub>3</sub>S and C<sub>2</sub>S. Consequently, the adsorption of SMF or SNF polymer molecules on the pre-hydrated cement surface is reduced and the subsequent dispersing action appears to

be much more effective than that recorded in the absence of the preliminary water treatment [19].

Results by Uchikawa [22] confirm that NSF polymer is more adsorbed, particularly on the C<sub>3</sub>A hydration products, when the immediate addition procedure is adopted. Moreover, according to Uchikawa [22], the superplasticizing effect is improved with a delayed NSF-polymer addition because of the lower adsorption of the polymer on the C<sub>3</sub>A hydration products; on the other hand, the adsorption of the PC acrylic polymer does not depend on the mode of addition (immediate or delayed).

## 2.9 Blending of superplasticizers

Combinations of different superplasticizers have been investigated [15]. For instance, blending of MLS with SMF or SNF has economical advantages since MLS is cheaper than SMF and SNF. Blending of SNF and SMF may be used to increase early strength than SNF alone [15].

More recently the performance of a combined chemical admixture based on AP and one of the other available superplasticizers (SNF, SMF and MLS) was studied [49].

Collepari et al. [7] noted that in some cases concrete producers use a combination of acrylic polymer with the cheaper naphthalene-based superplasticizer in order to reduce the cost of the chemical admixture for a superplasticized concrete with a low rate of slump loss. However, under some circumstances, the effect produced was worse than that expected for the individual superplasticizers [49]. Collepari et al.[7] also noted that in general, when AP is replaced by SNF in the blended superplasticizers the initial slump level of the concrete mix is reduced and the slump loss is increased, in comparison to the performance of the pure AP-based superplasticizer. However, a sort of antithetical effect (as the opposite of synergic) is sometimes and surprisingly recorded for the slump of the concrete mixture when the superplasticizer composition is 25% of AP and 75% of SNF. This specific blended superplasticizer performs significantly worse than any other blended superplasticizers or pure individual polymers [7].

Collepari et al. [7] further noted that, by changing the source of a given cement type, the antithetical composition effect occurs erratically and independently of the type or strength class of the cement. In some cases, even batches of the same cement type and coming from the same source, but stored for different periods of time, performed erratically with or without the antithetical composition effect of the AP-SNF blended superplasticizer.

Although, the available data cannot explain the mechanism of the antithetical A-N composition effect and why it is so erratic, Collepari et al. [7] observed that these data are able to explain why, under some circumstances, the combined use of AP and SNF on concrete batching plants performed worse than that of each individual superplasticizer. The performance of blended AP-SMF superplasticizers always decreases when the content of SMF increases. In other words, antithetical composition effect, which sometimes was recorded for the AP-SNF blended superplasticizer, does not occur for the AP-SMF blended polymers regardless of cement used.

Colleparidi et al. [7] observed that pure acrylic polymer performs better than pure lignosulfonate in terms of higher initial slump. However, the difference is smaller than that found in the AP-SNF or AP-SMF combination. The initial slump level of pure MLS treated concretes is relatively high due to the very high air content in form of large bubbles. The subsequent slump loss of this concrete is substantially due to the loss of part of this unstable air.

Colleparidi et al. [7] further observed that the blended superplasticizer with 25% of MLS performs quite well in terms of high initial slump level and negligible slump loss up to 60 mm. Moreover, since the air content of the concretes with this AP-MLS blended superplasticizer is as low as that of the other acrylic superplasticized concrete mixtures ( $< 2\%$ ), even the strength development is as good as that of the pure acrylic concretes. This result appears to be very interesting in view of the lower cost of lignosulfonate when compared to that of the acrylic polymer. With higher lignosulfonate contents ( $>25\%$ ), the slump loss is more remarkable and the strength is reduced to a level lower than that of the reference mix.

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

### 3.1 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.

### 3.2 Materials

#### 3.2.1 Cements

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

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

#### 3.2.2 Water

Tap water conforming to ASTM C94 – 1996 [8], Specification for ready mixed concrete [50] was used for all mixes.

### 3.2.3 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. Rheobuild RMC 80 meets the requirements of EN 934-2 and ASTM C-494, Standard Specification for Chemical Admixtures for Concrete, Types A, B, D, F and G [5].

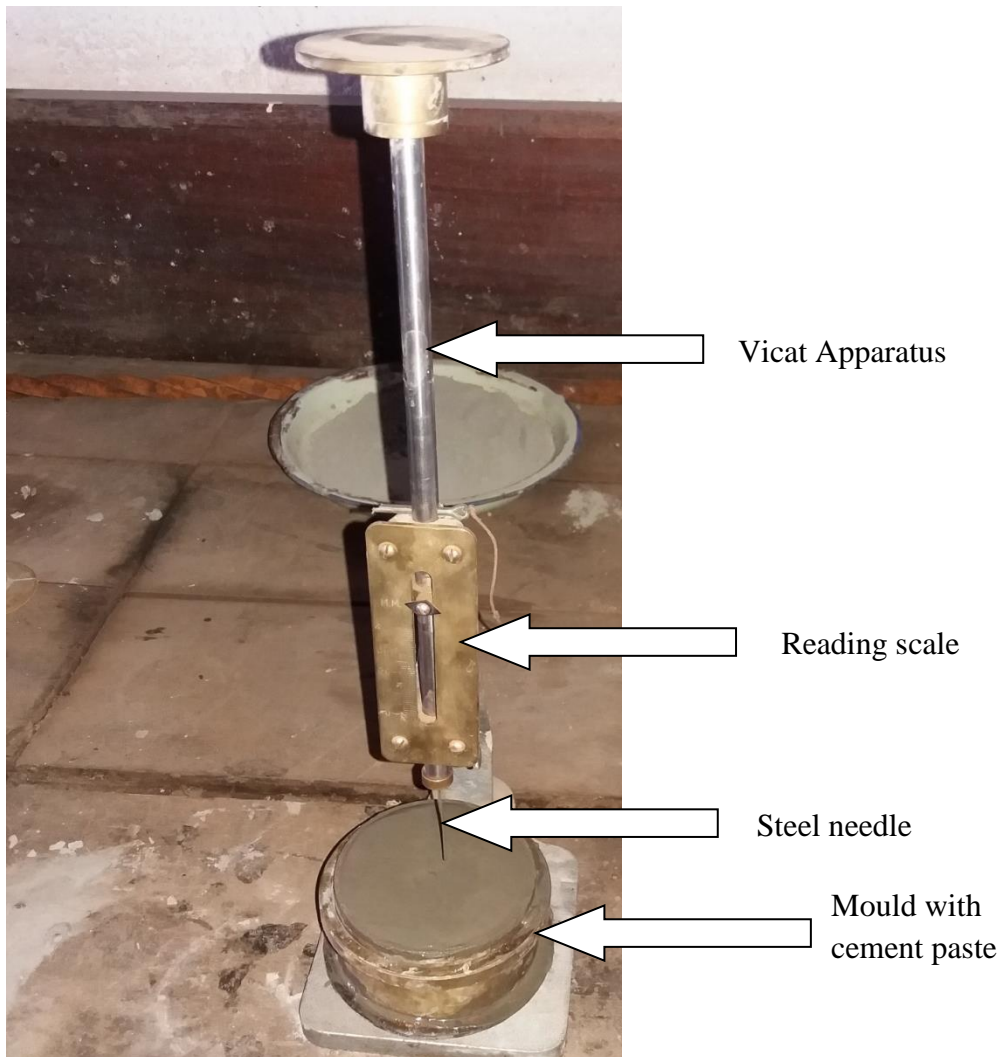
*Sika Viscocrete10* – This is a third generation high performance superplasticizer based on modified polycarboxylate polymer and produced by Sika. The manufacturer’s recommended dosage is 0.5 to 1litre per 100 kilogram of total cementitious material. Viscocrete 10 conforms to the requirements of EN 934-2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



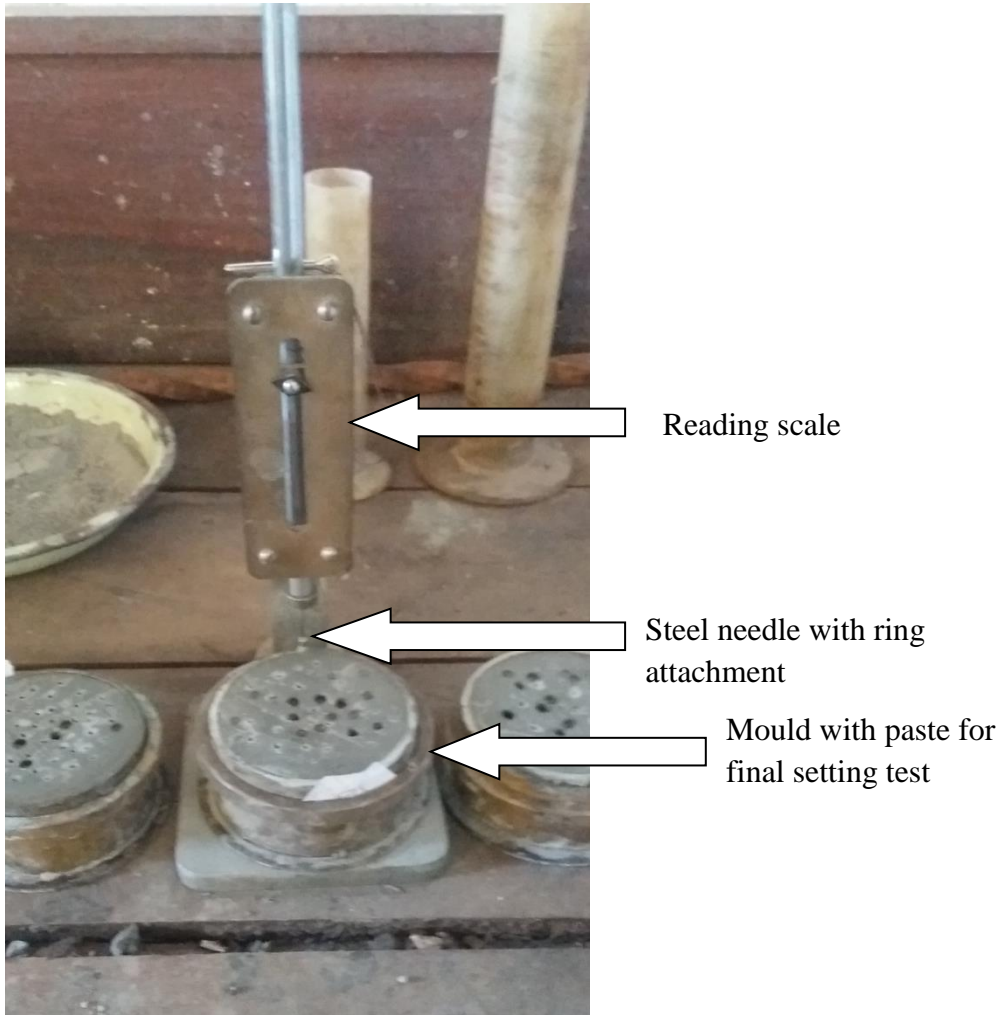
Figure 3.1: Samples of Master Rheobuild RMC 80 and Sika Viscocrete 10

### 3.3 Equipment

The 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 [51].



