Addis Ababa University
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Cost Optimization of (C-30 & C-40) Concrete Mixtures Using Superplasticizers

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A thesis submitted to the School of Graduate Studies of the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Construction Technology and Management)

Addis Ababa University
Addis Ababa, Ethiopia

September 2020

Addis Ababa University
Addis Ababa Institute of Technology
School of Civil and Environmental Engineering

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Declaration

I, the undersigned, declare that this thesis, entitled *'Cost Optimization of Concrete Mixtures Using Superplasticizers'*, is my original work and it has not been presented for masters or any other degree in this or any other university, and all sources of materials used for the thesis are properly acknowledged.

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September 2020
Addis Ababa, Ethiopia

Acknowledgments

My deepest gratitude goes to the Almighty God who gave me the courage to successfully carry out this research. Next, I would like to thank my advisor Dr. Ephraim Senbetta who has initiated me to look deep into the problems in the concrete construction industry and come up with applicable solutions. Finally, yet importantly, my gratitude goes to my family and friends, Ato Kassa Alem AAiT Digital Library head, Ato Biniam AAiT Materials Laboratory Assistant Technician, and Yancomad Construction PLC for providing coarse aggregates and W/ro Selamawit for providing the superplasticizing admixtures without a fee.

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List of Abbreviations

ACI - American Concrete Institute

ASTM - American Society for Testing and Material

BS - British Standard

C_3A - Tricalcium Aluminate

C_3S - Tricalcium Sulfate

EBCS – Ethiopian Building Code of Standard

GDP - Gross Domestic Product

HRWRA - High Range Water Reducing Admixture

HSC - High-strength Concrete

HPC - High-performance Concrete

NSC - Normal-strength Concrete

SO_3 - Sulfite

SCC - Self-consolidating Concrete

SCM - Supplementary Cementitious Materials

SMF - Sulphonated Melamine Formaldehyde

SNF - Sulphonate Naphthalene Formaldehyde

SP - Superplasticizer

PCE - Poly-carboxylic Ether

w/c - Water to Cement Ratio

w/cm - Water to Cementitious Materials Ratio

Abstract

Admixtures are playing vital roles in concrete, the second most consumed material on earth after water. Among these admixtures, *High Range Water Reducers (Superplasticizers)* have become one of the essential components in modern concrete.

Cement, the key ingredient in concrete, also represents 6 to 7% of the total global manmade emissions and the most expensive one compared to water and aggregates. Therefore, its optimization not only results in overall project cost reduction but also reduced cement consumption leading to reduced CO_2 emission, raw material depletion, and reduced energy consumption.

Concrete mixture cost optimization means minimizing the cost of concrete mixtures while maximizing the desired performance criteria. Hence, the main objective of this study is, therefore to investigate if significant cost-saving can be made by using superplasticizers without affecting the desired compressive and workability requirements. Accordingly, laboratory examination was conducted on 17 concrete mixtures.

According to this study, considerable cost reduction was achieved using HRWRA without sacrificing the desired workability and strength properties of concrete. Using Type-F HRWRA, on average 98 to 152 birr/m^3 cost-saving was recorded. However, higher slump-loss than the reference mixes was observed. In concrete mixes with Type-G HRWRA, 2 hours slump retention was achieved for 118-131 birr/m^3 less cost than mixes without the admixture.

Keywords: Cost optimization, Superplasticizers, Cost reduction, Cement consumption

Chapter – One

Background

1.1. Introduction

"Concrete is ubiquitous in the modern world. It is claimed to be the material that humankind uses most (in volume terms), after water of course" (1). High range water reducers (Superplasticizers) are an essential component in modern concrete especially in the production of high-strength, high-performance, and self-compacting concrete types. These admixtures have a capacity of reducing the amount of water required in a concrete mix by at least 12%, with some even more than 30%. Therefore, they enable the reduction of w/c ratio in a significant amount and give increased strength. Where this additional strength is not needed, superplasticizers still enable the production of low-cost concrete with improved workability and permeability by allowing cement content reduction.

Cement being the most expensive ingredient of concrete mixes, its optimization not only results in overall project cost reductions but also in reduced cement consumption, in the long run, leading to reduced CO_2 emission, raw material depletion, and energy consumption.

The production of Portland cement is a non-eco-friendly process with 1.5 tons of raw material needed for every ton of cement produced consuming 4 GJ energy in the process and emitting approximately a tone of CO_2 (2) (3 p. 34). On November 2017 www.worldhighways.com report, Ethiopian cement factories have nearly production capacity 16.5 million tons. Moreover, on average the annual consumption grows by10% (4). The annual production is around 6.5 Tons. This would mean 9.3 million tons of raw materials and 24.8×10^6 GJ energy may be consumed releasing approximately 6.5 million tons of CO_2. This energy is equivalent to the energy required to keep 12.4 million 60-watt bulbs continuously lit for twelve months. Minimizing cement consumption by optimizing the cement-admixture system may therefore, reduce the negative impact cement factories have on the environment. This is by contributing to lower carbon emission since coal is the major source of energy in these factories. “All cement firms in Ethiopia but Mugher cement predominantly use imported coal as their major source of energy” (5 p. 38). Furnace oil, imported and local coal used as major sources of energy in Ethiopian cement factories. Minimizing the cement consumption will enable our country to make some saving of foreign currency that is being spent on purchasing coal.

In general, optimization of the cement-admixture system will not only improve efficiency in concrete construction but also enable the use of a wide range of benefits of high-strength and high-performance types of concrete. Therefore, in this thesis concrete mixture cost optimization using HRWRAs is studied.

1.2. Statement of the Problem

Concrete strength and water to cement ratio have an inversely proportional relationship. In concrete preparation, water has two functions, hydration of cement and workability. The more water is added to the mix to bring it to the required level of workability, the higher the water to cement ratio, and the lower the concrete strength unless the additional water for workability is compensated by adding more cement to the mix or using water-reducing admixtures.

Adding more cement, on the other hand, comes with; increased cost, increased heat of hydration, higher modulus of elasticity (becoming more brittle), increased shrinkage, less stress relaxation due to creep, higher thermal stress and cracking (6 p. 98) (7 pp. 170-172) (8 pp. 412-434). The production process of cement is known to consume high energy and emit a large amount of carbon dioxide into the air both of which are big concerns for the globe today. Therefore, optimizing concrete mixtures with minimum cement content is very crucial to bring efficiency in the concrete construction industry to primarily reduce the energy used in cement production, lower carbon emissions, and raw material depletion in the long-run.

1.3. Scope of the Study

The scope of this experimental research was limited to Ordinary Portland Cement Dangote brand, class - 42.5R. HRWRAs Type-F (*high range water reducer*) and Type-G (*high range water reducer and retarder*) according to ASTM C-494 classification that is based on *Sulphonate Naphthalene Formaldehyde* (SNF) were selected for this study. Because, for superplasticizers to be used in ready-mix concrete are expected to retain slump for much longer hours which, might make one more preferable over the other for the site and/or ready-mix applications, both HRWRAs were selected for this study. Two classes of concrete C-30 and C-40 were studied and the selection was done in consideration of currently most used concrete strength classes on the market aiming at presenting applicable research findings.

1.4. Objective of the Study

This research was aimed at studying how to produce concrete mixtures with a minimum cost possible using superplasticizers, without compromising the desired slump and compressive strength properties of concrete.

The study specifically aimed at:

- Investigating slump, slump loss, and compressive strength of concrete produced with different amounts of cement and HRWRAs.
- Making cost analysis and optimizing the concrete mixture cost produced with HRWRAs.

Chapter – Two

Literature Review

2.1. Introduction

For a long time, admixtures have been used to improve concrete properties. The Romans were known to have used animal fat, milk, and lard to improve the concrete property. The discovery of air-entraining agents which added more resistance to freezing and thawing in concrete from blood, beef, and oil in the 1930s, led to more detailed research and improvements (2 p. 518).

According to Ramachandran, 80% of concrete produced in North America contains one or more types of admixtures (2). In Japan and Canada, almost 100% of concrete contains at least a water reducer and/or an air-entraining agent while in the United States and France; more than 50% of concrete contains admixtures (9).

2.2. Definition and Classification of Chemical Admixtures

2.2.1. Definition

From ACI concrete terminologies, an admixture is defined as; "a material other than water, aggregates, cementitious materials, and fiber reinforcement used as an ingredient of cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing" (10).

According to Neville A. M., "an admixture can be defined as a chemical product which, except in special cases, is added to the concrete mix in quantities no larger than 5% by mass of cement during mixing or during an additional mixing operation prior to the placing of concrete, for the purpose of achieving a specific modification, or modifications, to the normal properties of concrete" (8 p. 244).

Based on the definition of RILEM (*Reunion Internationale des Laboratoires d'Essais et de Recherches sur les Materiaux et les Constructions*), admixtures are defined as "inorganic (including minerals) or organic materials in solid or liquid state, added to the normal components of the mix, in most cases up to a maximum of 5% by weight of the cement or cementitious materials" (2 p. 89).

2.2.2. Classification

The ASTM C494 classifies and defines chemical admixtures in eight types: -

i. Type A-Water-reducing admixtures, an admixture that reduces the quantity of mixing water minimum by 5% required to produce concrete of a given consistency.

ii. Type B-Retarding admixtures, an admixture that retards the setting of concrete

iii. Type C-Accelerating admixtures, an admixture that accelerates the setting and early strength development of concrete

iv. Type D-Water-reducing and retarding admixtures, an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency and retards the setting of concrete.

v. Type E-Water-reducing and accelerating admixtures, an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency and accelerates the setting and early strength development of concrete.

vi. Type F-Water-reducing high-range admixtures, an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency by 12% or greater.

vii. Type G-Water-reducing high-range and retarding admixtures, an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency by 12% or greater and retards the setting of concrete.

viii. Type S-Specific performance admixtures, an admixture that provides a desired performance characteristic(s) other than reducing water content, or changing the time of setting of concrete, or both, without any adverse effects on fresh, hardened and durability properties of concrete such as, shrinkage reduction, mitigation of alkali-silica reaction, and viscosity modification are among specific performance requirements (11).

Mindess S. groups admixtures into the following four categories:

1. Air-entraining agents (ASTM C260) that are added primarily to improve the frost resistance of concrete;
2. Chemical admixtures (ASTM C494 and BS 5075) that are water-soluble compounds added primarily to control setting and early hardening of fresh concrete or to reduce its water requirements;
3. Mineral admixtures that are finely divided solids added to concrete to improve its durability or to provide additional cementing properties (slags and Pozzolans are important categories of mineral admixtures);
4. Miscellaneous admixtures, which include all those materials that do not come under one of the foregoing categories, many of which have been developed for specialized applications (12 pp. 165-166).

2.3. High Range Water Reducers (HRWRAs) or Superplasticizers

Since the late 1970s, the use of a new class of chemical admixtures has increased substantially in various segments of the concrete industry. When these admixtures are used, they significantly increase slump without adding more water or substantially reduce water content without loss in a slump. Often referred to as a superplasticizer, this material is properly categorized as a high-range water-reducing admixture (HRWRA) meeting the requirements of ASTM C494 Type F or G or ASTM C1017 Type I or II. To be categorized as a HRWRA under the requirements of ASTM C494, the admixture must be capable of reducing the water requirement by at least 12%. As originally marketed in Germany and Japan in the late 1960s, HRWRA consisted primarily of sulfonated condensate products of naphthalene or melamine. In the early 1980s, work began on the development of polycarboxylate-based HRWRAs.

In the early years, problems in using the admixture in concrete, such as higher-than-normal rate of slump loss, leading to the need for job-site addition of the material, limited the use of HRWRAs. Besides that, under laboratory conditions, Mather in 1978 reported a lowered resistance to freezing and thawing. Eventually, under laboratory and field conditions, concrete containing HRWRAs proved to be at least as durable as conventional concrete. However, rapid slump loss was a problem in some concrete mixtures. This concern led to the development of new products aimed at maintaining workability for longer periods.

Extended-life HRWRAs were developed in the 1980s, which imparted up to 2 hours longer working life to concrete, depending on mixture ingredients and environmental conditions. This allowed adding HRWRAs at the batch plant rather than at the job site, reducing wear on truck mixers, and lessening the need for ancillary equipment such as truck-mounted admixture tanks and dispensers. The result showed an increase in the use of HRWRAs in almost all areas of the concrete industry (13).

According to Steve, Beatrix, William, and ASTM C494 (AASHTO M194) High-range water reducers, i.e. Type-F (water-reducing) and Type-G (water-reducing and retarding), can be used to impart properties induced by regular water reducers but much more efficiently. They can greatly reduce water and cement contents, make low water-cement ratio and high-strength concrete with normal or enhanced workability (14 p. 109).

2.3.1. Composition

ACI stated that water-reducing admixtures are based on a variety of materials, most common of which are lignosulfonic acids and their salts, hydroxylated polymers, hydroxylated carboxylic acids, and their salts, sulfonated melamine or naphthalene formaldehyde condensates and polyether-polycarboxylates. Lignosulfonates, sulfonated naphthalene formaldehyde condensates, and polycarboxylic ether are generally considered as 1st, 2nd, and 3rd generation water reducers respectively (3 p. 70). *It is important to note however that it can be difficult to predict an admixture's performance based on its primary ingredients* (10).

Ramachandran V.S classified the main compounds in water reducers into four groups. The first containing Ca, Na, or NH_4 salts of ligno-sulfonic acids, the second containing hydroxyl-carboxylic acids generally as Na, NH_4, or tri-ethanolamine salts, the carbohydrates belonging to the third and the last group comprising other compounds (2 p. 291).

- ***Lignosulfonate***: - is a liquid waste of papermaking pulp and composed of 20-30% of a complex mixture of sulfonation products of lignin and decomposition products of cellulose, various carbohydrates, and free sulfurous acid and sulfates. Used as a retarder or water-reducing retarder, its composition widely varies depending on the successive processes of neutralization, precipitation, and fermentation of the liquid waste undergoes as well as on the type and age of the wood used as a raw material. Modified lignosulfonates, obtained by special treatments such as ultrafiltration, desugarization or sulfonation can compete with melamine sulfonate and naphthalene sulfonate superplasticizing admixture (2 pp. 293-295).
- ***Sulfonate Naphthalene Formaldehyde (SNF):-*** The production of SNF has three steps: the first being the sulphonation of naphthalene with sulphuric acid in which the substitution of hydrogen by sulfonate may take place in two positions depending on the temperature. The α-substitution occurs mostly below a temperature of 100 ^oC, whereas at temperatures higher than 150 ^oC the β-substitution will occur. The β-isomer represents the most thermo-dynamically stable compound. The degree of sulfonation determines the dispersing effect. The second step is the condensation reaction of β-naphthalene sulphonic acid with formaldehyde, producing poly-methylene naphthalene sulphonic acid. The third and last step is neutralizing the poly-methylene naphthalene sulphonic acid with sodium hydroxide or lime to free the polymer from alkalis. However, if lime is used, filtration becomes mandatory to remove excess lime and gypsum (9 pp. 150-157).
- ***Sulphonated Melamine-Formaldehyde Condensate (SMF)):-*** Similar to SNF, the synthesis of SMF involves numerous steps that start with the reaction of formaldehyde with amino groups of the melamine leading to a methylolated melamine. Then the sulfonation of one of the methylol groups using sodium bisulphite will occur under the same alkaline conditions.

Finally, polymerization by polycondensation performed under acidic conditions until the PH increases to a basic value that stops the reaction.

- ***Poly-carboxylic Ether (PCE):*** **-** is manufactured by a polymerization process in which a free radical mechanism with peroxide initiators is used (3 p. 70). They have several hydroxyl (OH) groups with one or two terminal carboxylic acids (COOH) groups attached to a relatively short carbon chain (2 p. 295).
- ***Carbohydrates:*** **-** include natural compounds, such as glucose and sucrose, or hydroxylated polymers obtained by partial hydrolysis of polysaccharides, such as those contained in cornstarch, to form polymers with low molecular weight, and containing from 3 to 25 glycoside units (2 p. 297).

2.3.2. Mechanism

Superplasticizers are effective due to their adsorption on and dispersion of the cement particles in the cement-water system (2 p. 114). The addition of HRWRAs makes cement particles deflocculated and dispersed; and with the attraction of opposite charges adjacent to particle surface leading to flocculation of cement particles, it consequently reduces the surface friction in cement paste (12 p. 178).

For naphthalene or melamine based HRWRAs, adsorption of the anionic part of the admixture at the solid-water interface is how they work. The nonpolar backbone of the polymer end adsorbs on to cement surface creating extremely negatively charged hydrophilic end that thrust toward the solution. These negatively charged cement grains start repelling each other (electrostatic repulsion) reducing the water requirement for a given degree of workability.

The retarding effect comes from a thin sheath developed during adsorption of superplasticizer on cement particles surface. It prevents the surface hydration reaction between water and cement as long as sufficient plasticizer molecules are available at the particle/solution interface, and as the number of available plasticizers decreases in time, the polymers become entrapped in hydration products (15 p. 129).

The water reduction effect depends on the dosage level, the sequence of addition, and molecular weight (14 p. 109). Mehta et al. stated that the interaction mechanism of superplasticizer is also dependent on the ambient temperature, cement fineness, and composition, especially the C_3A, SO_3, and alkali contents, which control the rate of ettringite formation, may affect too (16 p. 289).