*Figure 3.2: Vicat Apparatus fitted with needle for initial setting time test*



*Figure 3.3: Vicat Apparatus fitted with ring attachment for final setting time test*



### 3.4 Mix proportions

Cement pastes were prepared for use in the determination of standard consistency and setting time tests. The paste for standard consistency was determined without the addition of the superplasticizers. The determined water content for standard consistency 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 3.1) while the dosage of the superplasticizer was gradually increased from 0.3% to 1.1% (Table 3.2) until a non-workable paste was obtained. The w/c ratios were based on the cement paste of standard consistency and reduced until a non-workable paste was obtained.

*Table 3.1: 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

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 at every superplasticizer dosage (from manufacturers' minimum recommended dosage up to the maximum recommended dosage) as indicated in Table 3.2. This was repeated for all the cement pastes and the results compared.

*Table 3.2: 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

### 3.5 Mixing procedure

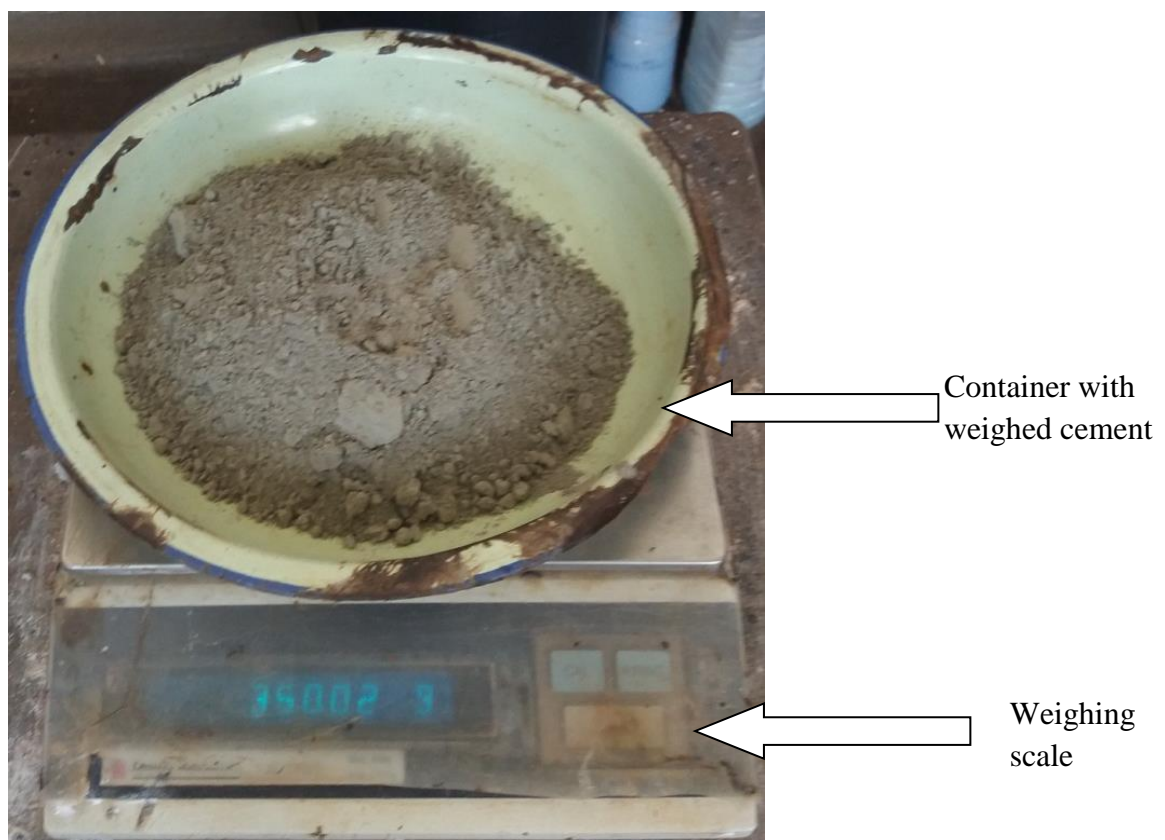
A digital weighing balance was used to measure 350g of cement (Figure 3.4). The required quantity of water was measured using a measuring cylinder.

For the control mix, the chemical superplasticizer was not used. The weighed cement was carefully placed into a bowl 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 mixed with 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.



*Figure 3.4: Weighing of 350g of cement*

## **3.6 Test procedure**

### **3.2.1 Standard consistence test [51]**

#### **Apparatus**

The manual Vicat apparatus and the plunger. The plunger consisted of a cylindrical non – corrodible metal of 10 mm diameter and 45 mm effective length.

The Vicat mould to contain the paste 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 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 using a steel trowel to leave the filled mould having a smooth upper surface.

#### **Determination of standard consistence**

The plunger was attached to the manual Vicat apparatus prior to the test. It was lowered to rest on the base plate and then the pointer adjusted to zero before being 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 released within 10 seconds and the plunger quickly allowed to penetrate vertically into the centre of the paste. The scale was read immediately 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 cleaned after every penetration.

The test was repeated three times 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.

### **3.2.2 Initial setting time test [51]**

#### **Apparatus**

Steel needle of effective length of 45 mm and diameter of 1.13 mm (Figure 3.2).

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

#### **Determination of initial setting time**

The paste of standard consistence was used to fill the Vicat mould. The mould and base plate were positioned under the needle of the Vicat apparatus and the moving parts released within 10 seconds in order for the needle to penetrate vertically into the paste.

The scale reading when penetration had ceased was recorded. The reading indicates the distance between the end of the needle and the base plate. 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 10 minutes intervals. The Vicat needle was cleaned immediately after every 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. A stop clock was used to record the start and end of the test.

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

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

### **3.2.3 Final setting time test [51]**

#### **Apparatus**

The Vicat needle fitted with a ring attachment of approximately 5 mm diameter in order to facilitate observation of 0.05mm penetrations accurately (Figure 3.3).

#### **Determination of the final setting time**

After the determination of the initial setting time, the same specimens were used for the final setting time.

The specimens were inverted so that the tests for final set were carried out on the face originally in contact with the base plate. Each of the inverted specimens was positioned under the needle of the Vicat apparatus after two hours and the moving parts released within 10 seconds in order for the needle to penetrate vertically into the paste.

The Vicat scale was read when the penetration had ceased. The penetrations were 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 30 minutes. Cleaning of the Vicat needle was done immediately after every penetration.

The time at which the needle first penetrated 0.5 mm into the specimen was recorded, together with the time from zero. This time was accurately established by reducing the time interval between penetrations near the final setting time and is the time at which the ring attachment failed to mark the specimen. 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 penetrated 0.5 mm into the specimen, is the final setting time of cement, to the nearest 15 min.

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

## CHAPTER FOUR

### 4.0 RESULTS AND DISCUSSIONS

#### 4.1 Introduction

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

#### 4.2 Data collection

##### 4.2.1 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 average initial and final setting times for the paste were recorded as indicated in Table 4.1. The individual results are captured in the Appendix A1.

*Table 4.1: Initial and final setting times of cement paste of standard consistence, w/c = 0.314*

Test	Initial setting time (Minutes)				Final setting time (Minutes)			
	t1	t2	t3	Mean $\bar{y}$	t1	t2	t3	Mean $\bar{y}$
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

#### 4.2.2 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 average results of the setting times are indicated in Tables 4.2, 4.3, 4.4, 4.5, 4.6 and 4.7.

The individual results are captured in the Appendix A2.

*Table 4.2: Setting times of cement pastes with Master Rheobuild RMC 80, w/c=0.314*

Water cement ratio = 110/350 = 0.314, Temp = 23°C								
Admixture (ml)	Initial setting time (Minutes)				Final setting time (Minutes)			
	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

*Table 4.3: Setting times of cement paste with RMC 80, w/c =0.3*

Water cement ratio = 105/350 = 0.3, Temp = 23°C								
Admixture (ml)	Initial setting time (Minutes)				Final setting time (Minutes)			
	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



Table 4.4: Setting times of cement pastes with RMC 80, w/c = 0.286

Water cement ratio = 100/350 = 0.286, Temp = 23°C								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture (ml)	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

Table 4.5: Setting times of cement pastes with RMC 80, w/c = 0.27

Water cement ratio = 95/350 = 0.271, Temp = 23°C								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture (ml)	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	Non-workable							
Mombasa PPC	49	45	36	26	606	602	601	599
Blue Triangle PPC	48	42	30	26	603	599	605	597

Table 4.6: Setting times of cement pastes with RMC 80, w/c = 0.257

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

Table 4.7: Setting times of cement pastes with RMC 80,  $w/c = 0.243$

Water cement ratio = $85/350 = 0.243$ , Temp = $23^{\circ}\text{C}$								
	Initial setting time (Mins)				Final setting time (Mins)			
Admixture (ml)	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	Non-workable							
Mombasa PPC	39	32	25	22	600	607	598	602
Blue Triangle PPC	42	33	26	21	606	597	612	596

### 4.2.3 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 average results of the setting times are indicated in Table 4.8, 4.9, 4.10 and 4.11. The individual results are captured in the Appendix A3.