2.3.3. Application

Some of the major benefits that make superplasticizers key ingredients of modern concretes are:

- enhancing workability without altering the water-to-cement (w/c) ratio that controls concrete durability and strength;
- decreasing the w/c ratio of concrete without compromising workability;
- reducing the environmental impact of concrete construction by reducing the cement content per cubic meter of concrete;
- reducing the amount of concrete required to achieve a defined load-bearing capacity and increasing of concrete service life by enhancing durability (9 p. 350).

Superplasticizers are not only used for the production of flowing, self-leveling, or self-compacting concrete but also the production of high-strength and high-performance concrete.

According to ACI 212, HRWRAs have not only increased the efficiency of construction, when used to increase slump, reduce w/cm, or both but also:

- **increased productivity** through faster placing, finishing and stripping of forms because of improved workability and/or flow-ability and high early-age strength gain;

- **reduced equipment costs** by increased use of forms reduced pump pressures;
- faster turnaround time of concrete trucks, and reduced vibration;
- **reduced material costs** by saving on cement cost through optimized concrete mixtures;
- allow the use of less-expensive cementitious material;
- **bettered the quality** by increasing the probability that concrete will meet the design specifications for strength, durability, appearance, and dimensional tolerance by reducing volume change (13).

Boosted design and engineering of concrete structures have also been observed when engineers and architects use high-strength and high-performance concrete, often made possible by the application of HRWRAs, to achieve specific design objectives like longer spans, smaller columns, more usable space, flatter slabs, thinner sections, reduced maintenance, longer service life, improved appearance, and architectural flexibility.

2.4. Effects of Cement Content on Properties of Fresh Concrete

2.4.1. Workability

According to Kosmatka et al. definition:

- Consistency- is the ability to flow
- Stability- is the resistance to segregation
- Uniformity- is a homogeneous mixture with evenly dispersed constituents
- Workability- is the ease of placing, consolidating, and finishing
- Finish-ability- is the ease of performing finishing operations to achieve specified surface characteristics (7 p. 153).

ASTM C125 defined the workability of concrete as property determining the effort required to manipulate a fresh mixed quantity of concrete with minimum loss of homogeneity (17).

Therefore, the workability of a given concrete mixture depends on the purpose it is prepared for. For instance, for roadside curbstone low slump concrete is suitable but in reinforced concrete shear wall higher slump might be required.

Factors that influence the workability of concrete are:

- **The method and duration of transportation**

Concrete must be capable of being transported and placed by any one or more of a variety of methods including barrow, dump truck, mixer truck, conveyor belt, and pumping. When transportation time is long, loss of slump will occur unless retarding admixtures are used. It is also important to note that the retarding effect of a retarder is smaller at high temperatures. Therefore keeping the concrete temperature as low as possible is important. On the other hand concrete temperature increases as the cement content increases, which results in rapid slump loss for a long duration of transportation.

A limit of 300 revolutions for both agitating and mixing is laid down by ASTM C94 or the concretes must be placed within $1^1/_2$ hr. of mixing. The BS 5328 – 1991, restrict this to 2 hours' time during which, cement and moist sand are allowed to remain in contact. However, the above restrictions are to be on the safe side. Exceeding these limits is not going to be harmful if the mix remains sufficiently workable for full compaction (15 p. 450).

In the case of pump-able concrete, a slump of (50 to 150 mm) is regarded as suitable. In higher slump mixtures, the coarse aggregate may separate from the mortar and cause pipeline blockage. Slumps obtained using superplasticizers, however, are usually pumped without difficulty. The use of extra quantities of cementitious materials as the only means to correct pumping difficulties is shortsighted and uneconomical (18). In cement rich mixtures, the cementitious fines tend to provide cohesion that can lead to stickiness (19 p. 56). Adding more cement may make the mixture too sticky (7 p. 386).

- **Quantity and characteristics of cementitious materials**

At low w/c, as the cement content increases consistency and cohesiveness also improve since more lubricant is available. In normal-strength-concrete, low cement content tends to produce a harsh mixture, which results in poor finish-ability (3 p. 100). As the proportion and/or fineness of cement particles increase, the cohesiveness of mixture improves but the fluidity decreases and the mix tends to be sticky (3 p. 101) (14 pp. 305-306).

- **Concrete consistency and slump**

Even though it does not characterize the rheology and workability of concrete mixture, quantitatively slump test measures the consistency of concrete from one batch to the next.

As discussed by Kosmatka et al. in conventional type of concrete, a low slump concrete indicates stiff consistency. Too dry and harsh concrete is difficult to place and compact; hence, segregation of large aggregate particles may occur. However, this does not mean wetter, more fluid mixture is necessarily more workable. Segregation, honeycombing, and reduced hardened properties can occur if the mixture is too wet.

Using excessive water to produce high slump is one of the primary causes of poor concrete performance, as it leads to bleeding, segregation, and increased drying shrinkage (14 pp. 3-4).

- **Grading, shape, and surface texture of fine and coarse aggregates**

Maximum aggregate size determines the cement paste requirement of a concrete mixture. The larger the aggregate size the smaller the total aggregate surface area will be, as a result, less cement paste is required. In normal-strength concrete, for a constant w/c and cement content, slump increases as the maximum aggregate size increases. Similarly, for a given water to cement ratio and cement content, aggregates with spherical shape and smooth surface texture result in higher slump. Increase of the sand to coarse aggregate ratio can lead to an increase in cohesiveness but reduces the flow-ability. An increase in the aggregate-cement ratio results in a lower flow-ability because of less cement paste is available for lubrication (3 p. 18).

- **Entrained air**

Air entrainment improves the slump and cohesiveness of concrete mixture. Air content and slump are directly proportional, even when the w/c ratio is held constant. An increase in the w/c ratio from 0.4 to 1.0 can increase the air content by 4% (14 p. 138).

- **Water content**

Fluidity of the concrete mixture increases as the water content increases since the amount of water for lubrication also increases; however, too much water will reduce stability, which will lead to segregation, bleeding, and reduced concrete strength (3 p. 100).

- **Concrete and ambient air temperature**

When freshly mixed concrete is directly exposed to the sun or wind, the concrete stiffens fast due to the evaporation of the mixing water. Besides, mixing water can also be consumed by aggregates and during the formation of hydration products. The stiffening of concrete varies with the richness of the mix, type of cement, the temperature of the concrete, and the initial slump. Because of increased hydration rate and loss of water, workability reduces faster at a higher temperature (3 p. 101). The rate of slump loss is lower for mixes of lower cement content, lower air, materials temperature, and water content (6 p. 98).

- **Admixture**

Admixtures are one of concrete workability influencing factors. Among this, the air-entraining agent increases the paste volume improves the consistency of concrete and cohesiveness by reducing bleeding and segregation. This effect of air-entrainment is more pronounced in harsh and low cement content concretes such as in mass concrete (12 p. 174).

2.4.2. Bleeding and Segregation

Bleeding is the appearance of water at the surface of the concrete after consolidation (6 p. 131). If evaporation of water from the surface of the concrete is faster than the bleeding rate, plastic shrinkage cracking may be generated (3 p. 134). Increasing the water content and w/c are the major causes of bleeding. To overcome this; increasing cement content, using finer cementitious materials, and increasing the volume of fines in the sand may be applied (14 pp. 3-4).

Segregation is the settlement or separation of coarser particles from the mixture. Some of the major causes of segregation are:

- increase in maximum particle size over 25 mm;
- increase in the quantity of large aggregate fractions;
- increase in the specific gravity of coarse aggregate compared with the specific gravity of fine aggregate;
- decrease in the proportion of fines;
- decrease in cement content;
- change in particle shape (round to angular);
- change in water content to make the mix either too dry or wet.

The addition of an air-entraining agent or a finely divided pozzolanic material reduces the tendency to segregation (6 pp. 133-134).

2.5. Effects of HRWRAs on Properties of Fresh Concrete

HRWRAs positively affect properties of fresh concrete such as higher slump without the addition of water, lower w/c at equivalent slump, and improved workability and pump-ability. On the contrary, rapid slump loss, increased setting time, segregation, bleeding and large size entrained air bubbles might be problems at the job site (13).

Neville A.M. stated that high cement content leads to high shrinkage and low water to cement ratio resulted using superplasticizer give lower shrinkage (8 p. 434).

2.5.1. Water Reduction

HRWRAs can reduce water content by at least 12% and some even more than 30% at a given slump. According to Li, they can reduce the water content by 40% (3 p. 70).

According to ACI, as the cement content of a concrete mixture increases, the required dosage of the HRWRA percentage by mass of cement is reduced. It has been found that the effects of these admixtures are also dependent on the calculated C_3A, C_3S, and alkali contents of the cement. (20)

S.Mindess stated that delaying the addition of the admixture until a few minutes after the water has been first added would increase potential water reduction, enhance air entrainment, and increase set-retardation (12 p. 180).

2.5.2. Slump

At a given water to cement ratio and water content in a mix, the dispersing action of superplasticizers increases the workability of concrete. ACI stated that at high dosage rates usually above the manufacturer's recommendation, adding more HRWRA provides no additional slump increase (13).

Rapid rate of slump loss can be a major problem with superplasticized flowing concrete according to S.Mindess. In such a case, adding a second dose of superplasticizers at the job site or delaying the initial addition time until placement can be taken as a solution. The HRWRA's with retarding formulations *(ASTM C494-Type G)* have been known to reduce slump loss, but newer superplasticizers designed to maintain a high slump for extended periods have recently been brought to the industry (12 p. 180).

The ACI states that workability-retaining admixtures can also be used to overcome slump loss since the duration of slump retention time in concrete depends on the type and quantity of cement, the temperature of concrete, type, and dosage of HRWRA used, and thoroughness of the mixing (10).

In as much as the addition of retarders such as calcium-gluconate can be used to maintain slump in superplasticized concrete; initial slump, type and amount of superplasticizer, type and amount of cement, time of addition of superplasticizer, humidity, temperature, method of mixing, and the presence of other admixtures in the mix are the determining factors for slump loss (2 p. 122) (3 p. 103).

Though the exact value of the loss in slump depends on several factors, Neville A.M. argues that, the higher the initial slump the greater the slump loss and that the rate of loss of slump is higher in cement rich mixes. He further stated that the rate of loss depends on the properties of the cement used i.e. the rate is higher when the alkali content is high and when the sulfate content is low (8 pp. 259-260).

2.5.3. Bleeding and Segregation

In a water-reduced concrete using superplasticizer, no excessive segregation or bleeding occurs. In concrete where an HRWRA is used as a water reducer, the bleeding generally is decreased because of the lower water content. Ramachandran and Malhotra verified this for concrete containing type I, II, and V cements as per ASTM C150 classification (2 p. 454). The ACI however stated that segregation might occur if precautions are not taken during proportioning and mixing while HRWRAs are used to create flowing concrete (13). According to Kosmatka et al., a significant reduction of bleeding may result from large reductions of water content, which may also cause finishing difficulties on flat surfaces when rapid drying conditions are present (14 p. 108).

According to Perenchio W. F. in most instances, however, superplasticizers reduce the drying shrinkage of concrete probably due to the reduced water content and this effect is more pronounced in concretes with higher cement contents (21).

Water reducers decrease, increase, or have no effect on bleeding, depending on the chemical composition of the admixture. Despite the reduction in water content, water-reducing admixtures may cause increases in drying shrinkage. Usually, the effect of the water reducer on drying shrinkage is small when compared to other more significant factors that affect shrinkage cracking in concrete (7 p. 126).

On the other hand, Mindess S. argues that water-reducers may not improve the cohesiveness of the mix as much as the slump. Those admixtures that are based on hydroxycarboxylic acids tend to increase bleeding than lignosulfonate based and overdosing can result in excessive bleeding and segregation (12 pp. 180-181).

Neville A. M. argues that in as much as repeated addition of superplasticizers to a mix may enable it to retain its workability; it may also increase bleeding, and segregation with other possible side effects such as set retardation and increase or decrease in the quantity of entrained air (22 p. 261).

2.5.4. Air Content

As Kosmatka et al. stated concrete with HRWRAs could have larger entrained air voids and higher void-spacing factors than normal air-entrained concrete (7 p. 127).

As stated in ACI 212.3, researches have shown that concretes with HRWRAs may still be durable even though the spacing factors may exceed accepted limits of 0.20 mm (20).

2.6. Effects of Cement Content on Properties of Hardened Concrete

2.6.1. Compressive Strength

Neville A. M. stated that the strength of concrete at a given age and cured in water at a prescribed temperature is assumed to depend primarily on two factors only w/c and degree of compaction. For a fully compacted concrete, strength is inversely proportional to w/c; however, very low w/c with extremely high cement content (probably above 530 kg/m^3) exhibits retrogression of strength when large size aggregate is used, which may be due to loss of the cement-aggregate bond or stress induced by shrinkage (8 p. 270).

According to Kosmatka et al., there is an optimum cement and supplementary cementitious content for every combination of materials; at which, strength does not continue to increase with greater amounts (7 p. 386).

2.6.2. Flexural Strength

Flexural strength, the ability to resist bending, is used to design pavements and slab on ground, which is 0.7 to 0.8 times square root of the compressive strength (7 p. 170). Hence, increasing the cement content after the concrete mix reached an optimum level will not increase the flexural strength too.

2.6.3. Permeability

Permeability is an ability of concrete to resist penetration by water or other substances (liquid, gas, ions). The paste permeability is associated with water to cement ratio, degree of cement hydration, and length of moist curing. Low water to cement ratio with proper curing can considerably reduce permeability (7 p. 170). Therefore, the higher the water and cement content the higher the permeability of the concrete mixture will be.

2.6.4. Shrinkage

According to Neville A.M., at constant water to cement ratio shrinkage increases with an increase in cement content (8 p. 433). The water content of freshly mixed concrete is a major shrinkage-influencing factor. Drying shrinkage increases as the water content increases (7 p. 182).

2.6.5. Durability

Durability of concrete is defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties (7 p. 172). With increasing water/cement ratios, the paste fraction of the concrete becomes increasingly porous. This has two direct consequences: one is the paste becomes weaker due to the increased porosity and the other more permeable because the pores are interconnected (8 pp. 482-487).

2.7. Effects of HRWRAs on Properties of Hardened Concrete

2.7.1. Compressive Strength

Kosmatka et al. stated that, for concretes of equal cement content, air content, and slump, the 28-day compressive strength of a water-reduced concrete containing a water reducer can be 10% to 25% greater than the concrete without the admixture (14 p. 108). The ACI complements that cement contents can thus be reduced without lowering 28-day strength (20).

Neville A.M. stated that superplasticizers do not alter the fundamental structure of hydrated cement, rather main effect being a better distribution of cement particles and the resultant better hydration (8 p. 258).

According to ACI, except for a slight acceleration of strength development at early ages, superplasticizers increase the compressive strength of concrete in proportion to the amount of water reduction effected (21). It is generally agreed that increase in compressive strength is up to 25% greater than would be anticipated from the decrease in w/c ratio alone (12 p. 181).

2.7.2. Flexural Strength

The ACI states, increase in flexural strength of concrete containing a water-reducing admixture are not proportionally as great as increase in compressive strength (20) and that HRWRAs do not alter the relationship between compressive strength and tensile strength or modulus of elasticity in concrete (13).

As Ramachandran V.S. stated, increase in flexural strength of about 10% for concrete at 7 days to 1 year old has been reported for lignosulfonate and hydroxycarboxylic acid-based water-reducing admixtures at a given slump and cement content. The increase in mechanical properties i.e., compressive and flexural strength and modulus of elasticity is generally achieved with reductions in w/c (2 p. 381).

2.7.3. Permeability

HRWRAs can reduce the water demand of concrete mixture, which reduces the water to cement ratio; as a result, less permeable concrete can be produced (22 p. 165).

2.7.4. Shrinkage

According to Neville A.M., water-reducing admixtures may cause a small increase in shrinkage, when they are used to reduce the water or cement content or both (8 p. 434). Plasticized concrete tends to develop less drying shrinkage than high-water-content concrete. However, high slump plasticized concrete has similar or higher drying shrinkage than conventional low-slump, low-water-content concrete (7 p. 172). High-range water reducers usually have little effect on drying shrinkage (7 p. 184) (8 p. 434).

Mindess S. states that data on the effect of water-reducing admixtures on drying shrinkage and creep are conflicting and depend very much on cement type and specific admixture (12 pp. 181-182).

2.7.5. Durability

Concrete with low water to cement ratio can be produced using superplasticizers; therefore, the resultant concrete, if properly cured, can have extremely low permeability and good resistance to the penetration of aggressive solutions. Resistance to chloride penetration is similar, or slightly better than, that of conventional concrete with the same w/cm but; when HRWRA is used to reduce the w/cm (13).

Neville A.M. argues that superplasticizers do not influence shrinkage, creep, modulus of elasticity and resistance to freezing and thawing; therefore they have no effect on the durability of concrete and specifically, durability to exposure of sulfates and finally noted that the improvement in durability is the result of reduced w/c (8 p. 263).

2.8. Optimizing Concrete Mixture Cost

In concrete mixture optimization, multi-dimensional understanding is very important. The need to optimize a concrete mixture shall not be considered from the direct cost saving made from minimizing the cement consumption only but also, the overall environmental, resource, and energy conservation for the coming generation.

Cement is not only the key ingredient in a concrete mix but also the most expensive one; hence, reducing its content is a factor to consider in minimizing concrete mixture cost. The reduction must however be done without compromising the desired properties of the concrete mixture such as strength and durability.

The other consideration is increasing the aggregate/cement ratio, which affects the workability, mechanical properties, and volume stability, and; due to the price difference between the aggregate and cement, increasing the aggregate/cement ratio will decrease the cost of concrete (3 p. 18).

Another factor to be considered in minimizing a concrete mixture cost is the dosage of superplasticizers. Since the performance of a given superplasticizer is different from one brand to another besides compatibility issue with the given cement, the comparison shall be made based on price for a needed effect.

2.8.1. Factors Affecting the Cost of Concrete In-Place

The cost of concrete widely varies depending on the location, fluctuating currencies, commodity prices, and unexpected political developments. The Ethiopian construction industry has been suffering from a shortage of raw material and an escalation of its price. For instance, Addis Ababa City Housing Development Enterprise has reported that a shortage of raw materials as one of the major factors for the late delivery of saving houses (23). Here below these factors are discussed:

- **Site Conditions**

Site conditions such as location, accessibility, and availability of construction materials, skilled and non-skilled labor near the site also affect the cost of concrete construction.

- **Economic Factors**

Construction is one of the major industries that suffer from any instability with politics, peace, and economy as a result affecting the concrete construction cost. Some of the economic factors are inflation, currency exchange rate fluctuations, and the demand-supply gap. The Ethiopian cement market is a good example to show the influence of these factors.

For instance, between the years 2002 and 2012, the cement market showed a huge demand-supply gap leading to price increment from 60 birrs/quintal until 2002, then increased to 500 birr/quintal in 2008. This forced the government to allow private investors to import cement. This demand-supply gap driven escalation continued until the time Derba Cement Factory join the market in 2012; then the price lowered to 200 birrs/quintal (24).

The *Ethiopian Cement Industry Development Strategy 2015-2025, published by FDRE Ministry of Industry* has clearly illustrated the demand and supply as well as cement factories installed capacity is on Fig. 2.8.1.

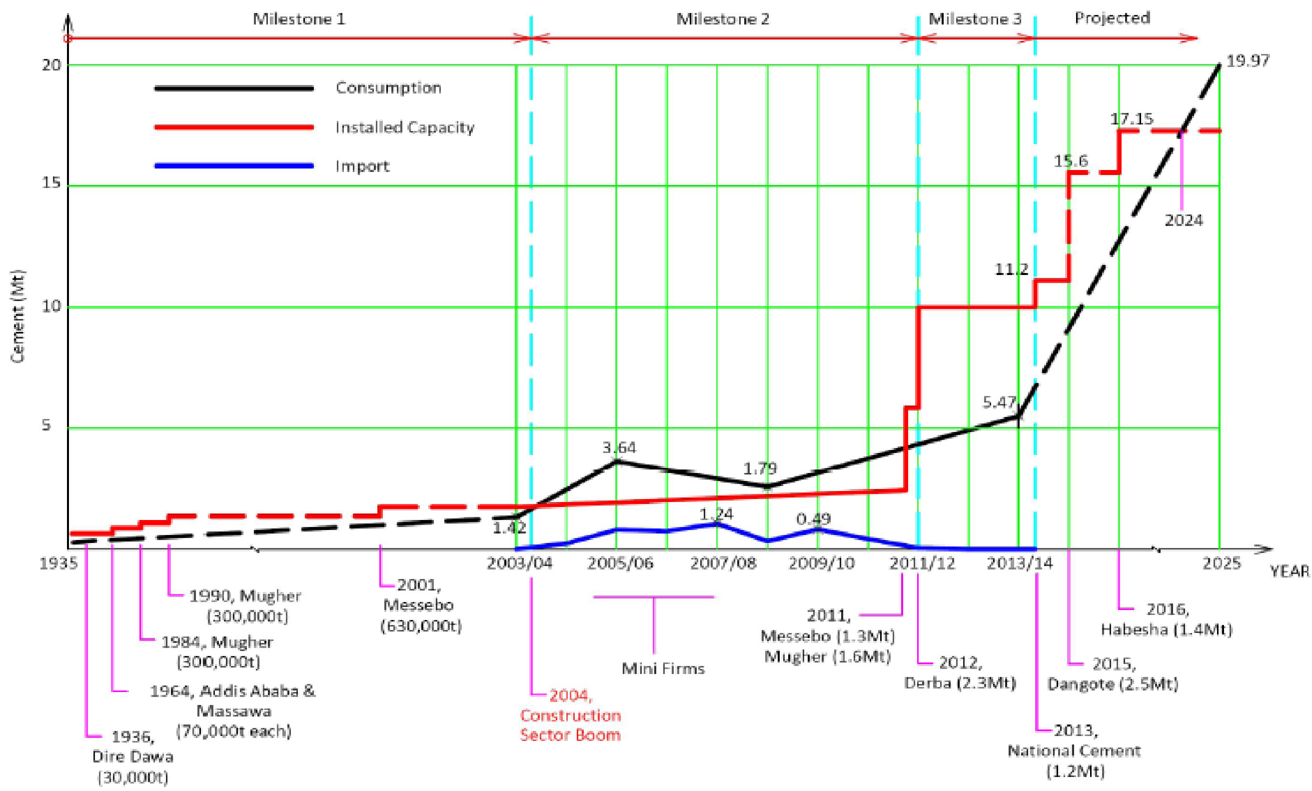

Fig. 2.8.1. Summarized historical development of Ethiopian cement industry (5)

- **Specifications**

The specification of a given concrete work also determines its cost. This effect can be explained from two perspectives:

- *specified method of mix proportioning*
- *selected concrete strength class*

In Ethiopia, it is common practice to use cement rich standard concrete mix proportions given in EBCS2-1995. Using this standard for C-30 concrete with 50-100 mm slump and nominal maximum aggregate size of 20 mm, 434 kg/m^3 cement is required. If the ACI 211.1 concrete mix design method is applied, the required cement content is reduced to 405 kg/m^3. If we further add superplasticizer and reduce the cement content by 15%, the cement content will be 345 kg/m^3.

If we compare the cost of the above three concrete mixtures, (*assuming cost of cement as 300 birrs/quintal and superplasticizer 35 birrs/lit and 3.5 liters being required per 1 m^3 of concrete*) the standard concrete mix proportion recommended by EBCS2 1995 costs 90-birr/m^3 more than the mix proportion using the ACI method. If the concrete mixture is 15% cement reduced with superplasticizer, the cost reduction becomes 145-birr/m^3.

According to ACI 363, Chicago-based structural engineers William Schmidt and Edward S. Hoffman compiled charts in 1975, indicated that the cost of supporting 445 KN of service load comes to $5.02 per floor with 41 MPa concrete, $4.21 with 52 MPa, and a drop to $3.65 with 62 MPa concrete.

A case study in the construction of New York City’s Palace Hotel built in 1979 found that 55 and 48 MPa concrete was used in the building columns while lightweight concrete with compressive strength of 24 MPa was used for floor slabs, and 34 to 41 MPa concrete was used in wall construction. A reduction of approximately 52% column sizes and 10% reinforcing steel on the lower five levels and even more economies like minimizing changes in column sizes and reducing column reinforcement on the upper floors of the hotel observed because of the concrete strength (25).

According to a master’s thesis titled *The Advantage of High-Strength Concrete (HSC) in High-Rise Buildings from Area Saving Aspect* by Sinit Tsegaye, 2014, a comparison between C-30 and C-95 concrete and reinforcement cost analysis shows 9 to 51% cost reduction in using HSC (C-

95) instead of NSC (C-30). The analysis is done for G+5 to G+20 building columns and shear walls; and the cost and area-saving by using HSC increases as the number of stories increase (26).

"Utilizing high-strength concrete (HSC) and ultra-high-strength concrete (UHSC) and a pre-stress technique during design and construction provides good ways of increasing the efficiency of concrete" (3 p. 483).

- **Life cycle cost**

Life-cycle cost, which is usually not a concern in our construction industry, has a huge impact on the cost of concrete both in monetary and environmental terms. Life cycle cost includes the cost of planning, design, construction, operation, maintenance, regulatory, environmental, safety, and other costs reasonably anticipated during the life of the project, whether born by the project owner or those otherwise affected.

In the Ethiopia construction industry, the common trend is estimating the cost of design and construction only. Usually, the long-term costs associated with the maintenance and operations of a project are overlooked. This is one of the major causes of early age deterioration and failure in some construction projects. By conducting life cycle, cost analysis long-term maintenance and operation cost can be reduced.

So, if life cycle cost is considered, the durability of concrete becomes essential. To produce durable concrete minimizing the water to cement ratio and optimizing the mixture with minimum cement content is very important.

- **Material costs**

Concrete is a mixture of water, cement, and aggregates in a proportion of 14-21%, 7-15%, and 60-75% respectively and air can take up to 8% (7 p. 7). With an assumption of (*cement specific gravity -3.15, price-3 birr/kg, aggregates- 520 birrs/*m^3) the cost of ingredients in a cubic meter of concrete range between 661.5-1417.5 birr for cement, 312-390 birr for aggregates and 0.12-0.37 birr for water. This makes the total raw material cost of concrete to be 973.62-1807.87 birr/m^3. Accordingly, cement takes 68-78% of the material cost. This shows that an optimized concrete mixture with minimum cement content results in a significant total project cost reduction.

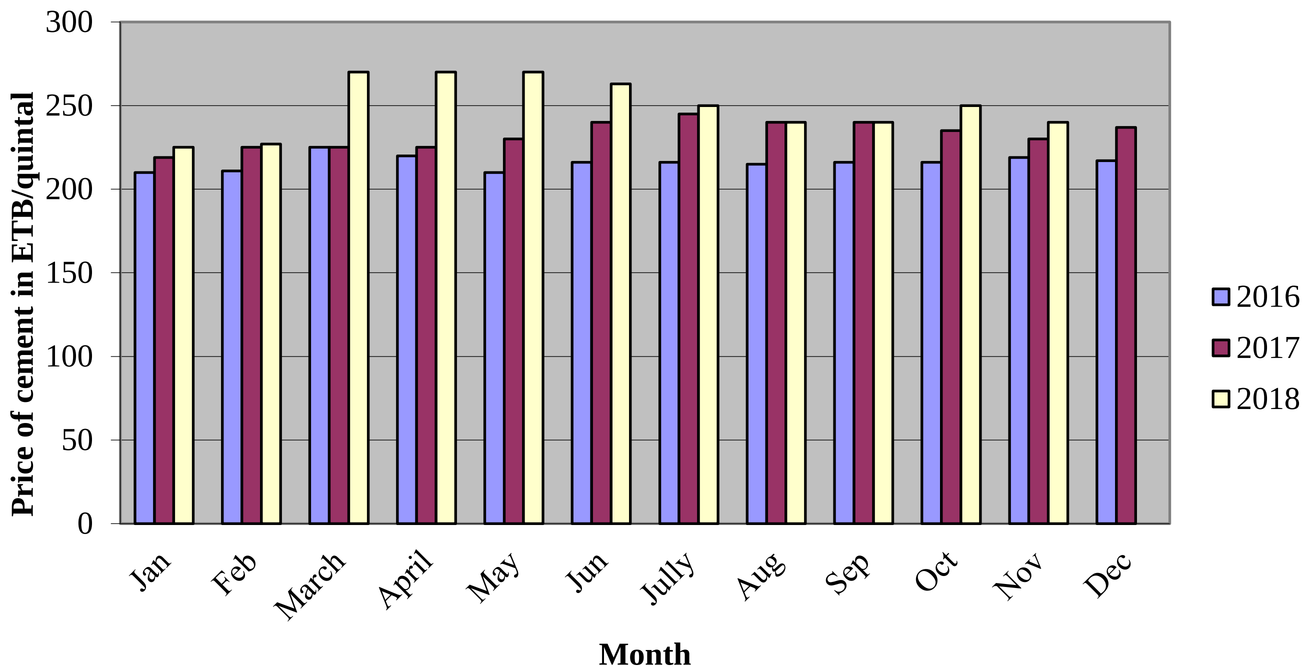

Fig. 2.8.2. Monthly retail price of Portland pozzolan cement (PPC) in Addis Ababa for the years 2016, 2017, and 2018 (41)

The average price of aggregates in Addis Ababa for the years 2017 and 2018 was about 461 birrs/m^3 for hauling distance less than 5 km. Similarly, coarse aggregate with a nominal maximum size of 25 mm is 534 birr/m^3 with periodic price fluctuations. The admixture market is less unstable compared to other concrete ingredients. Its price mainly depends on currency fluctuations since the factories use imported raw materials and some of the suppliers import the finished products.

- **Labor rates**

There is no fixed minimum wage in Ethiopia. Wages are fixed by negotiation between the company and the employee. According to the Ethiopian Investment Commission, the average labor cost in Ethiopia for manufacturing stands at 0.6 $/hr. Compared to other countries, labor cost in Ethiopia is 20% of China and lower than other East African countries. For instance, in Kenya, Nigeria, China, Bangladesh, and South Africa the average labor cost is about 2.2, 2.4, 3.2, 4.2, and 7.8 $/hr. respectively (27).

The labor price in the Ethiopian construction industry is similar to the manufacturing. In Ethiopia, most of the concrete construction projects use on-site mix by mechanical mixers and buggies for transporting, so it consumes a large labor force. During concreting work, a minimum of twenty to thirty workers are involved with the majority being daily labors with an hourly wage of 10-15 birrs/hr.

ANALYSIS SHEET FOR DIRECT & INDIRECT UNIT COSTS

PROJECT: *CONCRETE WORK* LABOUR HOURLY OUTPUT: 1.125 m^3 / hr.

WORK ITEM: (4.5) C-30 Concrete (Mechanical Mix) 1:2:3Column and shear wall EQUIPEMENT: Mixer & Vibrator

TOTAL QUANTITY OF WORK ITEM: 1 m^3 Sub structure RESULT: 2231.31 Birr/m^3

Material Cost (1:01)					Labour (1:02)					Equipment Cost (1:03)			
Type of Material	Unit	Qty *	Rate	Cost per Unit	Labour by Trade	No.	UF	** Indexed Hourly Cost	Hourly Cost	Type of Equipment	No.	Hourly Rental	Hourly Cost
Cement	Qnt.	4.20	225.00	945.00	Foreman	1.00	0.10	40.03	4.00	Mixer	1.00	63.34	63.34
Sand	m3	0.52	487.96	253.74	Mason I	2.00	1.00	34.69	69.39	Vibrator	1.00	30.02	30.02
Gravel (02)	m^3	0.78	448.08	349.50	Gang Lead	1.00	1.00	13.88	13.88	Tools	23.00	0.50	11.50
Water	m^3	0.21	3.50	0.75	D/L	23.00	1.00	10.41	239.39				
				0.00	Carpenter	1.00	0.25	34.69	8.67				
				0.00									
				0.00									
Total (1:-01)				1548.98	Total (1:02)				335.34	Total (1:03)			104.86

A= Materials Unit Cost 1548.98 Birr/m^3 B=Manpower Unit Cost 298.08 Br./m^3 C= Equipment Unit Cost : 93.21 Br./m^3

B = Total of (1:02) / Hourly Output; C = Total of (1:03) / Hourly output:

Direct Cost of work item = A+B+C =		1940.27	Birr/m^3
Overhead Cost:	8%	155.22	"
Profit Cost:	7%	135.82	"
Total Unit Cost :		2231.31	Birr/m^3

UF: UTILIZATION FACTOR

*: INCLUSIVE OF WASTAGE, TRANSPORTING, HANDLING, ETC.

**: INCLUSIVE OF BENEFITS, TRAVEL SUBSIDES AND COST OF OVERTIME RELATED TO TARGETED OUTPUT.

Fig. 2.8.3. Cost breakdown of concrete work in column and shear wall year 2010 (40)

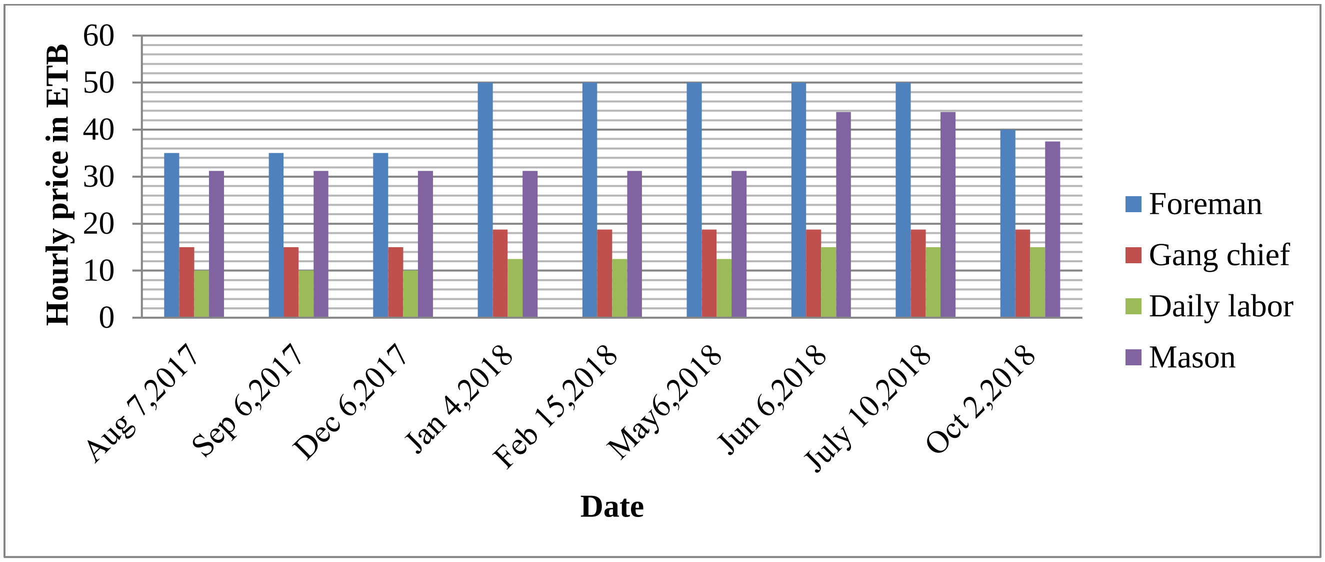

Fig. 2.8.4. Labor price for concrete work in Addis Ababa city (42)

Accordingly, from the total cost of concrete work, the material takes around 70%, labor 13% and the rest 17% is equipment, overhead, and profit. The cost of cement takes 61% of the material cost and 42% of the total concreting work cost. This estimation is made for labor-intensive work that is concreting in shear wall and columns. The labor cost decreases for horizontal members like slab, beam, and footing since hourly output increases. The material cost increases as the concrete strength class increases, due to increased cement content. This will lead to the conclusion that in our country's current situation, a major cost-saving can be made by minimizing costs of material especially cement than labor.