Table 4.8: Setting times of cement pastes with Sika Viscocrete 10, w/c=0.314

Water cement ratio = 110/350 = 0.314, Temp = 23°C								
Admixture (ml)	Initial setting time (Minutes)				Final setting time (Minutes)			
	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

Table 4.9: Setting times of cement pastes with Sika Viscocrete 10, w/c=0.3

Water cement ratio = 105/350 = 0.3, Temp = 23°C								
Admixture (ml)	Initial setting time (Minutes)				Final setting time (Minutes)			
	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

Table 4.10: Setting times of cement pastes with Sika Viscocrete 10, w/c=0.286

Water cement ratio = 100/350 = 0.286, Temp = 23°C								
	Initial setting time (Minutes)				Final setting time (Minutes)			
Admixture (ml)	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	Non-workable							
Mombasa PPC	131	155	168	172	605	605	605	607
Blue Triangle PPC	107	126	156	164	614	602	603	607

Table 4.11: Setting times of cement pastes with Sika Viscocrete 10, w/c=0.271

Water cement ratio = 95/350 = 0.271, Temp = 23°C								
	Initial setting time (Minutes)				Final setting time (Minutes)			
Admixture (ml)	1ml	2ml	3ml	4ml	1ml	2ml	3ml	4ml
Bamburi PPC	Non-workable							
Mombasa PPC	135	157	171	176	616	613	600	602
Blue Triangle PPC	121	135	153	169	596	607	614	602

## 4.3 Data Analysis and discussion

### 4.3.1 Effect of the superplasticizer on the setting time of the three cement pastes

#### 4.3.1.1 MasterRheobuild RMC 80

##### (i). Initial setting times

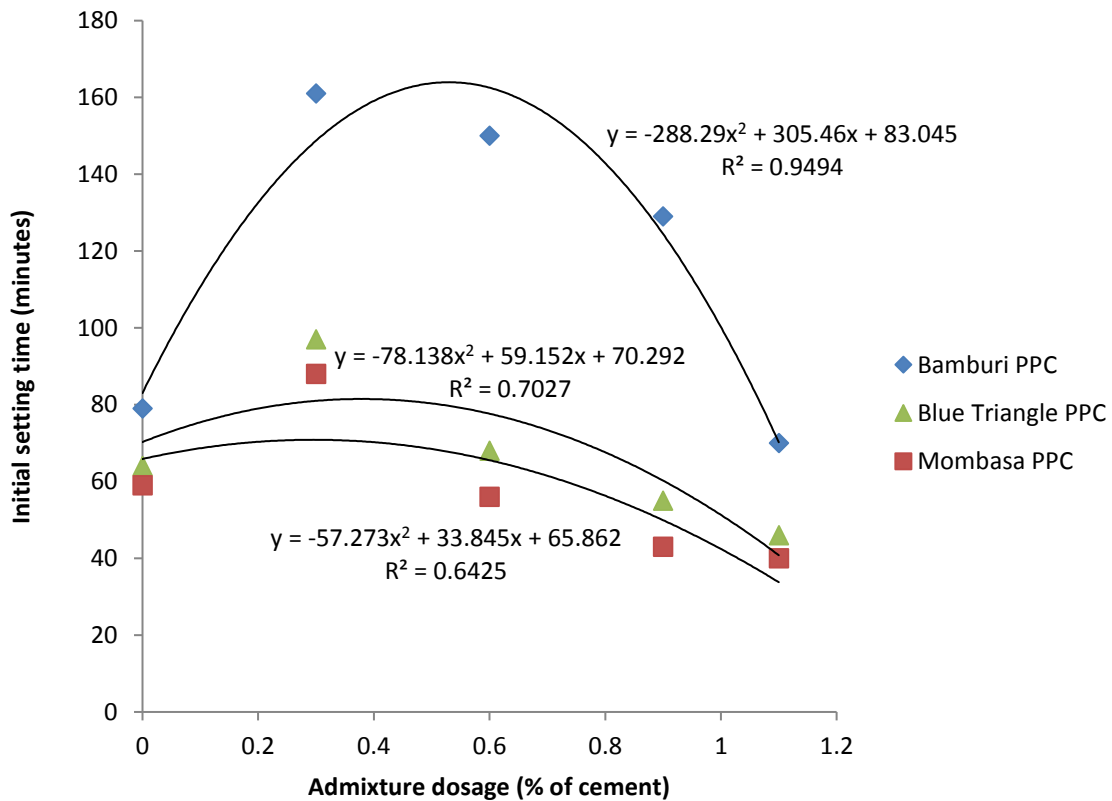


Figure 4.1: Effect of Master Rheobuild RMC 80 on the initial setting time of cement pastes of standard consistence.

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 4.1). Mombasa PPC recorded the highest reduction in the initial setting time by 49%, followed by Blue Triangle PPC and Bamburi PPC at 42% and 15% respectively (Table 4.12). There was however a slight increase in the final setting times, Blue Triangle PPC and Mombasa PPC exhibited a 4% increase while Bamburi PPC showed a 3% increase (Figure 4.2). It was noted that an increase in the dosage of RMC 80 beyond 0.5% resulted in slight shortening of the final setting time for Bamburi PPC and Blue Triangle PPC.

(ii). Final setting times

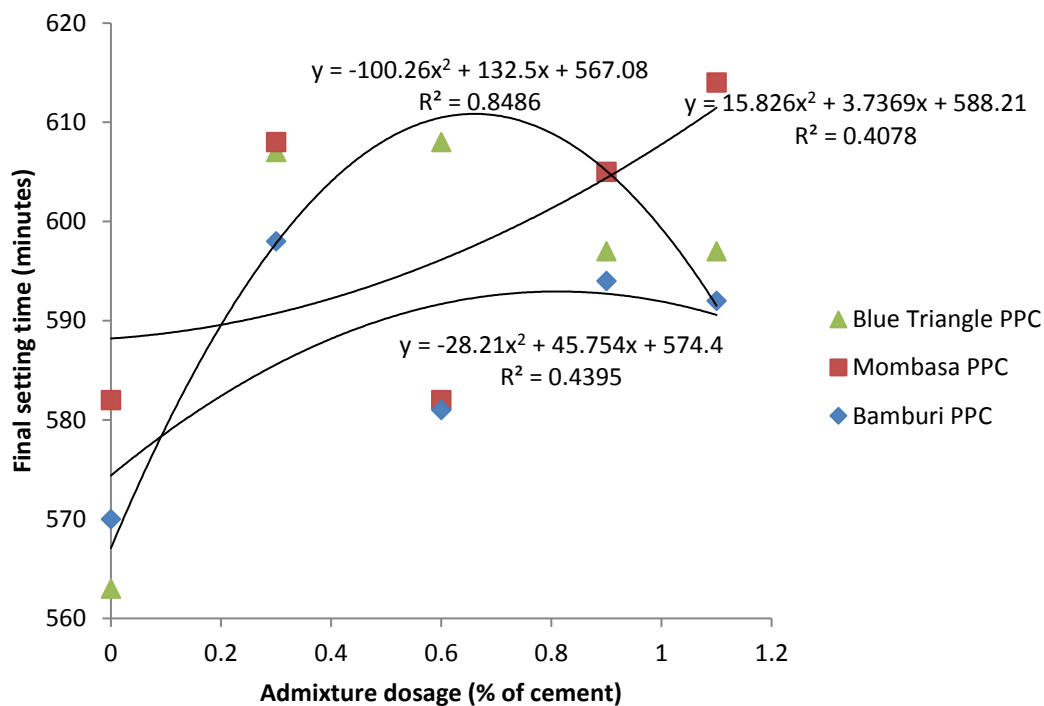


Figure 4.2: Effect of Master Rheobuild RMC 80 on the final setting time of cement pastes of standard consistence.

These results are in agreement with other published works which have shown that high dosage of first generation superplasticizers when added to concrete will cause quicker setting times. Whitney [14] has shown that first generation superplasticizers are known not to affect the chemical hydration process of cement. This implies that gypsum is solely responsible for the initial setting of cement.

These results have shown that at a lower dosage of Master Rheobuild RMC 80, the initial setting time of the cement pastes is increased by 35%. The optimum dosage required to increase the initial setting time is approximately 0.5%. Beyond 0.5% dosage of the superplasticizer, the initial setting of the cement pastes is shortened.

The exact cause for this behavior is not known but according to the author, at an optimum dosage of the Master Rheobuild RMC 80 superplasticizer (less than 0.6%), the solubility of gypsum in the cement paste is gradually increased. Concurrently, the electrostatic repulsion effect of the  $\text{SO}_3^-$  groups of the superplasticizer on  $\text{C}_3\text{A}$  particles of cement is also gradually increased. These lead to prolonged initial setting time.

Beyond 0.5% dosage of the superplasticizer, the content of C<sub>3</sub>A in the cement paste is completely eliminated by the the high affinity SO<sub>3</sub><sup>-</sup> groups and the soluble gypsum in the cement paste. Therefore, the excess amount of the superplasticizer increases the alkalinity of the solution which results in the accelerated hydration of the C<sub>3</sub>S and C<sub>2</sub>S in the paste causing rigidity of the paste. Previous studies have shown that the alkali content in cement affect the hydration process of silicates [34].

The low correlation values of 0.702 and 0.642 for Blue Triangle PPC and Mombasa PPC respectively (Figure 4.1) can be attributed to the percentage composition of the C<sub>3</sub>A, solubility of the gypsum and pozzolana in the cement. Mombasa PPC with a lower percentage of gypsum content and high percentage of C<sub>3</sub>A produces shorter setting times compared to Bamburi PPC and Blue Triangle PPC.

Coppola et al. [19] 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 sulfonated polymer; in the presence of Calcium Sulfate dihydrate, the fluidizing effect is much more significant than with hemihydrates.

From the results, the final setting times due to the addition of the superplasticizer are not significantly affected and this implies that the effect of the superplasticizer fades after complete hydration of the cement has occurred. The low correlation values of 0.439 and 0.407 for Bamburi PPC and Mombasa PPC respectively (Figure 4.2) can be attributed to the composition and solubility of the pozzolana in the cement. There might be some other inconsistent reaction between the hydration products and the pozzolana in the cement.

Care should however be exercised when using lignosulphonate based superplasticizers with pozzolanic cements. Trial tests are necessary before the application of the superplasticizer.