2.8.2. Environmental Impact of Cement

Cement, the key ingredient in concrete is also the largest CO_2 emitter and most expensive one. Hence reducing the cement content is a very effective measure for efficient concrete production. One of the most effective ways of reducing the cement content in the concrete mix is using water-reducers and supplementary cementitious materials.

As shown on Fig. 2.8.5. the Ethiopian Economic Association, in 2012 analysis on rainfall variability due to climate change, reported that the country would grow four-fold higher than the level of the economy had grown which was by 4.7% under less variable rainfall. "Ethiopia being dependent on rain-fed agriculture would suffer from extreme events. In particular, in the case of drought, shifting the economy from agriculture to industry and service may not rescue the country from the impact because such transformation under the dependency on hydroelectric power (HEP) means shifting the economy from rain-fed agriculture to rain-fed industry" (28). Therefore as a nation, working on minimizing CO_2 emission is necessary. Reducing the cement content of concrete mixtures using superplasticizers enables to minimize the CO_2 footprint of cement.

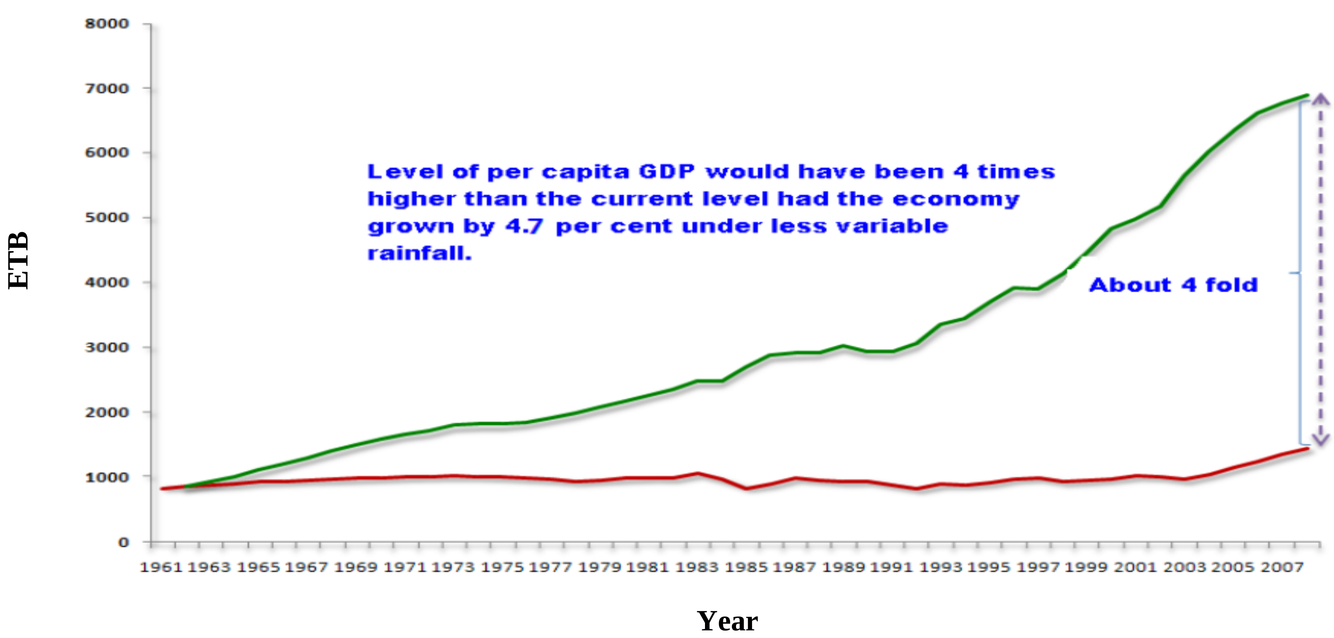

Fig. 2.8.5. Level of potential per capita GDP under less rainfall variability (28)

- **Carbon dioxide emission**

Cement production represents about 85% of the total emissions of concrete production. In the carbonation process, concrete structures are estimated to absorb at least 10% of the said CO_2

leaving a net amount of at least 2.7 billion tons of CO_2 representing 6 to 7% of the total global manmade emissions.

CO_2 emission during cement production varies considerably from one part of the world to the other, from plant to plant and between countries. Reports have however attributed the deviations to the technological advancement of the cement production process and the use of Pozzolanic materials but showed ranges from slightly below 0.6 to 1.2 tons of CO_2 per ton of cement (29 pp. 85-86).

- **Greenhouse gases**

However, some greenhouse gases other than CO_2, (*NOx- oxides of Nitrogen*, SO_2- *sulfur-dioxide*) constitute in small quantities but they are regarded as more damaging (29 p. 85).

- **Other hazards**

Exposure to dust and high temperature, contact with allergic substances, and noise exposure are some of the health-related hazards in the cement production process. Hence, using alternative raw materials such as fly ash, dust, and gypsum is one means of reducing the above hazardous gas emissions and effective cost-cutting method (29 pp. 85-92).

2.8.3. Energy Consumption in Cement Production

According to pieces of literature, cement production is said to cause approximately 5-8% of global manmade CO_2 emissions. About 50% of emission happens during clinker production, 40% come from the burning of the fuels to heat cement kiln, and about 10% from electricity use and transportation (3 p. 477) (30 p. 10).

According to the report titled *The Ethiopian Cement Industry Development Strategy 2015-2025,* heavily depending on imported and expensive sources of energy than exploring more alternatives that are efficient is listed as one of the limitations in the industry. The limited practical planning to use alternative energy sources', lack of energy audit practice, and inefficient thermal energy utilization are the challenges of these mainly coal-dependent factories.

Frequent power interruption is also another big challenge and reason to shift to alternative energy besides the significant cost reduction. In some cases, up to 3 million birrs is used per interruption since usually fossil fuels are used to restart kilns to operating conditions or temperatures.

In Ethiopia, there is a huge potential of alternative energy sources like municipal solid waste, biomass such as coffee husk, Jatropha, and sesame husk are some of the potential sources.

The experience of Hima cement of Uganda's in using the coffee husk, as an alternative energy source is a good example. Hima has been sourcing up to 70,000 tons of biomass annually from Uganda, Tanzania, and the Democratic Republic of Congo with coffee husks covering around 45% of its fuel needs. This led to a reduction in fossil fuel consumption, overall energy bill, and general CO_2 emissions.

The Indian cement industry experience with the use of advanced kilns and grinding equipment and greater production of blended cement is another example of low energy consumption. Studies show that the average energy consumption is 3.24 MJ/Metric ton of clinker as compared to 5.36 MJ/Metric ton in US 3.73 MJ/Metric ton in Canada and 5.12 MJ/Metric ton in China.

In China, the public service collects household waste and delivers it to the cement enterprises, and the latter get paid for the treatment/use of the waste. This has forced most cement firms to establish their plants near the industry where waste is abundant. The government has also set a policy/technical standard where a cement firm is exempted from VAT if it uses 30% of its energy from alternative and renewable sources like wastes (5).

2.9. Previous Studies on Concrete Mix-Optimization

Peter Taylor et al. had investigated the effect of required cementitious content at a given w/cm on workability, strength, and durability for 64 concrete mixtures. These were prepared with w/cm ranging 0.35-0.5, cementitious content 237-415 kg/m^3 and 0.42 fine to total aggregate ratio and tested for slump, unit weight, air content, setting time, compressive strength, chloride penetrability, and air permeability.

Their research stated two findings:

One was that about 1.25-1.5 times more paste was required than voids in aggregate to obtain minimum workability. However, the required paste content depended on the type and gradation of aggregates; in concrete with paste value below this, water-reducing admixtures were useless and increasing paste content above this value gave increased workability.

The second was that for a given w/cm ratio, increasing cementitious content:

- Did not improve compressive strength once the critical minimum was provided which was about twice the voids in aggregate
- Increased the chloride penetrability
- Increased the air permeability

Regarding setting time, the research finding showed that for high cement content, decreasing the w/cm ratio reduced the setting time because cement grains were closer to each other leading to reduce the time needed for hydration (31).

In optimization of high strength superplasticized concrete of 3-Gorge Dam in China by Zhang Y. et al., a comparison between performances of carboxylate and sulfonate based superplasticizers were made in a laboratory, a batching plant, and a site.

According to their report, PCE based superplasticizer compared to SNF-based superplasticizer showed 10.4-12.3% more mixing water reduction; this resulted in 47 and 40 kg less cementitious material for the production of 40 MPa and 45 MPa HSC respectively and 6ºC lower concrete temperature. Hence, PCE based superplasticizers were more cost-effective for the use in 3-Gorge Dam project in China since lower thermal stress reduced the temperature controlling cost in addition to reduced cementitious material content, and smooth placing process resulting from low slump-loss (32).

Using five brands of carboxylate-based superplasticizers and two cement types OPC and PPC from two cement producers, Antonia et al., investigated their optimum dosage by carrying out flow-ability and compressive strength tests using mortar test. The 7 and 28 days samples were produced with controlled sand gradation and distilled water. According to their report, different superplasticizer brands showed different behavior in setting time, strength development, optimum dosage, and slump retention time. Generally, the addition of superplasticizer improved flow-ability and compressive strength until the optimum dosage limit, which depended on the superplasticizer and cement type (32). In a related study, Muhit I.B. determined the dosage limit of superplasticizers by comparing concrete produced with and without superplasticizer and reported that; by mass of cementitious content, 1% of superplasticizer addition was the optimum dosage and at this dosage, the compressive strength for 28 days improved to 57 MPa as compared to the reference mix 35 MPa (33).

In a semi-experimental study by Shamsad Ahmad and Said A. Alghamdi, a statistical approach was developed to optimize concrete mixture by considering three major factors contributing to compressive strength i.e.

- w/c (0.38, 0.43 and 0.48);

- cementitious material composed of 92 % Type-I cement (ASTM C150, classification) and 8 % silica fume content;
- fine to total aggregate ratio of (0.35, 0.4 and 0.45).

The test results from trial mixes were used to carry out an analysis of variance (ANOVA) and develop a polynomial regression model for compressive strength in terms of the three design factors.

This statistical method of concrete mix optimization was less precise because of the variation in material characteristics of aggregates and types of cement but less expensive. As an alternative to this approach, they recommended fully experimental and semi-experimental approaches though they are more time consuming and give results, which can be applied to the materials considered in the study going ahead (34).

In his experimental study for a master's thesis, Yurdakul Ezgi tested 16 concrete mixtures with fixed fine to coarse aggregate ratio 0.42 and constant void content of combined aggregates. Slump, setting time, 1, 3 and 28-day compressive strengths, 28 day chloride penetration and air permeability tests were conducted for 0.35,0.4,0.45, 0.5 w/c and 237.31, 296.64, 355.96, 415.3 kg/m^3 cement content.

1 and 3-day compressive strengths were observed to be around 35 and 60% of the 28-day compressive strengths respectively.

In conclusion, Yurdakul Ezgi stated that for a given w/c, workability decreased as the cement content decreased and that as the cement content decreased overall setting time increased because of low paste content while increasing paste content increased chloride and air permeability of increased capillary pores and vice versa (35).

Wisconsin Highway Research Program tested concrete properties. *Compressive strength development, modulus of rapture, and length change at 1 and 365 days resistance of concrete to rapid chloride permeability test at 30 and 90 days and rapid freezing and thawing up to 300 cycles* tests were conducted. This research aimed at reducing cement content of concrete from 340 to 315 kg/m^3 and 335 to 280 kg/m^3 to be used for pavement and bridge structure works respectively.

They stated that with proper selection and usage of modern superplasticizers and optimal aggregate blends, an 18% reduction of cementitious materials content was achievable for low slump concrete. The use of PCE based superplasticizers enabled up to 10% more w/c reduction than sulfonate-based water-reducing admixtures.

As a conclusion, concrete produced with reduced cementitious materials had sufficient durability. However, they frequently demonstrated poor workability and that the solution to this problem was applying a multi-faceted approach to optimize concrete mixture proportions.

Besides, they suggested that concrete mixtures could effectively be designed by optimizing two essential phases comprising the material, the aggregates, and cement paste. Aggregate packing could alone be used as an effective tool to optimize the aggregate blends; while, the heat of hydration was useful for the optimization of the dosage of chemical admixtures before application in concrete (36).

Özlem Akaln et al. researched to get the optimum dosage of admixture that gave the maximum compressive strength on mortar with a minimum cost of admixture and used a desirability function and cost analysis to proportion each component. This study suggested that the use of mixture experiments supported by prior mortar performance tests could be useful to reduce the intensive work based on trial and error (37).

Previous studies show that adding more cement for given water to cement ratio does not improve the compressive strength of concrete, and decreasing the amount of cement affects the flow-ability and setting time of concrete. There is an optimum dosage limit of superplasticizers with a given cement type combination. Hence, it is possible to minimize the cost of concrete by using minimum cement content without affecting the compressive strength of the consistency of concrete using superplasticizers. Therefore, this research shows steps to optimize the cost of concrete using superplasticizers.

As it has been discussed by pieces of literatures HRWRAs allows higher reduction of cement content without affecting the desired concrete properties. Cement being the key element in concrete production as well as very expensive and environmental unfriendly ingredient, optimizing concrete mixtures before production becomes very important.

In this processes water reducing admixtures plays significant role by allowing lower water cement ratio. As result instead of adding more cement to the concrete mixes, improving their performance by using HRWRAs is preferable.

A lot of research shall be done in the optimization of concrete mixtures for locally available materials and different types of concrete.

Chapter- Three

Methods and Materials

This experimental research was mainly focused on laboratory investigations. It began by material characterization, and then produced control mixes (without superplasticizer); later special mixes with (Type-F (HRWRA) and Type-G (HRWRA-retarder). In this chapter, the materials and methods used for the study are discussed. The purpose of this research was to study how superplasticizers can be used to minimize concrete mixture costs for given performance requirements. As a result, the research fixed two parameters: the first being initial slump and the second 28-day compressive strength consequently conducting slump, slump loss, and compressive strength tests.

3.1. Research Design

In this section, the variable and fixed parameters used in this experimental study are discussed with the applied mix proportioning method. Based on the research scope, parameters such as water content and superplasticizer dosage were varied while slump and cement content being fixed. Moreover, in this section, these parameters are discussed in detail.

3.1.1. Research Variables

- To determine the most effective w/c ratio that would give the required compressive strength besides, workability, water content, and superplasticizer dosages were varied.
- Control-mix and special-mix using Type-F superplasticizer were designed to produce concrete with a slump of 90±25 mm; based on the recommendation given on EBCS2-1995, for 25 mm nominal maximum size of aggregate. Slump tolerance limits stated on ASTM C94 were used.

- Special-mix with Type-G superplasticizer was designed to produce concrete to give slump of 150± 40 mm; based on slump tolerance limits stated on ASTM C94.
- Special-mixes were produced by reducing water content by 15%, 20%, and 25% for both Type-F and Type-G HRWRAs, and 30% using Type-F only.
- The cement content was also reduced by 15%, 20%, 25%, and 30%. W/c ratio is variable since slump was maintained and cement content was fixed.

Table 3.1.1. Summary of research design

Total trial-mixes (17)	Reference-mixes (2)
	Special-mixes (15)
Tests conducted	Slump
	Slump-loss (every 30 minutes for 2 hours)
	Compressive strength (3, 7 and 28 days)

3.1.2. Fixed Parameters

- The aggregates for all trial mixes were from a single lot of sound materials that conform to the requirements of ASTM C33.

3.1.3. Mix Proportioning Method

The amount of water, cement, coarse and fine aggregate was proportioned according to "*Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1)*" (43). Based on the mix-proportion of the control-mixes, the fine aggregate-to-total aggregate ratio was **fixed as 0.45 and 0.41 for C-30 and C-40** concrete mixes respectively**.** The addition of the HRWRAs was with the last 10-15% of mixing water. The mix-proportioning and mixing process will be discussed in detail in section 3.3.

3.2. Materials

To prepare concrete trial mixes, the following materials were used.