*Table 4.12: Rate of change of the initial and final setting times of standard consistence cement paste with Master Rheobuild RMC 80*

Admixture (% cement)	Rate of change of initial setting time (%)				Rate of change of final setting time (%)			
	0.3	0.6	0.9	1.1	0.3	0.6	0.9	1.1
Bamburi PPC	+79	+96	+50	-15	+2	+3	+3	+3
Mombasa PPC	+8	-1	-24	-49	0	+1	+3	+4
Blue Triangle PPC	+15	+11	-14	-42	+5	+8	+7	+4
Average (%)	+34	+35	+4	-35	+2	+4	+4	+4

### 4.3.1.2 Sika Viscocrete 10

#### (i). Initial setting times

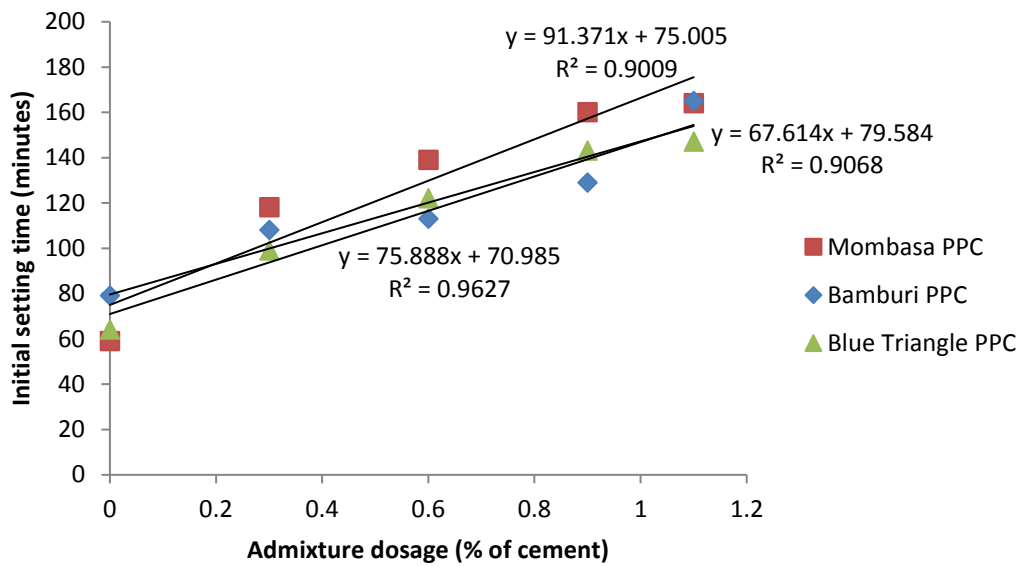


Figure 4.3: Effect of Sika Viscocrete 10 on the initial setting time of cement pastes of standard consistence.

#### (ii). Final setting times

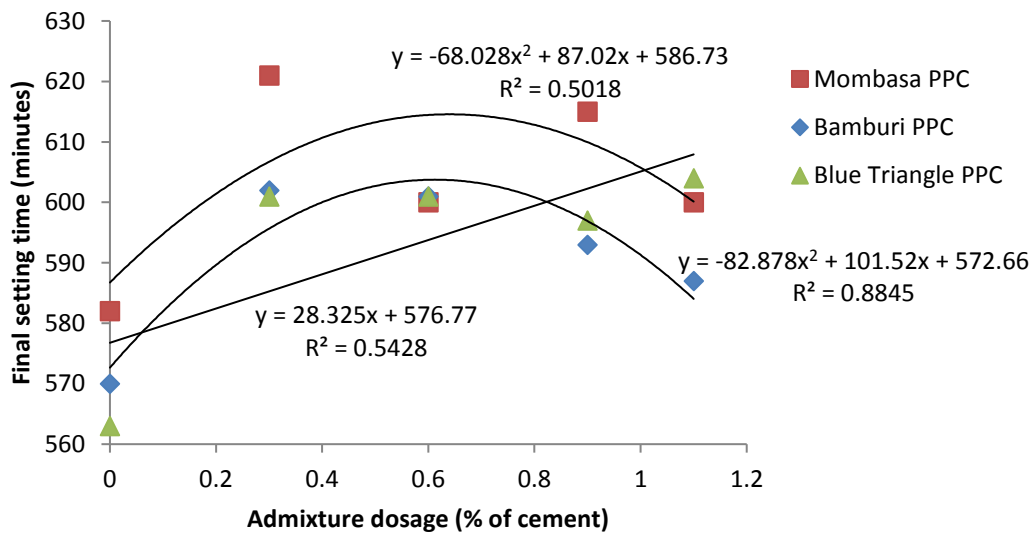


Figure 4.4: Effect of Sika Viscocrete 10 on the final setting time of cement pastes of standard consistence.

The addition of Sika Viscocrete caused marked retardation in the initial setting times for each of the three cements (Figure 4.3). Mombasa PPC produced the highest retardation of 134%,



followed by Blue Triangle PPC and Bamburi PPC at 118% and 94% respectively (Table 4.13). The delay in the final setting times was however minimal, the highest being exhibited by Blue Triangle PPC at 5% followed by Mombasa PPC and Bamburi PPC both at 2%.

*Table 4.13: Rate of change of the initial and final setting times of standard consistence cement paste with Sika Viscocrete 10*

Admixture (% cement)	Rate of change of initial setting time (%)				Rate of change of final setting time (%)			
	0.3	0.6	0.9	1.1	0.3	0.6	0.9	1.1
Bamburi PPC	+26	+51	+77	+94	+4	+5	+4	+2
Mombasa PPC	+37	+73	+110	+134	+3	+5	+4	+2
Blue Triangle PPC	+32	+64	+96	+118	+1	+3	+4	+5
Average (%)	+32	+63	+94	+115	+3	+4	+4	+3

Viscocrete 10 acts by steric hindrance effect (Figure 2.2). The negative carboxylic groups (hydrophilic) are adsorbed on the surface of cement particles while the non-polar hydrophobic side of the polymer chains is responsible for the dispersion of cement particles and subsequent fluidizing action of the admixture. When the dosage of Viscocrete 10 is increased, the high number of the protruding side chains of the polymer will disperse the hydrated cement particles through steric hindrance effect resulting in a much lower slump.

When Viscocrete 10 is added to the cement pastes, the hydration process slows down through dispersion of hydrated cement particles by steric hindrance effect. Consequently, the necessary amount of the hydration products giving rigidity to the cement paste will require longer time to form. The dispersion effect of the superplasticizer will continue until it is eliminated from the solution by reaction with  $C_3A$  from the cement [19]. Thus, cement pastes having Sika Viscocrete 10 superplasticizer remain plastic for longer time. At a higher dosage of the admixture, more time will be needed for its removal from the solution and therefore the retarding tendency of the superplasticizer increased with higher dosage. The behavior of Sika Viscocrete 10 is similar to published works by other researchers on polycarboxylate based superplasticizers [16].

From figure 4.3, Sika Viscocrete 10 produces the best compatibility with the selected pozzolanic cements based on the high regression values.

### 4.3.2 Comparative setting times of the three cement pastes with the admixtures

#### 4.3.2.1 Master Rheobuild RMC 80

##### (i). Initial setting times

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

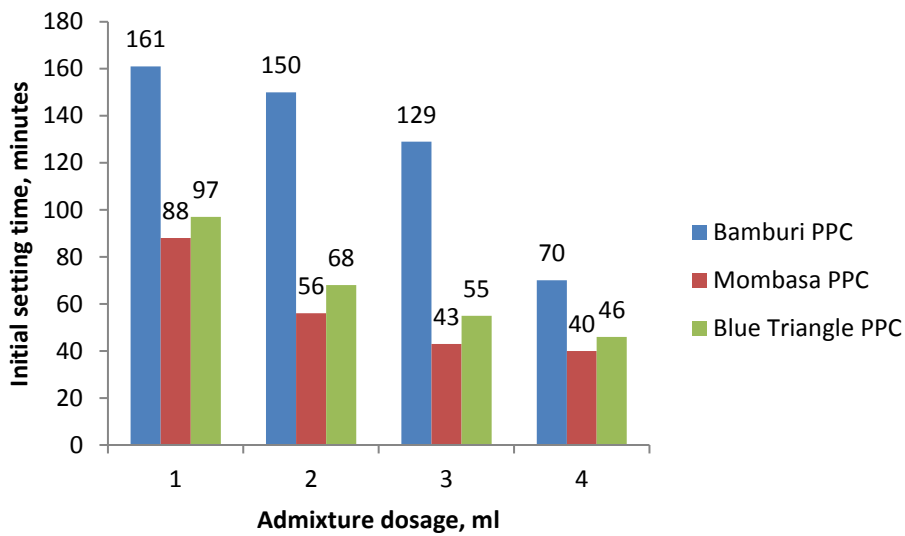


Figure 4.5: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.314.

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

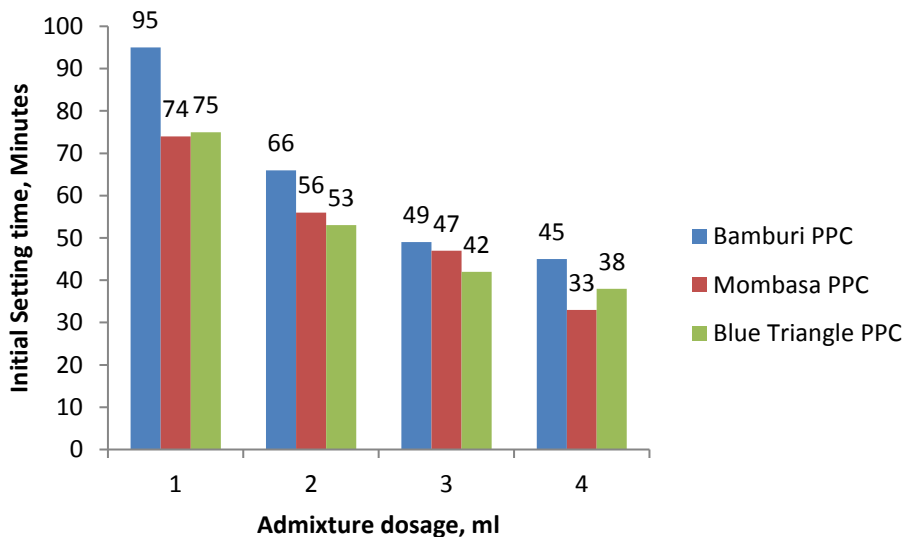


Figure 4.6: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.3.

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

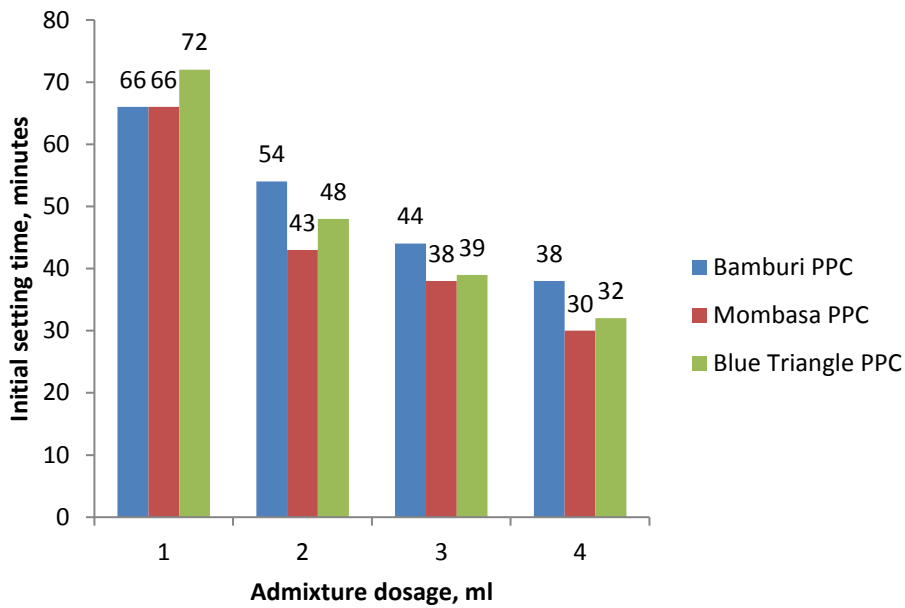


Figure 4.7: Effect of RMC 80 on the initial setting times of the three cement pastes at  $w/c = 0.286$ .

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

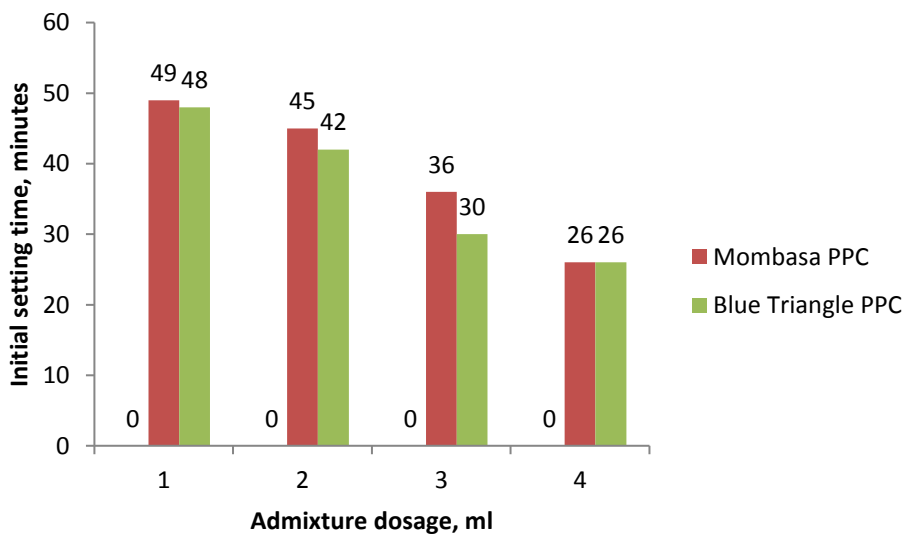


Figure 4.8: Effect of RMC 80 on the initial setting times of the three cement pastes at  $w/c = 0.271$ .

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

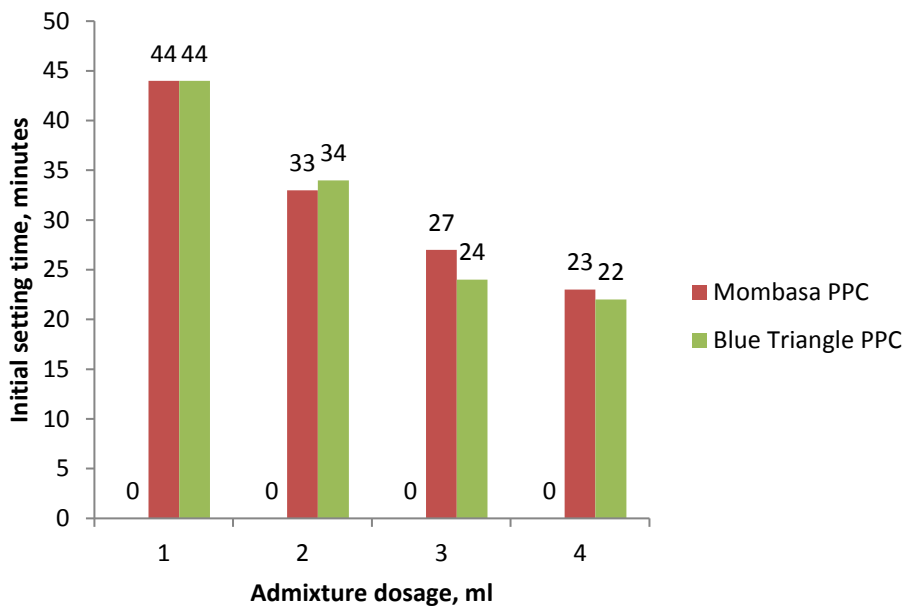


Figure 4. 9: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.257.

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

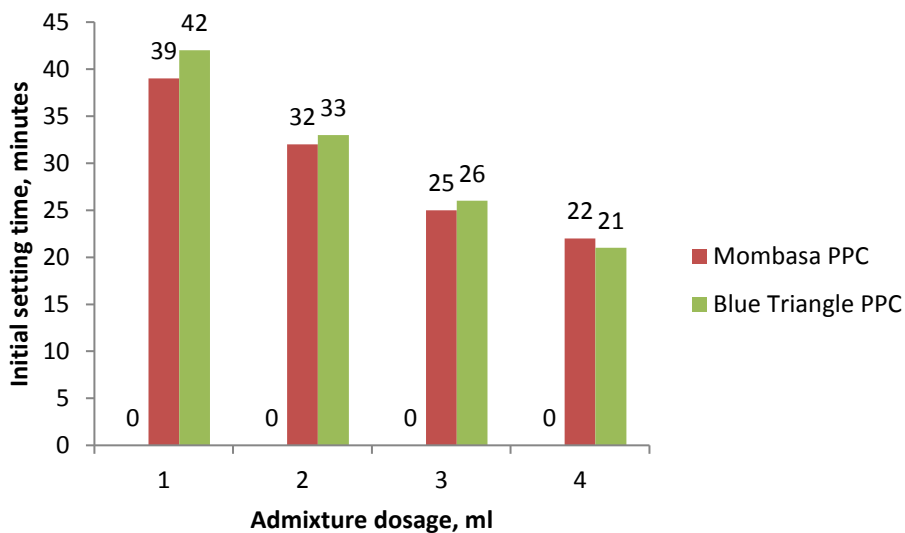


Figure 4. 10: Effect of RMC 80 on the initial setting times of the three cement pastes at w/c = 0.243.

From the comparative results (Figure 4.5 to 4.10), 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 80 at a lower w/c ratio can be related to the high molecular weight of the superplasticizer which causes a high initial adsorption speed when in contact with cement. The greater the adsorption of the superplasticizers, the higher the repulsion effect of the cement particles [21]. The sulphate ions of the superplasticizer are responsible for the electrostatic repulsion which prevent the reaction of  $C_3A$  + with water and therefore maximizing fluidity of the cement paste. Therefore, at high dosage of the admixture the fluidity effect is significant due to the high adsorption effect and can allow a reduction of the w/c ratio without compromising the workability [9, 15].

Master Rheobuild RMC 80 has a water reducing capacity of up to 23%. This is within the range obtained by other researchers [13] for lignosulfonate based superplasticizers.

Bamburi PPC when mixed with RMC 80 is workable up to a w/c ratio of 0.286. 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 initial setting time of the cement paste is decreased. The reaction between the excess quantities of the admixture and the cement causes rigidity of the paste and does alter the setting time.

(ii). Final setting times

a) At  $w/c = 0.314$

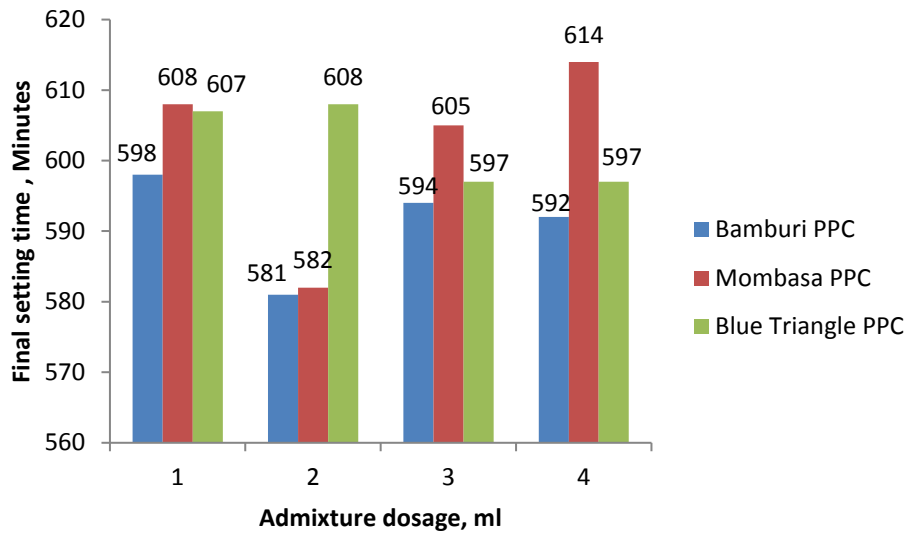


Figure 4.11: Effect of RMC 80 on the final setting times of the three cement pastes at  $w/c = 0.314$ .