Table 3.2.1. Type of concrete ingredients used

Material	Type
Cement	Ordinary Portland Cement (OPC) class-42.5R
Fine Aggregate	River sand washed and air-dried before using
Coarse Aggregate	Crushed basalt stone
HRWRAs	Sulphonated naphthalene formaldehyde-based, Type-F, and Type-G according to ASTM C494 classification
Water	Tap water

Before mix proportioning the following tests were conducted to characterize aggregate properties.

Table 3.2.2. Test methods used to characterize concrete ingredients

Test	Applied test method
sieve analysis of fine and coarse aggregates	ASTM C136
relative density (specific gravity) and absorption of aggregate	ASTM C127 and ASTM C128
bulk density (unit weight) and voids in aggregate	ASTM C29

The specific gravity and absorption of the fine and coarse aggregates were determined using ASTM C128 and ASTM C127 respectively. These tests were conducted three times to observe accurate results. The gravimetric procedure was used to determine the specific gravity of the fine aggregates.

Table 3.2.3. Coarse and fine aggregate properties

Aggregate properties	Fine aggregate	Coarse aggregate
Air-dried specific gravity	2.38	2.8
Moisture content	6.6	0.2
Absorption capacity (%)	5	0.7
Dry rodded unit weight (kg/m^3)	1690	1630
Loss unit weight (kg/m^3)	1610	1470

Table 3.2.4. Fine aggregate sieve analysis test result

Sieve size	Weight retained (g)	% Retained	% Passing	Cumulative % retained
4.75 mm	0	0.0	100.0	0.0
2.36 mm	56	11.2	88.8	11.2
1.18 mm	129	25.9	62.9	37.1
600 µm	169	33.9	29.1	70.9
300 µm	80	16.0	13.0	87.0
150 µm	48	9.6	3.4	96.6
75 µm	17	3.4	0.0	100.0
pan	0	0.0	0.0	
Total	**499**	-	-	**302.8**

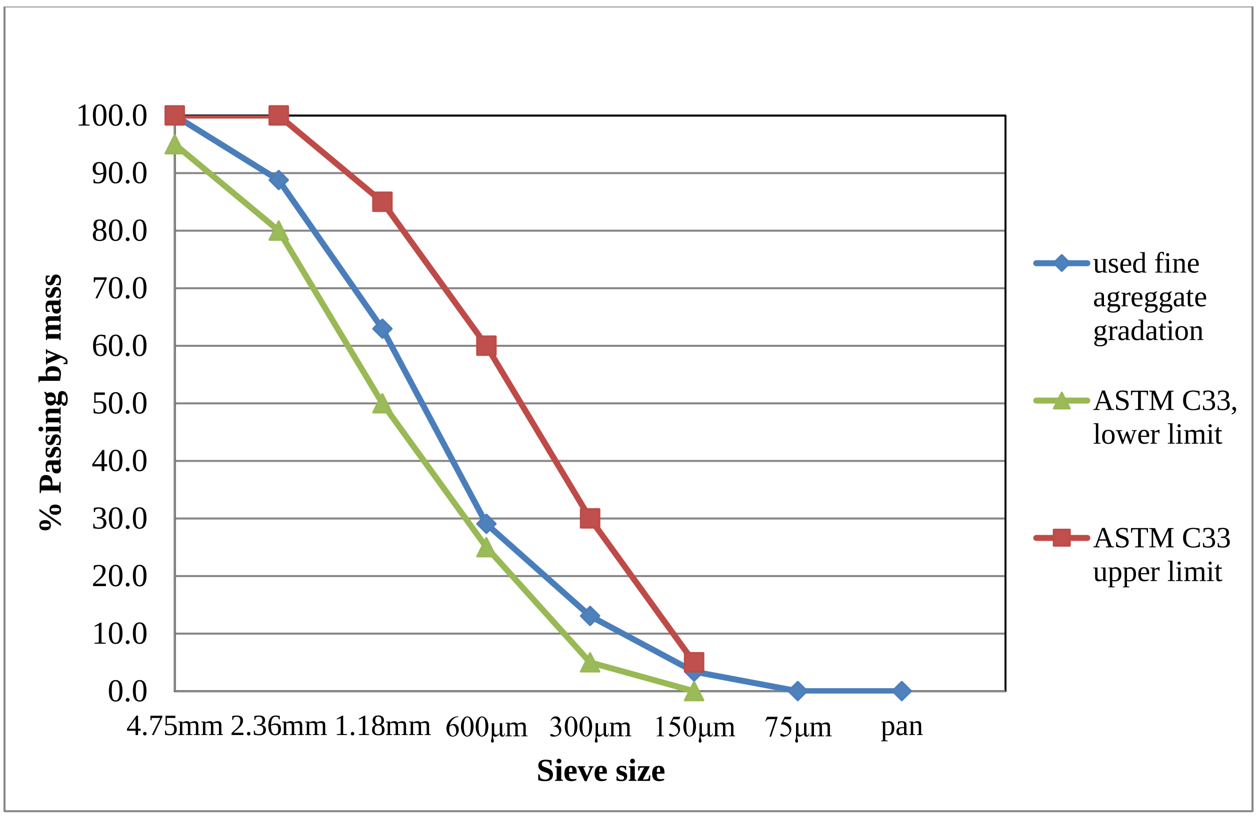

Fig. 3.2.1. Fine aggregate gradation conformance to ASTM C33 specification

Table 3.2.5. Coarse aggregate sieve analysis test result

Sieve size (mm)	Weight retained (g)	% Retained	% Passing	Cumulative % retained
37.5	0	0.0	100.0	0.0
25	662	13.2	86.8	13.2
19	834	16.7	70.1	29.9
12.5	1570	31.4	38.7	61.3
9.5	1155	23.1	15.6	84.4
4.75	758	15.2	0.4	99.6
	20	0.4	0.0	100.0
Total	**4999**	**100.0**	-	**388.5**

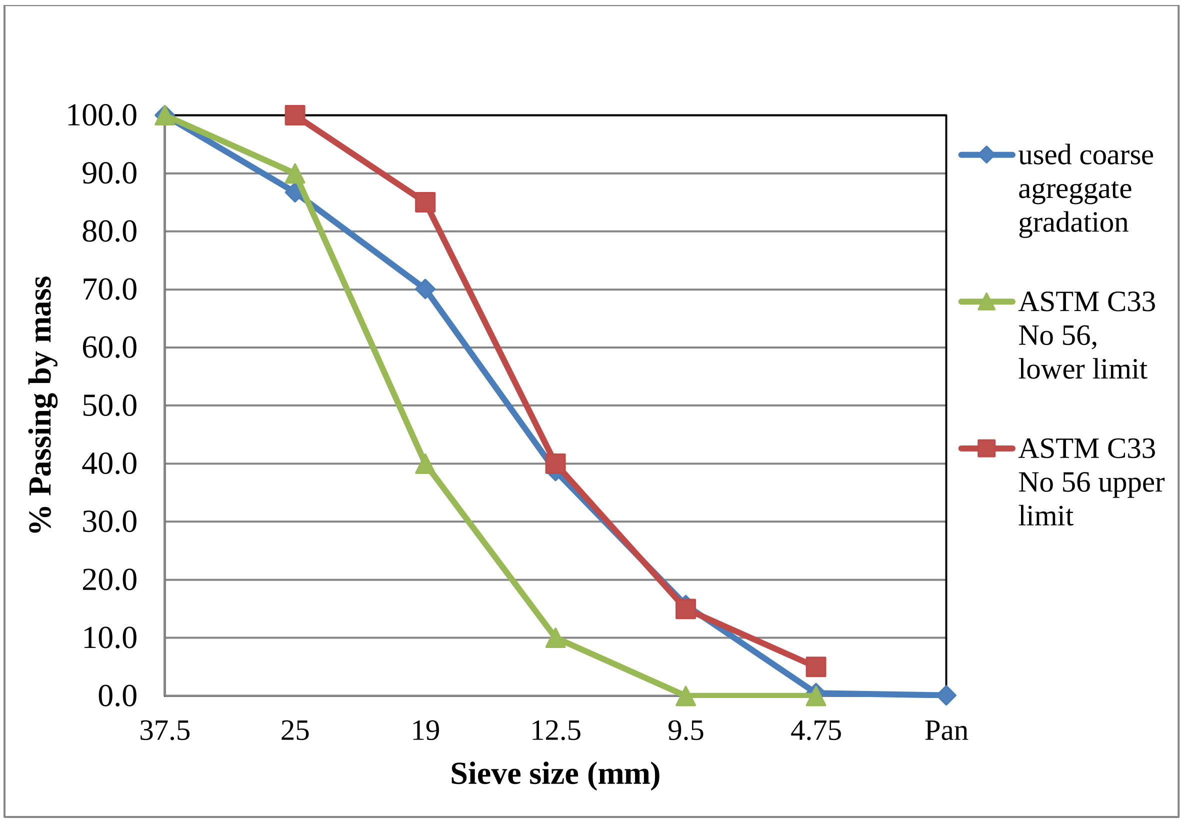

Fig. 3.2.2. Coarse aggregate gradation conformance to ASTM C33 specification

3.3. Mix Proportions

Mix proportioning was done following the procedures given in ACI 211, 2002 report.

- ***Step 1- Selecting slump and 28-day compressive strength***

As previously discussed slump being fixed as 90 mm and the specified 28 days 150 mm cubic specimen compressive strength (f'c) at 30 MPa and 40 MPa, the equivalent cylindrical (150 mm dia. × 300 mm) compressive strength was calculated based on the conversion factor given in EBCS2-1995, Table 2.2, which is 1.25. The respective required compressive strength was therefore calculated as follow:

$f'c$ (cylindrical)= $f'c$ (cube)/1.25= 30/1.25=24 MPa and 40/1.25=32 MPa

$f'cr$ = $f'c$ +8.5= 24+8.5=32.5 MPa and 32+8.5=40.5 MPa

Where: $f'c$ - specified compressive strength and;

$f'cr$ - required compressive strength

- ***Step 2- Choice of the nominal maximum size of aggregate***

As can be seen from the sieve analysis test result the nominal maximum size of coarse aggregate was 25 mm.

- ***Step 3- Estimation of mixing water***

According to ACI 211.1 Table A1.5.3.3, for nominal maximum size of 25 mm coarse aggregate and 90 mm slump, the estimated water content is 193 kg/m^3 and approximated entrapped air 1.5%.

- ***Step 4- Selection of w/c***

From ACI211.1 Table A1.5.3.4 (a) for 32.5 and 40.5 MPa 28th day compressive strength, the w/c were estimated by interpolation and found as *0.505* and *0.415* respectively.

- ***Step 5- Calculation of cement content***

The respective estimated cement contents for 32.5 and 40.5 MPa concretes were 382 kg and 465 kg per cubic meter of concrete.

- ***Step 6- Estimation of coarse aggregate content***

From ACI211.1 Table A1.5.3.6, for the nominal maximum size of 25 mm coarse aggregate and 3.00 fineness modulus of fine aggregate, the volume of dry-rodded coarse aggregate per unit volume of concrete equals 0.65 m^3.

Therefore, the weight of coarse aggregate= 0.65 m^3*1630 kg/m^3 =1059.5 kg

- ***Step 7- Estimation of fine aggregate content***

With cement 382 kg and 465 kg for C-30 and C-40 concrete respectively, water 193 kg, and 0.65 m^3 coarse aggregate quantities established, and the approximate entrapped air content of 1.5% determined in step 3. The sand content was calculated by dividing the mass of an ingredient by density of water and its specific gravity as shown below and summarized on Table 3.3.1. and 3.3.2.:

$$\text{Volume of water } = \frac{193}{1000} = 0.193$$

$$\text{Volume of cement} = \frac{382}{1000 * 3.15} = 0.121, \qquad \frac{465}{1000 * 3.15} = 0.148$$

$$\text{Volume of coarse aggregate} = \frac{1059.5}{1000 * 2.8} = 0.378$$

Table 3.3.1. Mix-proportion of ingredients for 1 m^3 of concrete

Mix-Constituents	**Volume C-30 (m^3)**	**Volume C-40 (m^3)**
Cement	0.121	0.148
Water	0.193	0.193
Entrapped air	0.015	0.015
Coarse aggregate	0.378	0.378
Total	0.708	0.734
Fine aggregate	=1-0.708=0.292	1-0.734=0.266

Table 3.3.2. Weight of concrete constituents before moisture adjustment

Ingredient	**Weight C-30 (kg)**	**Weight C-40 (kg)**
Cement	382	465
Water	193	193
Coarse aggregate (Air Dried)	1060	1060
Fine aggregate (Air Dried)	696	633

- ***Step 8- Adjustment of water and aggregate content***

In coarse aggregate for moisture-content 0.7 and absorption capacity 0.28%

Deduct water = (0.28-0.7) % * 1060= -4.45 kg

Added coarse aggregate= (0.7-0.28) % * 1060= 4.45 kg

In fine aggregate for moisture content 6.6% and absorption capacity 5%

Deduct water in C-30= (5-6.6) % * 696= -11.14 kg

C-40= (5-6.6) % * 633= -10.13 kg

Deduct fine aggregate in C-30= (6.6-5) * 696 = 11.14 kg

C-40 = (6.6-5) * 633 = 10.13 kg

Table 3.3.3. Mix-proportions for 1 m^3 of control concrete mixes after moisture adjustment

Constituents	C-30 Weight (kg)	C-40 Weight(kg)
Cement	382.00	465.00
Water	177.41	178.42
Coarse aggregate	1064.45	1064.45
Fine aggregate	707.14	643.13
Total	2331.00	2351.00

Based on the above estimation the concrete trial mix proportions were scaled down to 0.04 m^3.

The special-mix proportions were proportioned by reducing the cement and water contents by 15, 20, 25, and 30%. These reduced masses were substituted by adding aggregates to keep concrete yield constant. The additions of aggregates were done by keeping fine aggregate to total aggregate volume ratio constant, which is 0.45 for C-30 and 0.41 for C-40 concretes.

3.4. Mixing, Specimen Preparation, Curing and Testing Techniques

3.4.1. Mixing

The mixing process was started by combining all the weighted ingredients in the mixer except water and the superplasticizer and dry mixing for 3 min. Then 50% of the mixing water was added and mixed for another 3 min. Finally, the rest of the water was added little at a time to maintain the required slump.

In the special-mixes (with superplasticizers) the reserved 50% mixing water was added after being mixed with the superplasticizer solution which was made by deducting 1 kg water from the estimated mixing water for dissolving the superplasticizer. The rest of the mixing water was added little at a time until the specified workability was achieved. The naming of trial mix samples is given as shown in the table below (Table 3.4.1).

Table 3.4.1. Trial mix samples name

Mix-ID symbols *(left to right)*	**Symbol**	**Meaning**
1^{st}	R	Reference-mix
	S	Special-mix
2^{nd}	3	C-30
	4	C-40
3^{rd}	15	15% cement reduction
	20	20% cement reduction
	25	25% cement reduction
	30	30% cement reduction
4^{th}	F	Type-F HRWRA
	G	Type-G HRWRA

Table 3.4.2. Trial mix proportions

*Mix ID	Trial batch quantities in (kg)								
	Cement	Sand	Coarse aggregate	Water		w/c	HRWRA	HRWRA %	Actual yield (m^3)
				estimated	**used				
R3	15.28	28.29	42.58	7.09	8.05	0.527	0	0	0.0400
S3-15F	12.99	31.36	46.18	6.13	5.92	0.456	0.130	1.0	0.0397
S3-20F	12.22	31.12	47.39	5.78	5.28	0.432	0.134	1.1	0.0392
S3-25F	11.46	31.83	48.59	5.318	4.89	0.427	0.138	1.2	0.0393
S3-30F	10.70	32.53	49.79	4.96	6.26	0.585	0.139	1.3	0.0411
S3-15G	12.99	31.36	46.18	6.19	6.56	0.505	0.195	1.5	0.0404
S3-20G	12.22	31.12	47.39	5.82	5.56	0.455	0.183	1.5	0.0394
S3-25G	11.46	31.83	48.59	5.46	6.08	0.530	0.172	1.5	0.0404
R4	18.6	25.7	42.58	7.14	7.67	0.412	0	0	0.0396
S4-15F	15.81	27.78	46.7	6.20	6.32	0.400	0.158	1.0	0.0397
S4-20F	14.88	28.48	48.07	5.85	5.6	0.376	0.164	1.1	0.0395
S4-25F	13.95	29.17	49.45	5.49	4.98	0.357	0.167	1.2	0.0393
S4-30F	13.02	29.86	50.82	5.14	5.37	0.412	0.169	1.3	0.0402
S4-15G	15.81	27.78	46.7	6.20	5.85	0.370	0.237	1.5	0.0392
S4-20G	14.88	28.48	48.07	5.85	5.6	0.376	0.223	1.5	0.0395
S4-25G	13.95	29.17	49.45	5.49	5.25	0.376	0.209	1.5	0.0396
S4-15G	14.88	28.48	48.07	5.85	7.66	0.515	0.149	1.0	0.0415

* For Mix-ID, see Table 3.4.1

** Used water content is the adjusted volume of water by visually inspecting and conducting slump test while making trial batches in the laboratory.

3.4.2. Specimen Preparation

Three 150 mm cube specimens were prepared for each 3, 7 and 28-day compressive strength tests. Compactions for the specimen were done using a vibrating table. The applied duration of vibration depends on the slump of concrete. Vibration is applied until the concrete becomes relatively smooth and large air bubbles stop showing up on the top surface. Slump loss was measured in a 30-minute interval for 2 hours.

3.4.3. Curing

The cube specimen was taken out of the molds after 24 hours and cured by soaking in water until the testing date. The mixing and curing were done under constant temperature (18-20) ^{o}C.

3.4.4. Testing

Three specimens for each 3, 7 and 28-day compressive strength tests were taken out of the water and dried using a towel, then their respective weights and compressive strengths were tested.

The compressive-strength testing machine has 3,000 KN capacity. The rate of loading 0.28 MPa/sec was used.

Chapter- Four

Results, Analysis and Discussion

In this chapter, the study findings are reported, analyzed, and discussed based on the laboratory test results of 17 concrete mixtures having different cement content and superplasticizer dosage. This study aimed to investigate if significant cost reduction can be made using HRWRAs without affecting the desired slump and compressive strength properties of a concrete mixture. Therefore, the slump, slump-loss, and compressive strength properties of the trial concrete mixtures are discussed.

4.1. Slump and Rate of Slump-loss

As described in section 3.1.1. Research Variables, the initial slump of control and special mix concrete with Type-F superplasticizer is limited to be 90 ± 25 mm. Therefore, the investigation on slump was focused on the dosage of HRWRA related to mixture water consumption to produce concrete that satisfies the stated slump requirement.

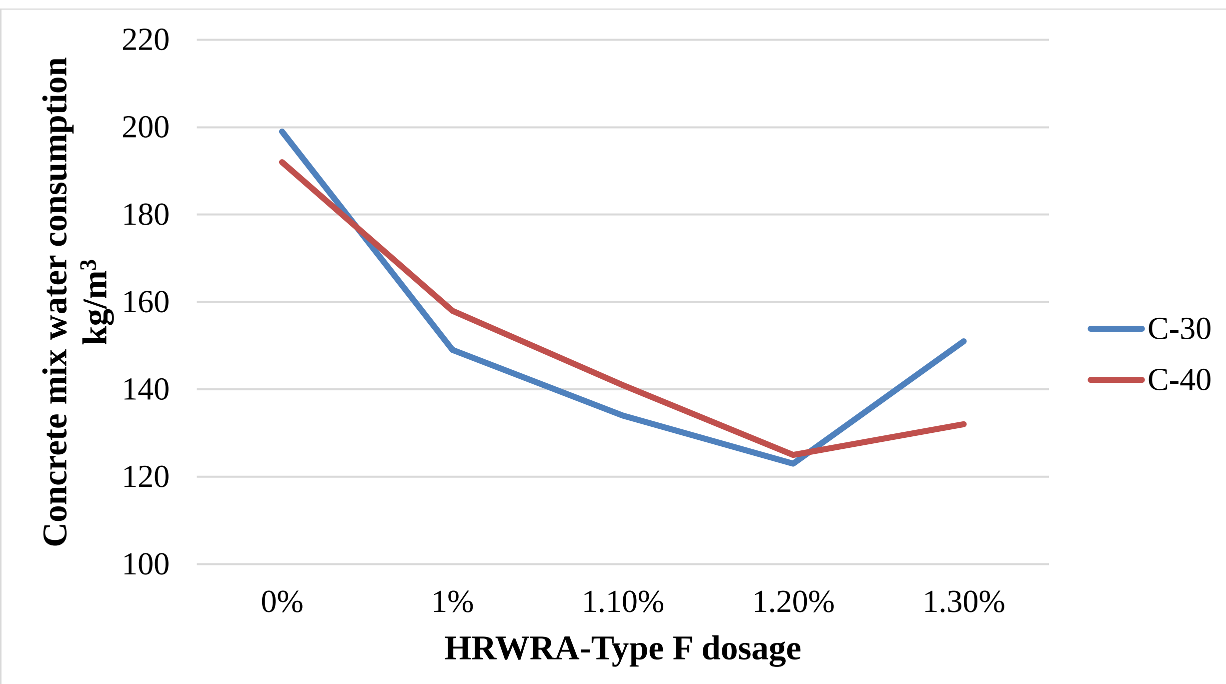

Fig. 4.1.1. Water consumption versus Type-F HRWRA dosage

Hence, it was observed that as the dosage of HRWRA (Type-F) increases the required quantity of mixing water to get a similar slump decreased until 1.2% dosage. At HRWRA dosage of 1.3%, the water consumption has increased. This may indicate adding more HRWRA above the optimum dosage does not improve the workability of concrete. This result agrees with the ACI 212, adding more HRWRA above the manufacturer's recommendation provide no additional slump increase. Here it is also important to note that cement-admixture compatibility is a crucial factor that determines the optimum water-reducer dosage.

Table 4.1.1. Slump and slump-loss test results

*Mix ID	Quantities						Slump (mm) at time (min)				
	Cement kg/m^3	Sand kg/m^3	Coarse aggregate kg/m^3	Water kg/m^3	w/c	HRWRA (Lt/m^3)	0	30	60	90	120
R3	382	707	1065	201	0.527	0.00	80	70	60	50	35
S3-15F	327	790	1163	149	0.456	3.27	110	90	40	25	10
S3-20F	312	795	1210	135	0.432	3.43	115	85	40	20	0
S3-25F	292	811	1238	125	0.427	3.50	75	60	25	20	0
S3-30F	260	791	1211	152	0.585	3.38	85	70	30	20	15
S3-15G	322	777	1144	163	0.505	4.83	170	170	150	110	70
S3-20G	310	789	1202	141	0.455	4.65	160	145	120	90	65
S3-25G	283	787	1201	150	0.530	4.25	120	120	110	90	70
R4	470	649	1076	194	0.412	0.00	85	75	60	40	25
S4-15F	398	700	1177	159	0.400	3.98	115	65	10	0	0
S4-20F	377	722	1218	142	0.376	4.15	100	55	20	0	0
S4-25F	355	742	1257	127	0.357	4.26	90	60	30	5	0
S4-30F	324	743	1264	134	0.412	4.21	85	55	30	10	0
S4-15G	403	708	1191	149	0.370	**6.05**	170	160	145	90	80
S4-20G	377	722	1218	142	0.376	5.66	160	160	155	110	90
S4-25G	352	737	1249	133	0.376	5.28	170	170	160	120	65
S4-15G	358	686	1158	184	0.515	**3.58**	145	145	140	65	20

* For Mix-ID, see Table 3.4.1

In this study two rate of slump loss controlling factors were considered: one being cement content and the other superplasticizer dosage. According to literature, (see section 2.4.1) the effect of cement content on the rate of slump loss depends on several factors such as ambient temperature, initial slump, type of cement, aggregate moisture condition, and so on. In this study, the rate of slump loss is investigated under laboratory conditions (18-20) ^{o}C with OPC-42.5R type of cement and controlled initial slump.

The effect of the initial slump on the rate of slump loss is illustrated in the graphs 4.1.2 to 4.17.

As the initial slump of concrete increases, the rate of slump loss also increased. SNF HRWRAs that are not formulated with retarding effects have shown slump loss higher than the control mixes. This effect is expected.

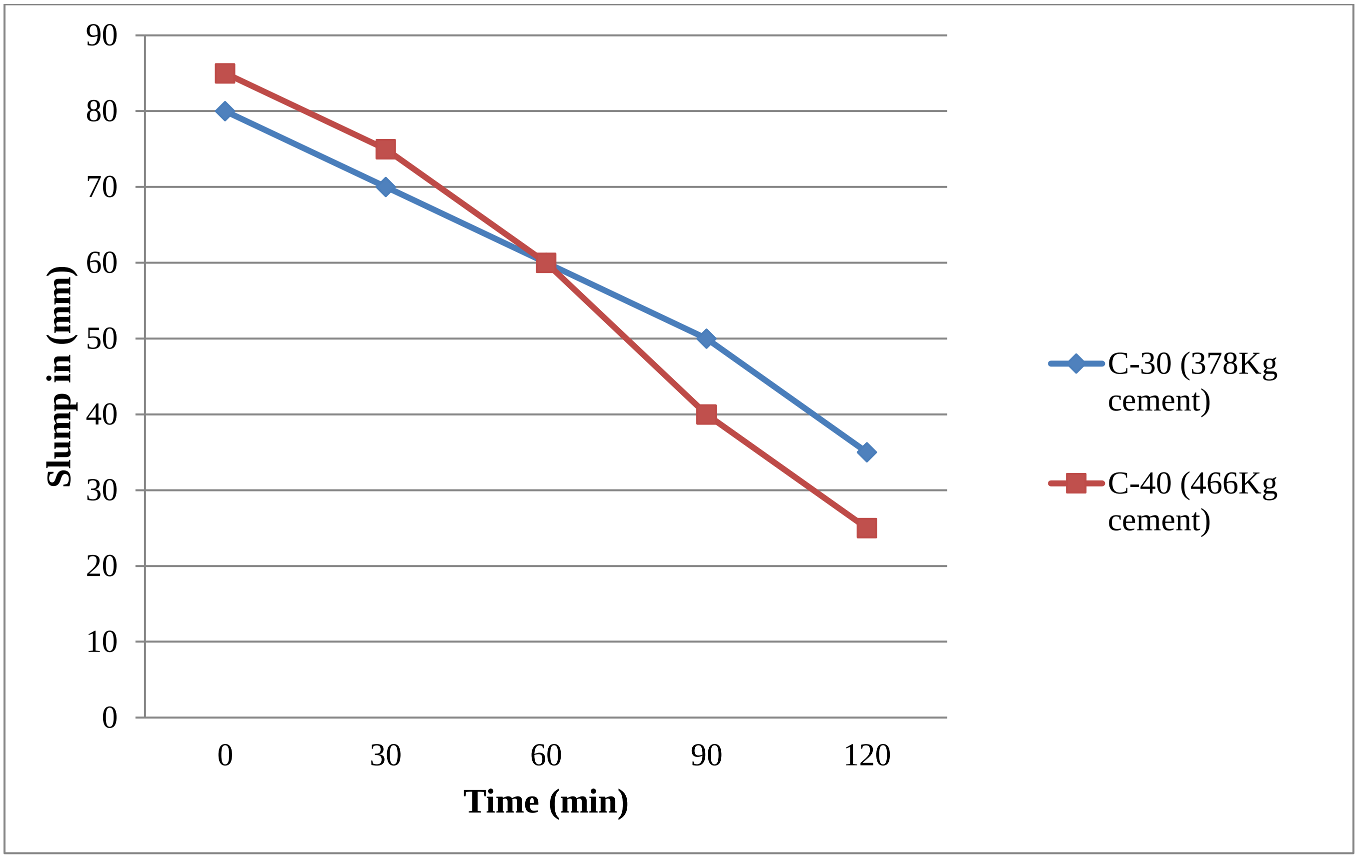

Fig. 4.1.2. Slump loss in C-30 and C-40 control mixes

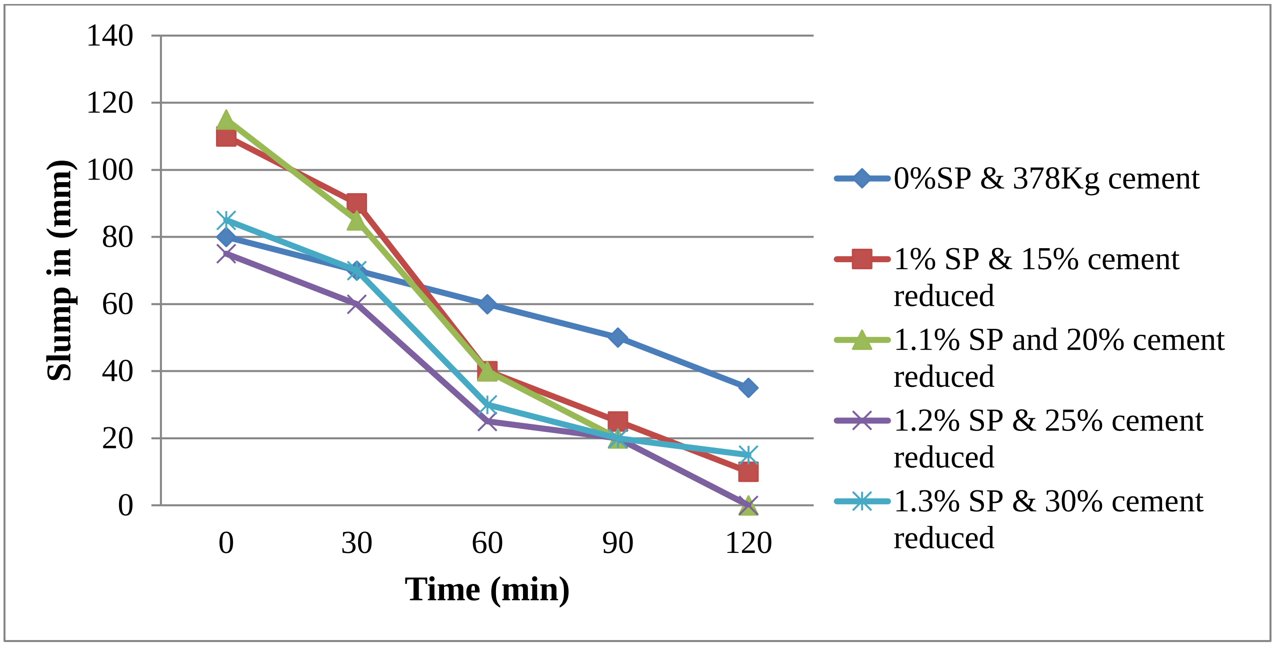

Fig. 4.1.3. Slump loss in C-30 concrete mix with and without Type-F HRWRA

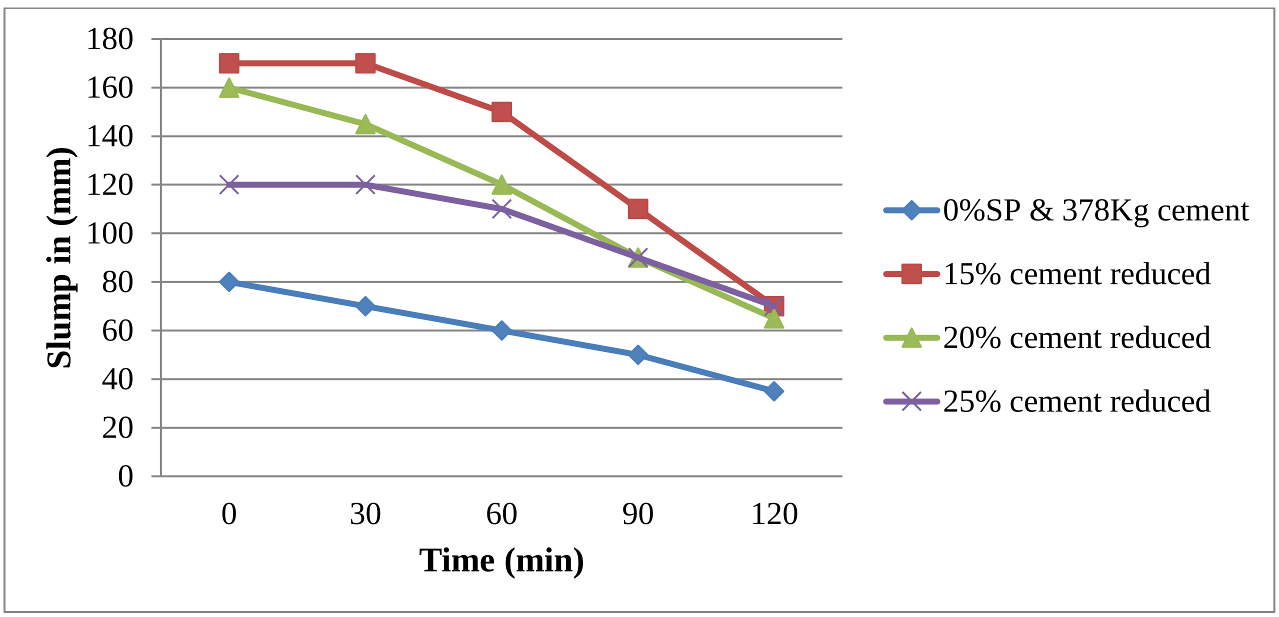

Fig. 4.1.4. Slump loss in C-30 concrete mix with and without Type-G HRWRA

As can be seen from the above graphs, using superplasticizer with retarding formulation has significantly improved the rate of slump loss *(for similar initial slump -120 mm, the concrete mix with Type-F HRWRA lost its initial slump by 80 mm after an hour; wherewith Type-G HRWRA only 10 mm loss was recorded).*

In concrete mixes with high initial slump the rate of slump loss was also higher *(the concrete mix with initial slump 170 mm lost 60% of its initial slump after 2 hr where the 120 mm initial slump the loss was 45% only).*

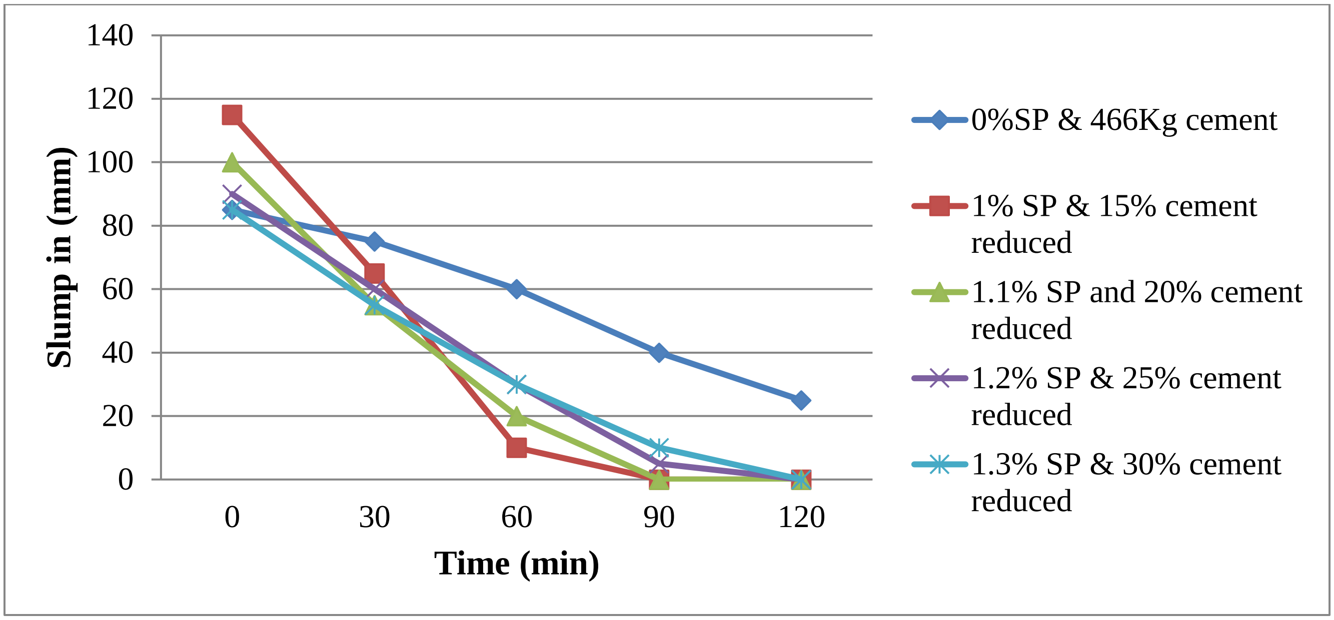

Fig. 4.1.5. Slump loss in C-40 concrete mix with and without Type-F HRWRA

The rate of slump loss in C-40 concrete mixtures showed more or less similar pattern to that of C-30 concrete. The concrete lost 100% of its initial slump after 90 min in C-40 concrete. However, in the case of C-30 mixes, this time was longer around 120 min. Besides, in C-30 concrete mixtures, the initial slump loss of the reference and special trial mixes for the first 30 minutes is maximum 15 mm, but it was around 35 mm with C-40. This might be due to higher cement content in the C-40 concrete mix.