b) At  $w/c = 0.3$

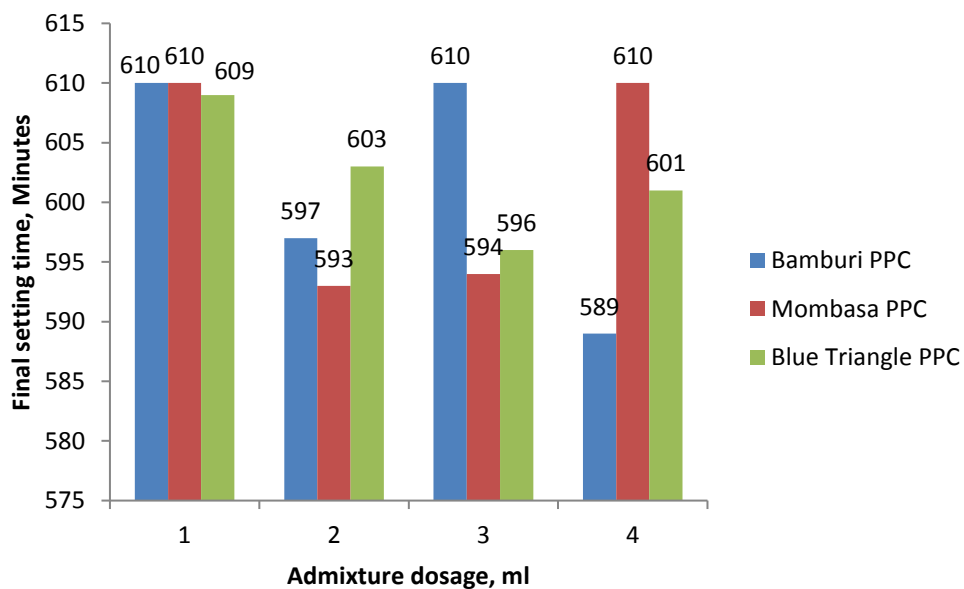


Figure 4.12: Effect of RMC 80 on the final setting times of the three cement pastes at  $w/c = 0.3$ .

**c) At w/c = 0.286**

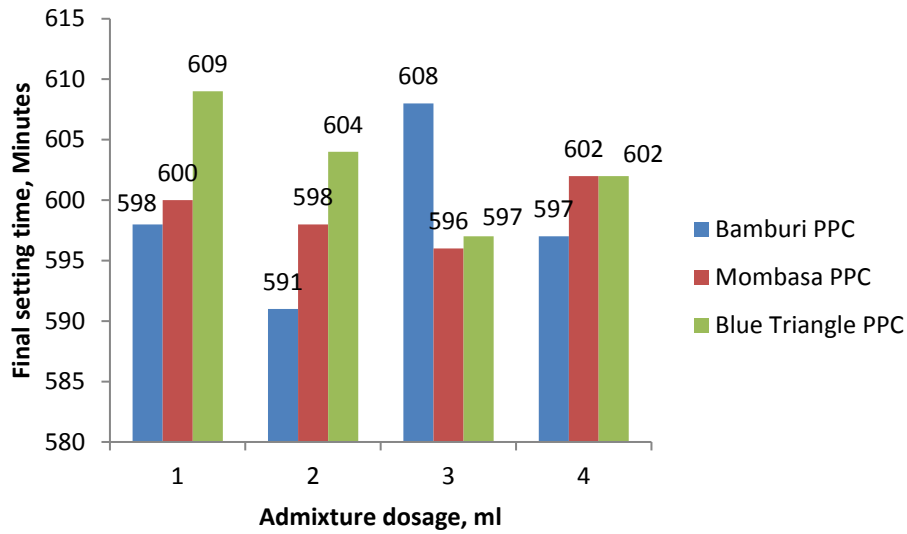


Figure 4.13: Effect of RMC 80 on the final setting times of the three cement pastes at w/c = 0.286.

**d) At w/c = 0.271**

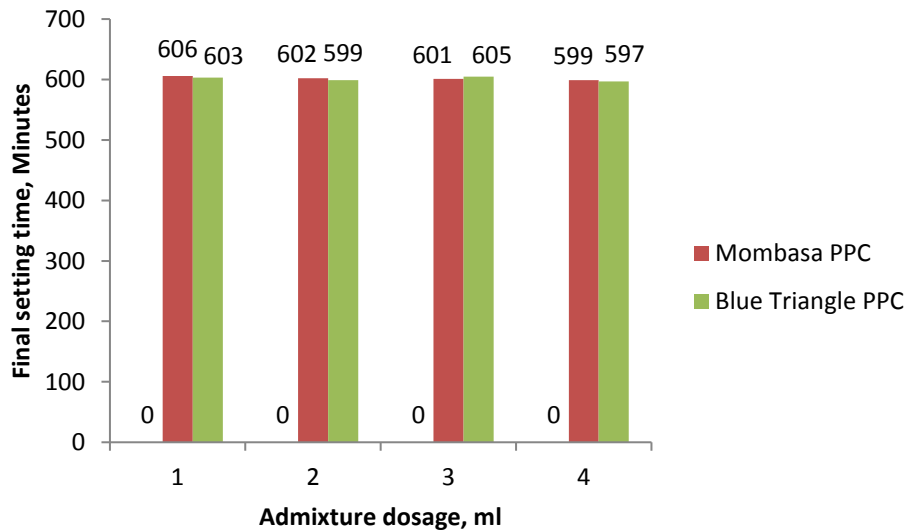


Figure 4.14: Effect of RMC 80 on the final setting times of the three cement pastes at w/c = 0.271.

e) At  $w/c = 0.257$

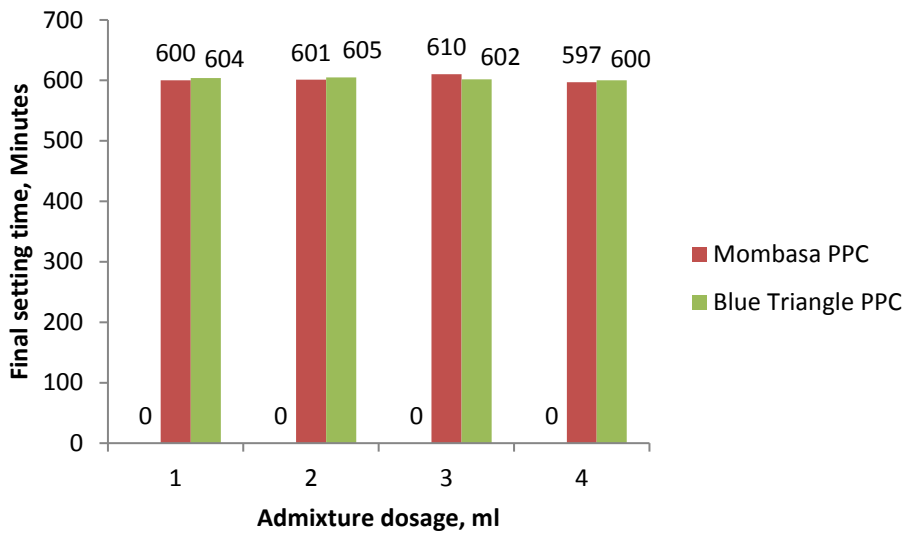


Figure 4.15: Effect of RMC 80 on the final setting times of the three cement pastes at  $w/c = 0.257$ .

f) At  $w/c = 0.243$

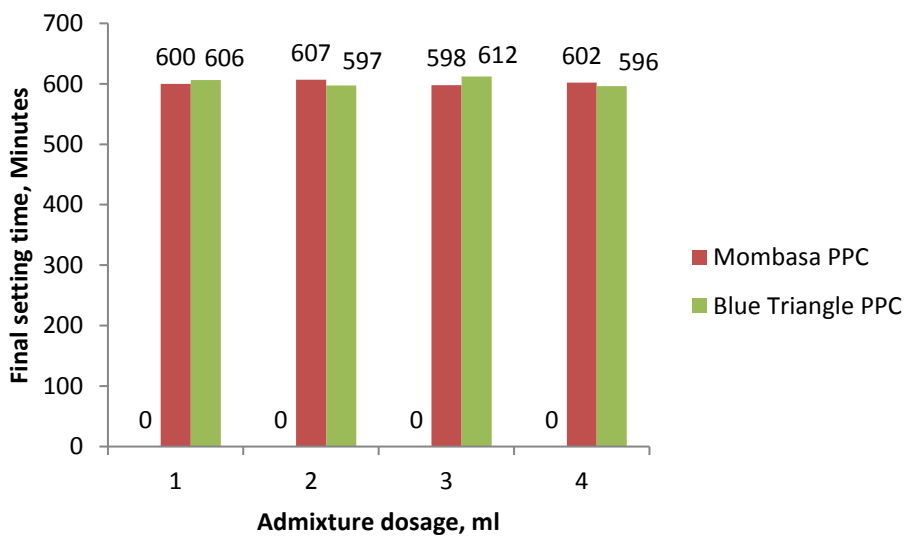


Figure 4.16: Effect of RMC 80 on the final setting times of the three cement pastes at  $w/c = 0.243$ .



The comparative results (Figure 4.11 to 4.16) reveal that the addition of RMC 80 to the cement paste does not significantly affect final setting of the cement. 4% delay in final setting time was recorded for Blue Triangle cement, while Mombasa PPC and Bamburi PPC recorded 4% and 3% respectively. This is similar to the results obtained by other researchers [9, 15].

### 4.3.2.2 Sika Viscocrete 10

#### (i). Initial setting times

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

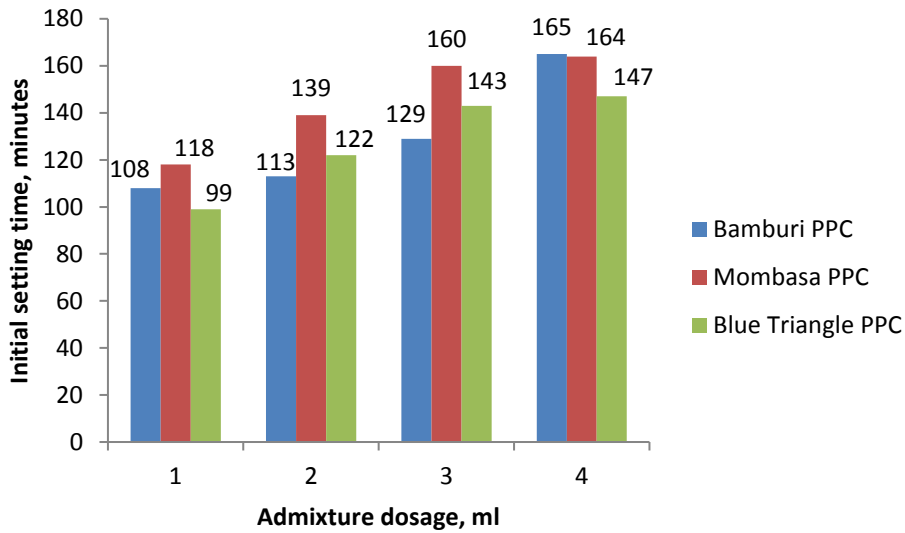


Figure 4.17: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.314.

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

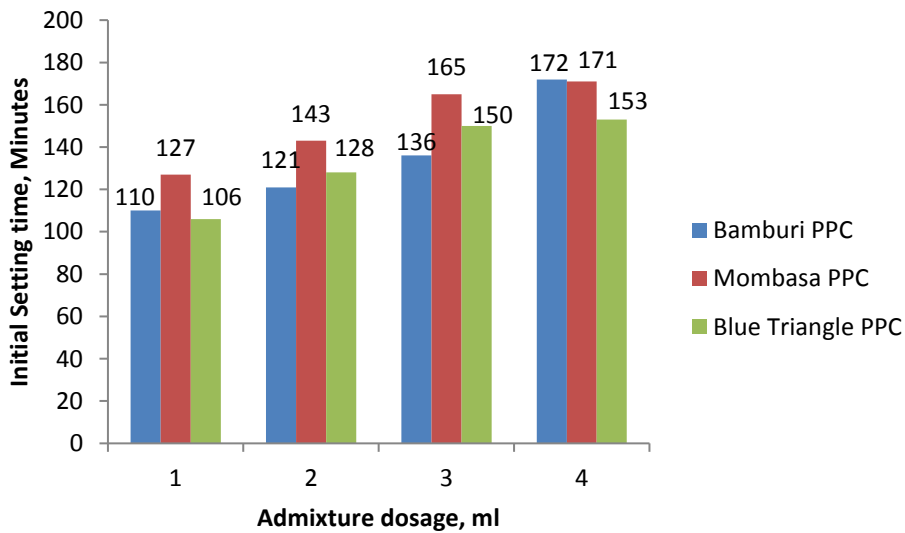


Figure 4.18: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.3.

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

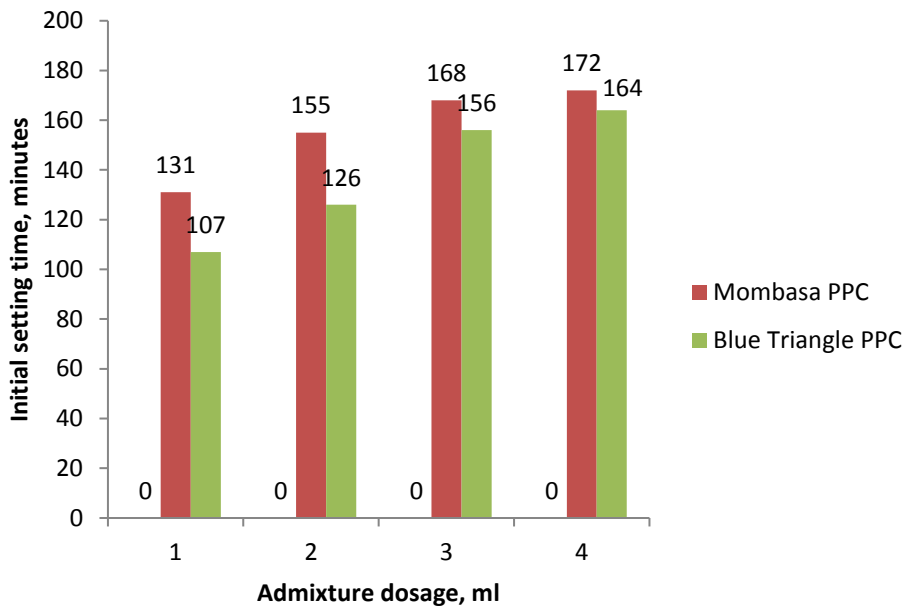


Figure 4.19: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.286.

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

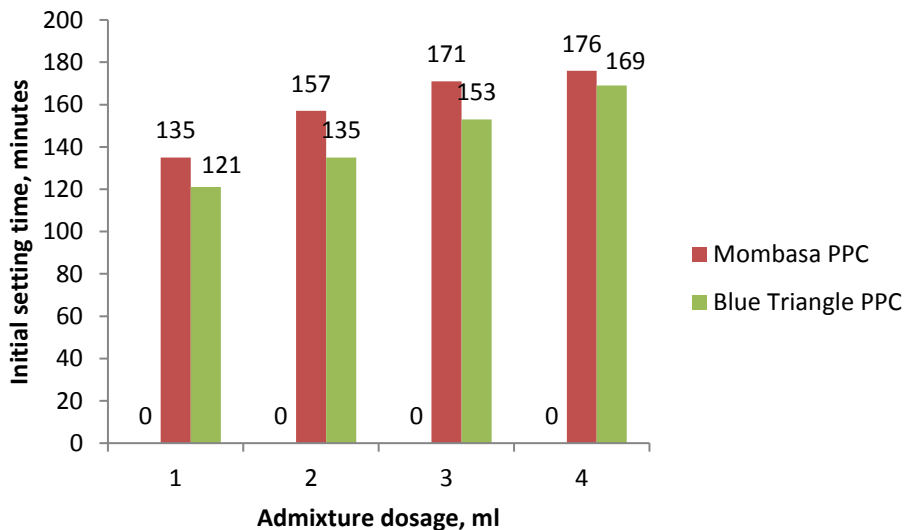


Figure 4.20: Effect of Sika Viscocrete 10 on the initial setting times of the three cement pastes at w/c = 0.271.

The bar charts in Figure 4.17 to 4.20 reveal that the addition of SikaViscocrete 10 superplasticizer significantly extends the initial setting time of the three pastes by 115%. This

therefore implies that with the addition of 1.1% of Sika Viscocrete 10 to any of the three cement pastes, 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 added to the 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% [13]. The cause of this difference can be related to the lower initial adsorption speed of Viscocrete 10 when in contact with cement. Carboxylic groups are responsible for adsorption of the PC based superplasticizers and their initial low numbers will cause negligible initial adsorption and dispersing effect. The number of carboxylic units gradually increase after the hydrolysis effect (Figure 2.5) which is related with the  $\text{OH}^-$  presence in the aqueous phase of the cement paste and therefore gradually increasing the adsorption of the polymer on the surface of the cement particles.

Viscocrete 10 produces a lower initial adsorption effect and does not ensure maximum fluidity in comparison to RMC 80 which has a high initial adsorption effect. Therefore, at high dosage of the Viscocrete 10 the fluidity effect is not higher than RMC 80.

(ii). Final setting times

a) At  $w/c = 0.314$

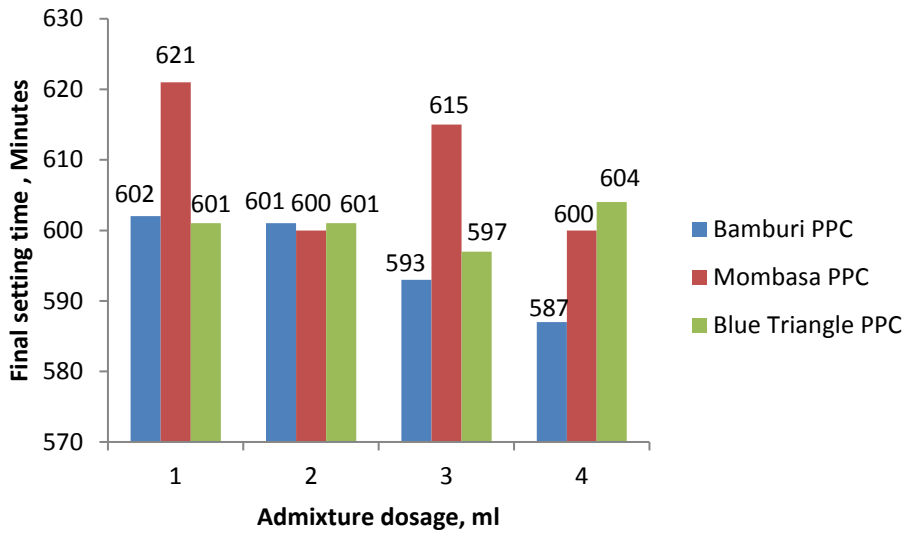


Figure 4.21: Effect of Sika Viscocrete 10 on the final setting times of the three cement pastes at  $w/c = 0.314$ .

b) At  $w/c = 0.3$

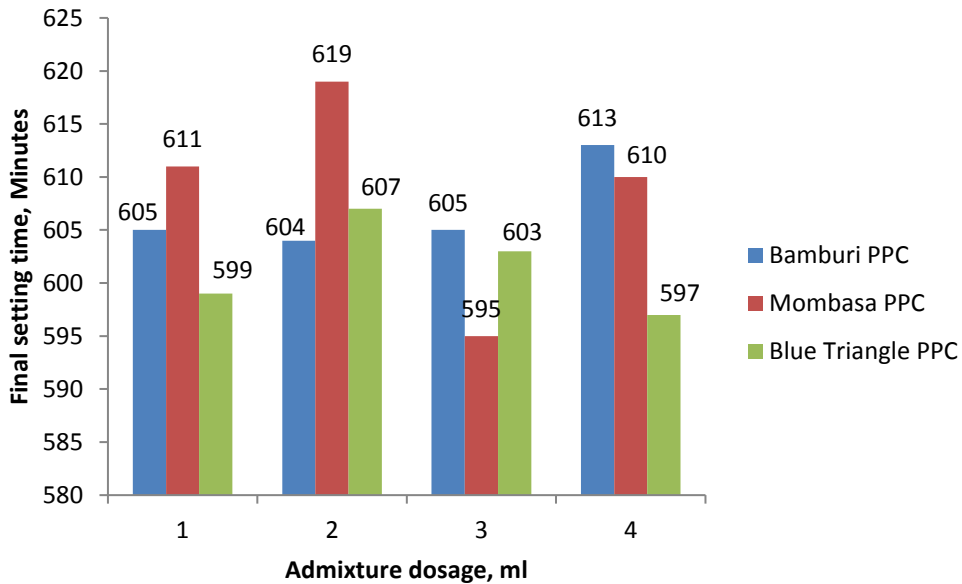


Figure 4.22: Effect of Sika Viscocrete 10 on the final setting times of the three cement pastes at  $w/c = 0.3$ .