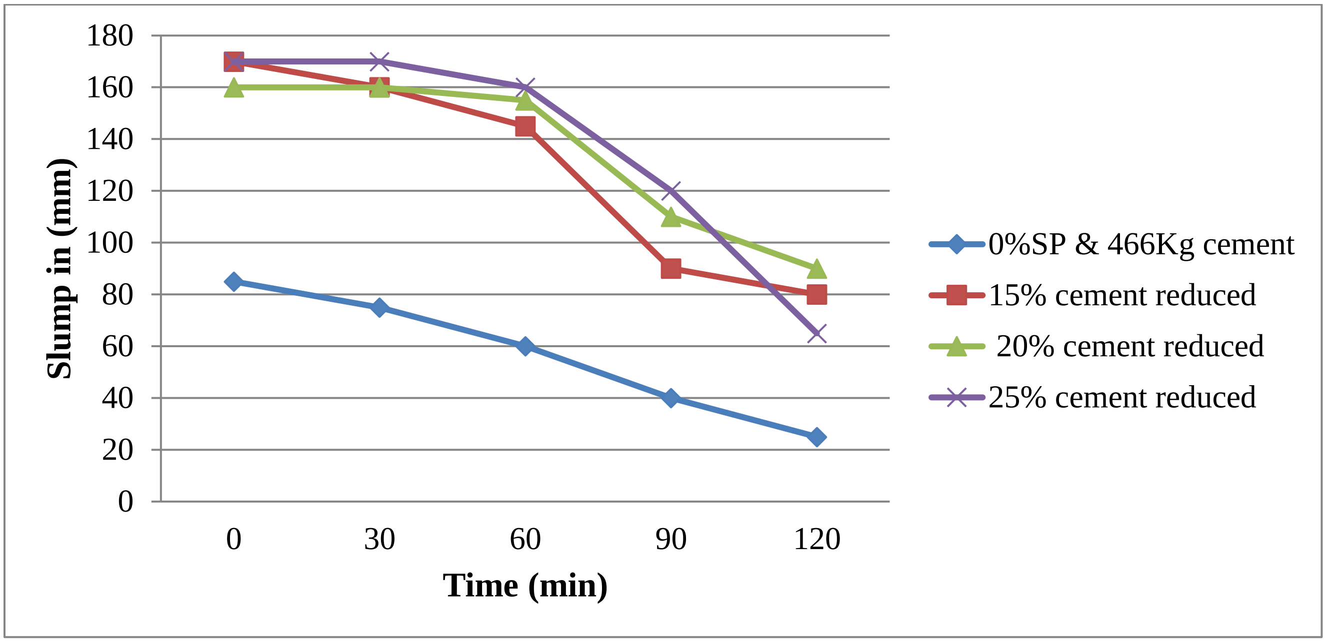

Fig. 4.1.6 Slump loss in C-40 concrete mix with and without 1.5% Type-G HRWRA

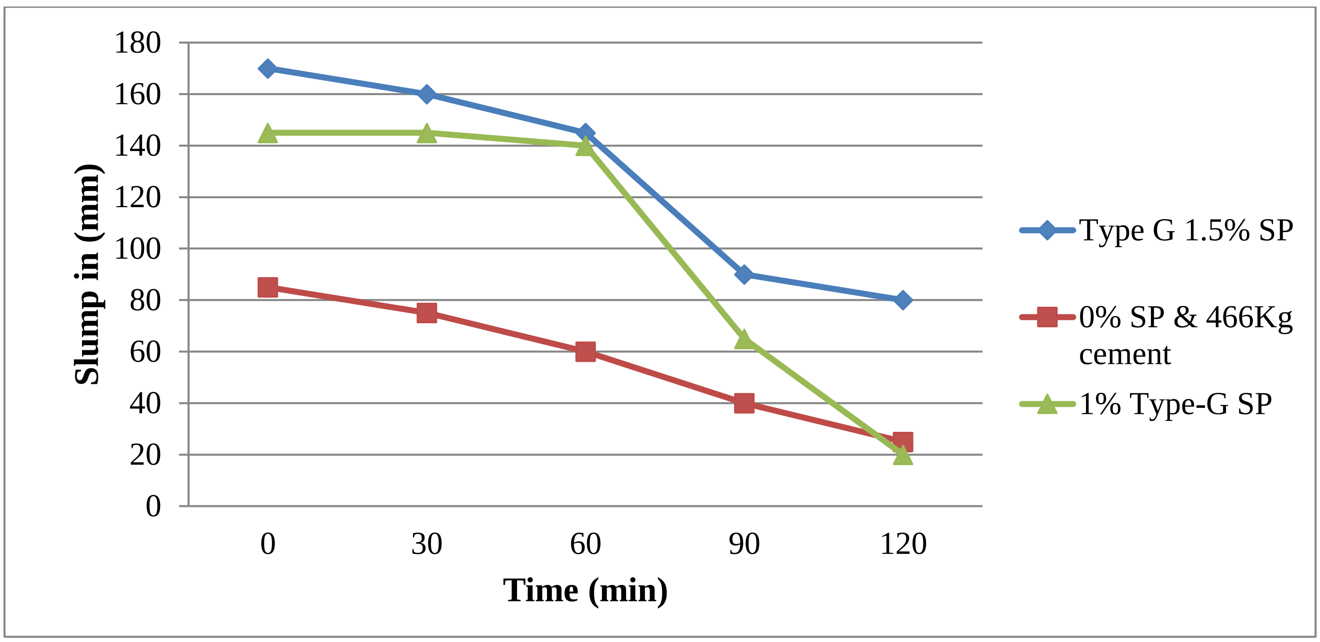

Fig. 4.1.7 Slump loss in C-40 concrete with 1% and 1.5 % Type-G HRWRA and 15% cement reduced mix

The different dosages and types of HRWRA and compatibility with the type and brand of cement used in concrete mixtures significantly affect its rate of slump loss property. However, the tolerance limit of this property depends on the application, mixing, and transporting method of concrete. The slump loss property of concrete mixtures is highly affected by ambient conditions when it is delivered and placed.

Though the use of Type-F HRWRA enabled to produce concrete with similar slump and less water content, which improved compressive strength for less cost, the workability was short-lived than both the reference and Type-G HRWRA mixes. Therefore, when longer slump retaining property of concrete is required, it is recommended that the mixture optimization is done using Type-G HRWRA or on the job site addition of Type-F HRWRA. Using the correct amount of mixing water and cement is needed to achieve the specified slump within tolerances at the job site in consideration of ambient temperature and delivery time.

4.2. Compressive Strength

The compressive strength of concrete primarily depends on the w/c of the mixture. Accordingly, the 28th day compressive strength test results of this study also showed that concrete mixes with equal w/c give similar compressive strength regardless of the dosage of HRWRA. (*28th day compressive strength of C-40- reference mix is 42.19 MPa where concrete mix with 1.3% Type-F HRWRA with 30% less cement content gave 41.45 MPa for an equal slump of 85 mm and w/c of 0.412*). In the C-30 type of concrete, 30% cement-reduced with 1.3% of Type-F HRWRA, the w/c was higher than the reference mix. This may be due to low paste and high aggregate content, which required more water to give a similar slump (80 mm). Qualitatively speaking, the 30% cement reduced C30 concrete mix looked harsh. (*28th day compressive strength of C-30 reference mix was 35.86 MPa where the concrete mix with 1.3% Type-F HRWRA with 30% less cement content gave 28.54 MPa for 80 mm slump*). According to the technical data sheet of the HRWRA used in this study, the admixture has a water reduction capacity of 25%. Practically, it enabled to reduce by 30% in C-40 concrete mixture. Therefore, it is important to note that only tests can tell the maximum water reduction capacity of a water-reducer for a given cement and water reducer combination.

Table 4.1.2. Compressive strength test results

Mix ID	Quantities						Average compressive strength (MPa), test ages (days)		
	Cement kg/m³	Sand kg/m³	Coarse aggregate kg/m³	Water kg/m³	w/c	HRWRA (Lt/m³)	3	7	28
R3	382	707	1065	201	0.527	0.00	19.53	25.38	35.86
S3-15F	327	790	1163	149	0.456	3.27	18.11	27.94	37.41
S3-20F	312	795	1210	135	0.432	3.43	20.61	28.91	40.57
S3-25F	292	811	1238	125	0.427	3.50	22.49	32.89	44.81
S3-30F	***260***	791	1211	152	***0.585***	3.38	15.06	21.15	***28.54***
S3-15G	***322***	777	1144	163	***0.505***	4.83	21.24	28.16	***33.72***
S3-20G	310	789	1202	141	0.455	4.65	21.41	32.59	39.91
S3-25G	283	787	1201	150	0.530	4.25	25.38	29.96	35.53
R4	***470***	649	1076	194	***0.412***	0.00	25.15	29.98	***42.19***
S4-15F	398	700	1177	159	0.400	3.98	29.24	36.00	47.55
S4-20F	377	722	1218	142	0.376	4.15	25.84	40.35	50.15
S4-25F	355	742	1257	127	0.357	4.26	29.30	45.68	51.03
S4-30F	***324***	743	1264	134	***0.412***	4.21	21.99	30.70	***41.45***
S4-15G	403	708	1191	149	0.370	6.05	38.49	43.57	55.00
S4-20G	377	722	1218	142	0.376	5.66	36.66	42.15	50.54
S4-25G	352	737	1249	133	0.376	5.28	34.07	39.80	49.29
S4-15G	***358***	686	1158	184	***0.515***	3.58	20.02	33.92	***42.70***

* For Mix-ID, see Table 3.4.1

* The underlined test results are lower than the compliance criteria of EBCS

According to EBCS2-1995, the expected average 28th day compressive strength of C-30 and C-40 types of concrete is 35 MPa and 45 MPa respectively. Therefore, among the 17 mixes, 12 only satisfied the compliance criteria. This means additional cement and/or HRWRA is required to bring those mixes to satisfactory strength, since constant slump is maintained lowering the water content only may not help. For instance, the highest w/c that gave satisfactory compressive strength in the C-40 class of concrete is w/c of 0.4. To lower R4 mix w/c to 0.4 from 0.412, reducing the water content by 6 kg or adding more than 15 kg of cement is required depending on the slump.

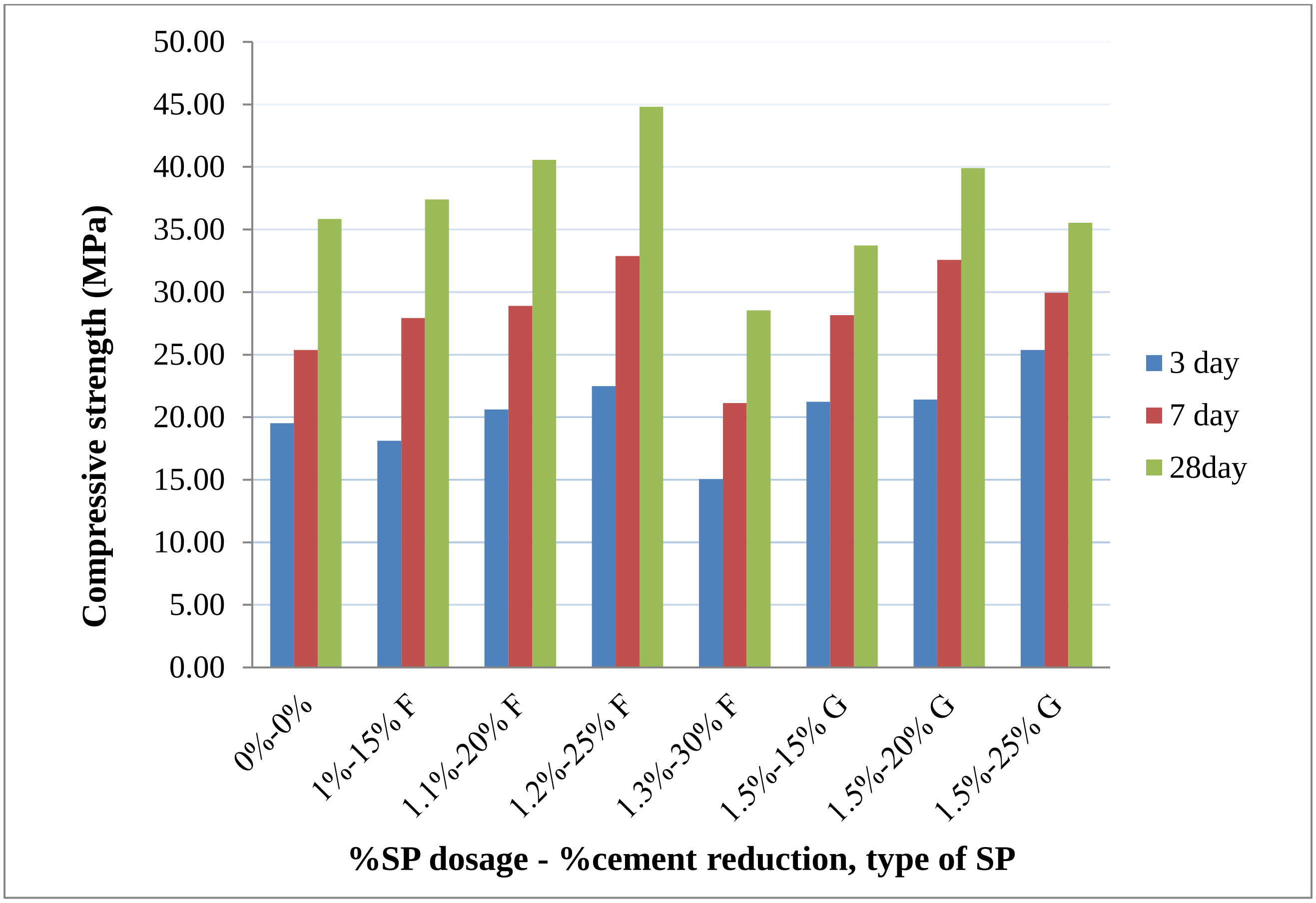

Fig. 4.2.1. Compressive strength for C-30 concrete mix with and without Type-F and Type-G HRWRA

In the C-30 mix with Type-F HRWRA, in every 0.1% dosage increment and an additional 5% cement reduction, 1 to 1.6 MPa increase in 28-day compressive strength was recorded. In Type-G HRWRA 20% cement reduction, using a 1.5% dosage gave the highest compressive strength value. Despite higher dosage (1.5%), the Type-G HRWRA did not result in higher strength compared to the Type-F and this may be because of the presence of retarding molecules for dual effect (water reduction and retardation) and/or the higher dosage used to retain slump for about 1 hour.