c) At w/c = 0.286

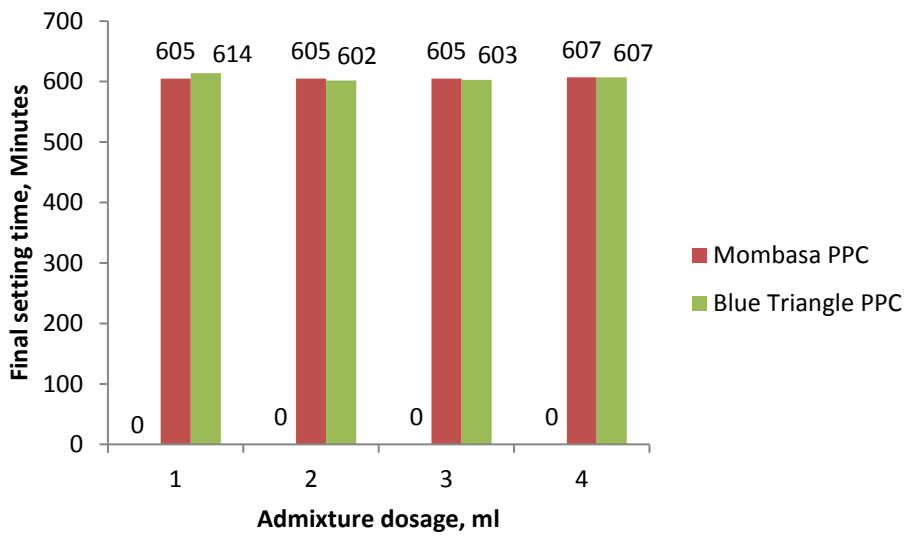


Figure 4.23: Effect of Sika Viscocrete 10 on the final setting times of the three cement pastes at w/c = 0.286.

d) At w/c = 0.271

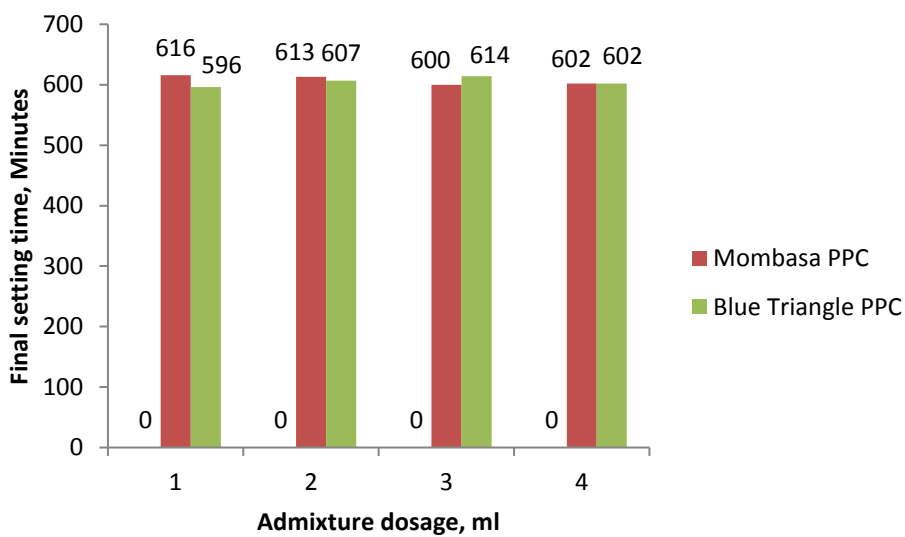


Figure 4.24: Effect of Sika Viscocrete 10 on the final setting times of the three cement pastes at w/c = 0.271.

The results from figure 4.21 to 4.24 reveal that the final setting times of the cement pastes mixed with Sika Viscocrete 10 are not significantly affected. This implies that Sika Viscocrete 10 is effective during the hydration of cement at the initial stages of setting and its effect fades after the hydration process.

### **4.3.3 Similarities and contrasts of the findings**

This research has confirmed that superplasticizers extend the initial and final setting times of cement pastes. These results are similar to those obtained by Zakka et al. [9] for the effect of superplasticizers on the setting time of OPC in Texas, USA.

The results also confirm that the use of first generation superplasticizers (Master Rheobuild RMC 80) with Portland Pozzolanic Cement requires careful examination and trial tests are mandatory before application in the field. This is similar to observations made by Khan et al. [14].

The results of this research also show that superplasticizers can be used as a high range water reducer. This has been confirmed by Whitney [14]. The research however does not concur with the range of 20% to 30% water reduction indicated by Whitney [14] for all the superplasticizers. It was observed that Sika Viscocrete 10 produced 14% water reduction while Master Rheobuild RMC 80 produced 23%.

## **4.4 Application of the superplasticizers**

### **4.4.1 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 order to achieve high slump retention times, 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 transportation of concrete, and especially for ready mixed concrete. Master Rheobuild RMC 80 quick setting properties makes 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.

### **4.4.2 Effective w/c ratio**

The research has been based on the w/c ratio obtained for the paste of standard consistence. This w/c ratio is the minimum amount of water 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 ascertain the amount of mixing water in concrete that will be absorbed by the aggregate.

The variation in the absorption of the mixing water by the aggregates is dependent on the surface condition, the type and size of the aggregates. For instance, porous aggregates may absorb large amounts of water than the non-porous but also the absorption of water by some aggregates may continue after mixing.

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



## CHAPTER FIVE

### 5.0 CONCLUSIONS

The research set out to determine the suitability of two commonly used superplasticizers for use in ready mix concrete in Nairobi based on their setting times. Lack of proper guidelines on the use of superplasticizers in ready mix concrete has resulted to setting of concrete while in transit, due to unavoidable traffic delays or incompatibility between the cement and the superplasticizer. The findings of this research have been outlined below:

1. 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 115% (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 the ASTM classification of superplasticizers.
2. Master Rheobuild RMC 80 produces an average retarding effect and is capable of extending the initial setting time of cement by 35% at a dosage of 0.5% (% of weight of cement) but this is reversed when the dosage of the admixture exceeds 0.5%. It was found that the superplasticizer can cause quicker setting of cement paste by up to 35% when the dosage of the admixture is increased to 1.1%. Due to traffic delays in Nairobi, the superplasticizer is not recommended for purposes of ready mix concrete without the addition of a retarder to prolong the initial setting of concrete. RMC 80 can be classified as a first generation superplasticizer based on ASTM classification of superplasticizers.
3. 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%.
4. It was found that BASF Master Rheobuild RMC 80 shows inconsistent pattern when used with the three individual cement pastes. The superplasticizer causes great retarding effect of +96% with Bamburi cement and lesser effect with Mombasa PPC and Blue Triangle PPC at 8% and 15% respectively. Therefore, trial tests are necessary to confirm the behavior of the superplasticizer with pozzolanic cements prior to usage.

5. Master Rheobuild RMC 80 and Sika Viscocrete 10 were found to be responsive to the three cement pastes and therefore compatible with the three brands of cements tested.
6. It is critical that the correct amount of dosage is administered for both RMC 80 and Sika Viscocrete 10. Sika Viscocrete 10 is capable of producing an 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.
7. The author has published these findings in an international journal to enable interested researchers and ready mix concrete companies across the world access this useful information [52].

## **CHAPTER SIX**

### **6.0 RECOMMENDATIONS**

1. Based on the conclusions, Sika Viscocrete 10 is recommended for use at the batching plant for ready mix concrete production in Nairobi while Master Rheobuild RMC 80 due to its high water reducing properties is suitable for use in the production of high strength concrete at site. For ready mix concrete subjected to delays, a retarder is recommended for use with Master Rheobuild RMC 80 in order to prolong the initial setting time of concrete.
2. The research has been limited to three types of cement pastes and two superplasticizers and therefore the findings are not recommended for use with other cement pastes not considered. Further research on other types of superplasticizers and cement needs to be done.
3. The research has been limited to the setting time and water reducing capacity of the two superplasticizers and therefore more investigation on the effect of the superplasticizers on other properties of fresh and hardened concrete is necessary.
4. The research has not considered the effect of blending the two superplasticizers on the setting times of cement and therefore recommends more research to be done in this area.

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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 $\bar{y}$	t1	t2	t3	Mean $\bar{y}$
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 $\bar{y}$	t1	t2	t3	Mean $\bar{y}$
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 $\bar{y}$	t1	t2	t3	Mean $\bar{y}$
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 $\bar{y}$	t1	t2	t3	Mean $\bar{y}$
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)			
<b>Admixture</b>	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)			
<b>Admixture</b>	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)			
<b>Admixture</b>	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			
<b>Admixture</b>	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)			
<b>Admixture</b>	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)			
<b>Admixture</b>	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)			
<b>Admixture</b>	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)			
<b>Admixture</b>	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)			
<b>Admixture</b>	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 = $95/350 = 0.271$								
Admixture	Initial setting time (Mins)				Final setting time (Mins)			
	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 = $90/350 = 0.257$								
Admixture	Initial setting time (Mins)				Final setting time (Mins)			
	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 = $85/350 = 0.243$								
Admixture	Initial setting time (Mins)				Final setting time (Mins)			
	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,  $\bar{y} = \frac{\text{Test 1} + \text{Test 2} + \text{Test 3}}{3}$

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)			
<b>Admixture</b>	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)			
<b>Admixture</b>	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)			
<b>Admixture</b>	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 = $95/350 = 0.271$								
Admixture	Initial setting time (Mins)				Final setting time (Mins)			
	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)			
<b>Admixture</b>	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)			
<b>Admixture</b>	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,  $\bar{y} = \frac{\text{Test 1} + \text{Test 2} + \text{Test 3}}{3}$

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	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 = $95/350 = 0.271$								
Admixture	Initial setting time (Mins)				Final setting time (Mins)			
	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