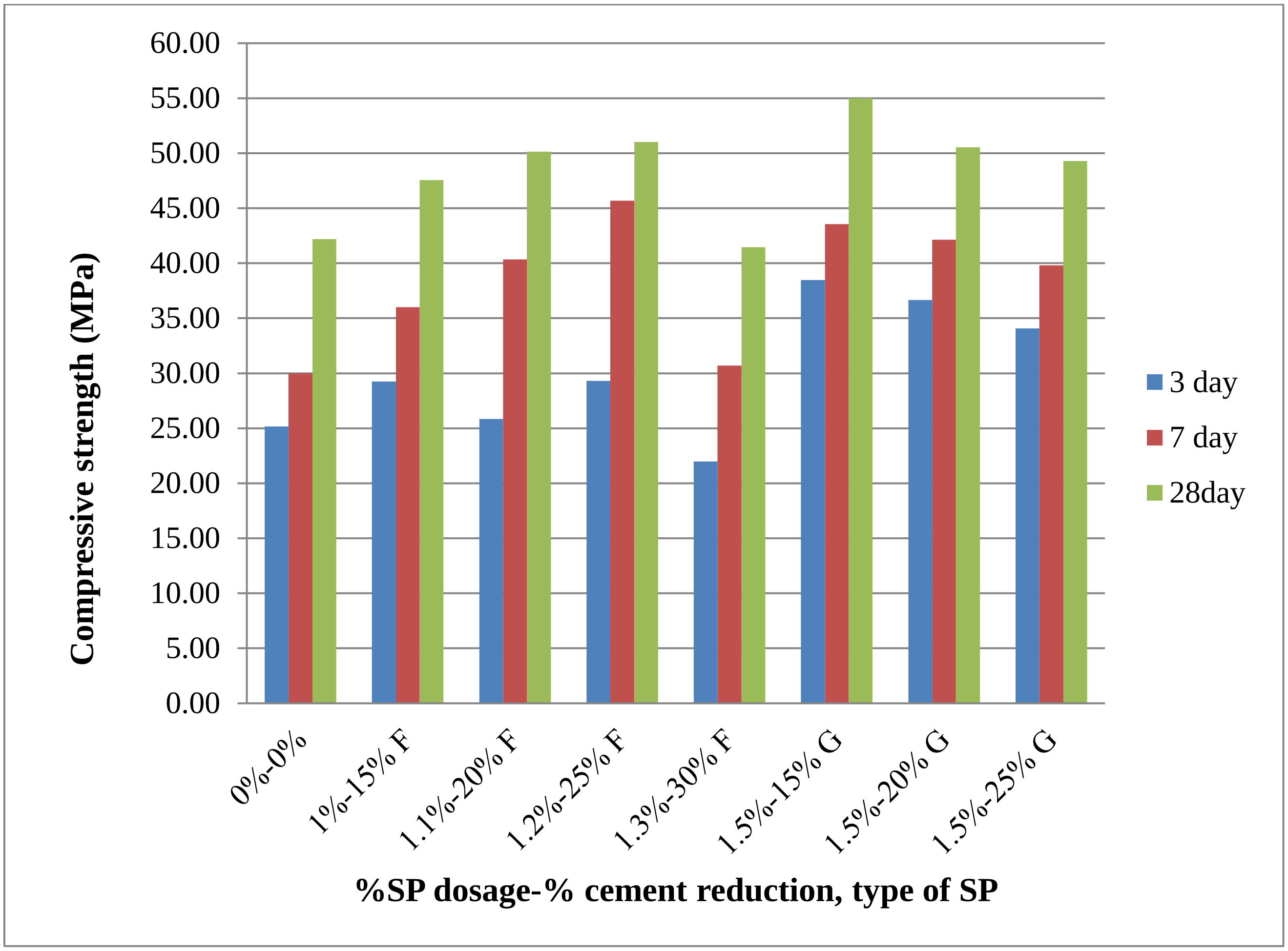

Fig. 4.2.2. Compressive strength for C-40 concrete mix with and without Type-F and Type-G HRWRA

As can be seen in the above graph, the compressive strength with Type-F HRWRA increased as the cement content decreased and the admixture dosage increased. However, this continued until the optimum dosage is achieved. This is also true for mixes with Type-G HRWRA.

With 1.5% Type-G HRWRA, the observed compressive strength results agree with ACI, that is as the cement content of concrete mixture increases, the required dosage of HRWRA by mass of cement is reduced. (See section 2.5.1)

Table 4.1.3. Comparison table for C-40 concrete mix with and without Type-G HRWRA

Mix ID	Cement kg/m^3	Water kg/m^3	W/C	Type-G HRWRA (dosage %)	Slump at time (0 min)	Slump at time (120 min)	28th day Compressive strength (MPa)
R4	470	194	0.412	0	85	0	42.19
S4-15G	403	149	0.370	1.5%	170	80	55.00
S4-15G	358	184	0.515	1%	145	20	42.7

The above table shows how much concrete strength will be affected by achieving workability through the addition of more water into the mix. Not to mention that the added water did not improve the slump compared with 1.5% HRWRA Type-G added mixture which gave a better slump (170 mm initially), with 50% slump retention after 2 hr.

Reducing cement content of concrete mixtures using HRWRAs improves the compressive strength property. For every class of concrete, there is distinct optimum cement and HRWRA dosage combination that gives the highest compressive strength value. Test and only test can tell that since results depend on the concrete ingredients individual and combined characteristics.

4.3. Cost Optimization

By definition, optimization is the action of making the best or most effective use of a situation or resource. Therefore, in the case of concrete mix, ***cost optimization means***, minimizing the cost of the concrete mixture while maximizing the desired performance criteria. Mostly the performance criteria are workability, strength, and durability. In this experimental research slump, slump-retaining and compressive strength properties are investigated to select the optimum concrete mixture.

4.3.1. Cost Analysis

The cost analysis is done based on construction materials price on May 2018 in Addis Ababa. Loading and unloading costs are not included.

Table 4.3.1. Price of concrete ingredients in Addis Ababa on May 2018

Constituents	Unit	Price (Birr)/ unit
Cement (OPC-42.5R)	qt	360
Sand	m^3	560
Gravel 02	m^3	550
Water	m^3	0.4
HRWRA Type-F	Lt	48
HRWRA Type-G	Lt	45

Table 4.3.2 Cost analysis per 1 m^3 of concrete

Mix ID	Batch quantities					Cost per cubic meter (ETB)
	Cement (kg)	Sand (m^3)	Coarse aggregate (m^3)	Water (m^3)	HRWRA (Lt)	
R3	382	0.30	0.38	0.20	0.00	1,751.03
S3-15F	327	0.33	0.42	0.15	3.27	1,748.65
S3-20F	312	0.33	0.43	0.13	3.43	1,713.28
S3-25F	292	0.34	0.44	0.12	3.50	1,653.08
S3-30F	260	0.33	0.43	0.15	3.38	1,523.31
S3-15G	322	0.33	0.41	0.16	4.83	1,783.69
S3-20G	310	0.33	0.43	0.14	4.65	1,746.68
S3-25G	283	0.33	0.43	0.15	4.25	1,632.55
R4	470	0.27	0.38	0.19	0.00	2,055.93
S4-15F	398	0.29	0.42	0.16	3.98	2,021.09
S4-20F	377	0.30	0.44	0.14	4.15	1,965.89
S4-25F	355	0.31	0.45	0.13	4.26	1,902.94
S4-30F	324	0.31	0.45	0.13	4.21	1,791.24
S4-15G	403	0.30	0.43	0.15	**6.05**	2,123.92
S4-20G	377	0.30	0.44	0.14	5.66	2,021.33
S4-25G	352	0.31	0.45	0.13	5.28	1,924.84
S4-15G	358	0.29	0.41	0.18	**3.58**	1,840.42

4.3.2. Cost versus Performance

The cheapest does not always represent the best. Therefore, it is very crucial to set performance criteria for the required fresh and hardened concrete properties before investigating the optimum mix proportion. In this study, slump and 28th day compressive strength properties were set as performance criteria. Slump-loss was not included because different slump requirements at the time of placing could be specified depending on the application of the concrete.

Table 4.3.3 Cost saving per a cubic meter and concrete properties

	Concrete properties									
	Average compressive strength in MPa at age (days)			Slump (mm) at time (min)						
Mix ID	**3**	**7**	**28**	**0**	**30**	**60**	**90**	**Cost per cubic meter (ETB)**	**Cost-saving compared to reference mix (ETB)**
R3	19.53	25.38	35.86	80	70	60	50	1,751.03	
S3-15F	18.11	27.94	37.41	110	90	40	25	1,748.65	2.38
S3-20F	20.61	28.91	40.57	115	85	40	20	1,713.28	37.75
****S3-25F***	***22.49***	***32.89***	***44.81***	***75***	***60***	***25***	***20***	***1,653.08***	***97.95***
****S3-30F**	15.06	21.15	28.54	85	70	30	20	1,523.31	227.72
S3-15G	21.24	28.16	33.72	170	170	150	110	1,783.69	-32.66
S3-20G	21.41	32.59	39.91	160	145	120	90	1,746.68	4.35
****S3-25G***	***25.38***	***29.96***	***35.53***	***120***	***120***	***110***	***90***	***1,632.55***	***118.48***
****R4**	25.15	29.98	42.19	85	75	60	40	2,055.93	
S4-15F	29.24	36.00	47.55	115	65	10	0	2,021.09	34.84
S4-20F	25.84	40.35	50.15	100	55	20	0	1,965.89	90.04
****S4-25F***	***29.30***	***45.68***	***51.03***	***90***	***60***	***30***	***5***	***1,902.94***	***152.99***
****S4-30F**	21.99	30.70	41.45	85	55	30	10	1,791.24	264.69
S4-15G	38.49	43.57	55.00	170	160	145	90	2,123.92	-67.99
S4-20G	36.66	42.15	50.54	160	160	155	110	2,021.33	34.60
****S4-25G***	***34.07***	***39.80***	***49.29***	***170***	***170***	***160***	***120***	***1,924.84***	***131.09***
****S4-15G**	20.02	33.92	42.70	145	145	140	65	1,840.42	215.51

* Selected optimum- mixes based on compressive strength test result and cost

** Mixes which do not fulfill compressive strength compliance criteria

Therefore compared to concrete mix without HRWRA, using 1.2% of HRWRA Type-F with 25% less cement content had 98 birrs less cost and 7.51 and 8.95 MPa higher 7^{th} and 28^{th} days compressive strength respectively. Additional cost-saving from early form removal time can also be made by using this mixture since the 7^{th} day test result is 106% of the design compressive strength (30 MPa).

Using 1.2% of HRWRA Type-F with 25% less cement content, 152 birr/m^3 cost saving has been made with 15.7 and 8.84 MPa higher 7^{th} and 28^{th} compressive strength respectively compared to the reference mix.

The higher early-age strength increase is observed in the C-40 type of concrete than C-30, this might be due to higher cement content and the resulted hydration reaction.

Despite the highest cost reduction observed while, using 1.3% HRWRA dosage to reduce cement by 30%, the mixture was harsh. Besides, compared to the reference mix 20.4% less 28^{th} day compressive strength was recorded. In C-40 type concrete, a 1.3% dosage with 30% cement reduction did not affect the workability or compressive strength compared to the reference mix.

4.3.3. How to Select the Optimum Cost

As has been discussed in the literature review part of this document, the cost of concrete is the sum of many factors. Among these factors cost of cement in monetary terms, environmental and energy aspects make it the most important but expensive and environmentally unfriendly ingredient. Therefore, the optimum cost for concrete means the possible minimum cost of concrete that satisfies the stated performance criteria for a given application.

To select the optimum concrete mixture, the cost-saving made from cement reduction must be greater than the cost of HRWRA and additional aggregate quantity to get constant yield.

Therefore,

$Cp*Cr \geq Ap*Aa + Hp*H$……………………………………………Equation-4.1

Where: Ap - Price of aggregate

Aa - An additional quantity of aggregate

Cp - Price of cement

Cr - Reduced quantity of cement

Hp - Price of HRWRA

Hq - Quantity of HRWRA

Assumptions:

- Fine aggregate to total aggregate ratio is constant for both the control and the optimized concrete-mix.
- The price of ingredients (Ap, Cp, Hp) is fixed based on the market price at a given time.
- Cement specific gravity is assumed to be 3.15.
- Quantities of control concrete-mix ingredients are predetermined at the mix-designing stage; therefore, the amount of cement reduced is based on the HRWRA water reduction capacity (12-30) %.

Therefore by substituting the market price of concrete ingredients at a given time and using the graphical method, the breakeven point (*where the cost of concrete with and without HRWRA is equal*), one can select the theoretical optimum dosage of HRWRA and cement reduction percentage and conduct trial mix proportions.

$$\text{Volume of cement reduced} = \frac{\text{Cr}}{1000*3.15} = \text{ volume of substitute aggregate} \;\ldots\ldots \text{Equation-4.2}$$

Table 4.3.4. Mix proportion for 1 m^3 of control concrete mixes (*price referred from Table 3.3.3)*

Constituents	Unit	C-30	C-40	Price (ETB/unit)
Cement	kg	382	465	3.60
Coarse aggregate	m^3	0.3796	0.3796	550.00
Fine aggregate	m^3	0.3071	0.2794	550.00
HRWRA Type-F	Lt			48.00
HRWRA Type-G	Lt			45.00
Fine to total aggregate ratio		0.407	0.385	

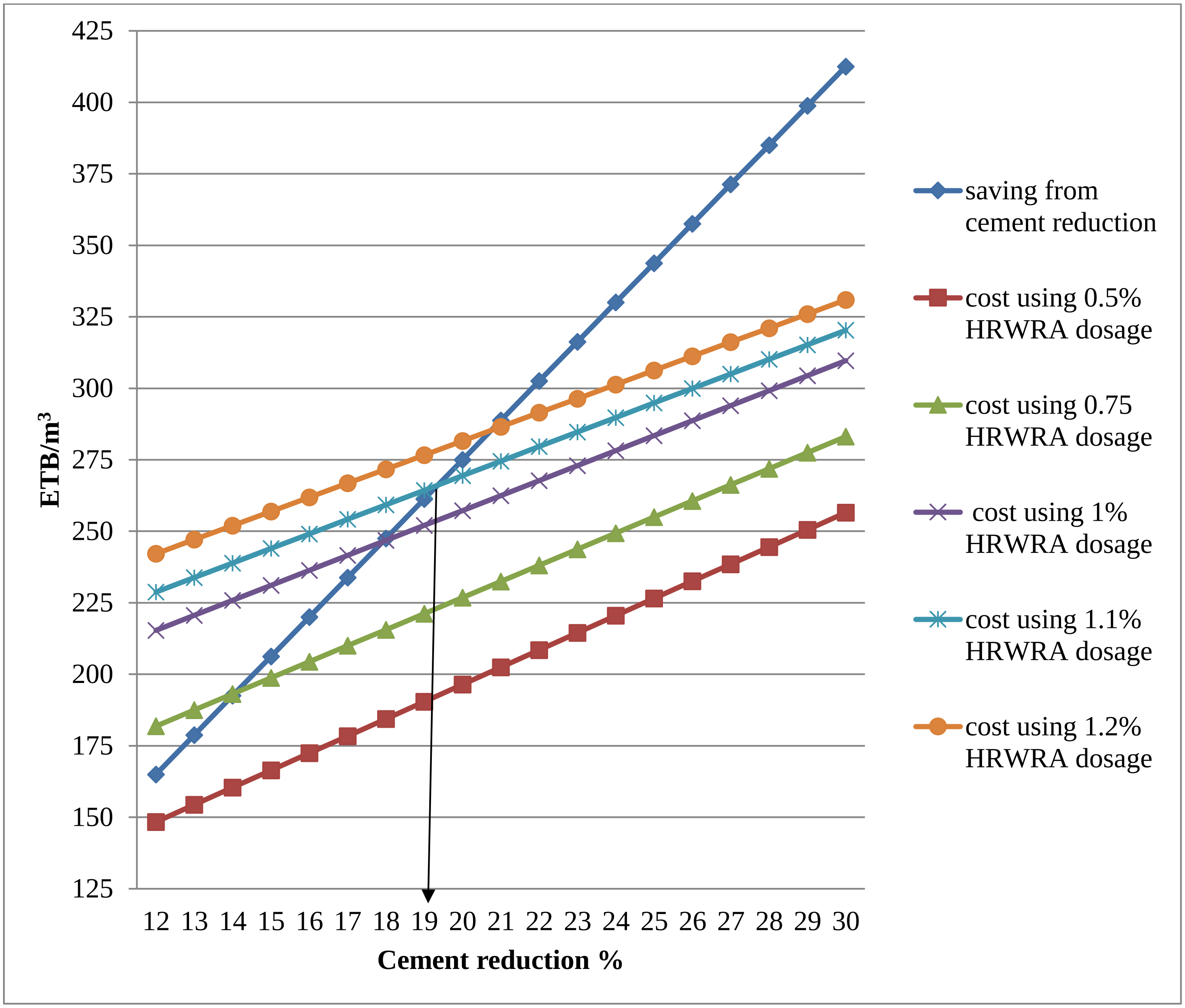

Fig. 4.3.1. Saving from cement reduction and cost of using Type-F HRWRA in C-30

(The cost analysis is done based on materials price given on Table 4.3.4.)

Note: *Saving from cement reduction is the quantity of cement reduced times price of cement. The cost of using different dosages of HRWRAs is the cost of the admixture plus the cost of additional aggregate required to compensate for the reduced quantity of cement so the mix gives approximately equal yield. For example, for the materials used in this research if one wants to make cost-saving using 1.1% of HRWRA dosage, the minimum cement reduction must be above 19%. If the percentage of cement reduced is less than 19% it means using 1.1% HRWRA dosage is expensive than not using the admixture at all in cost of material aspect.*

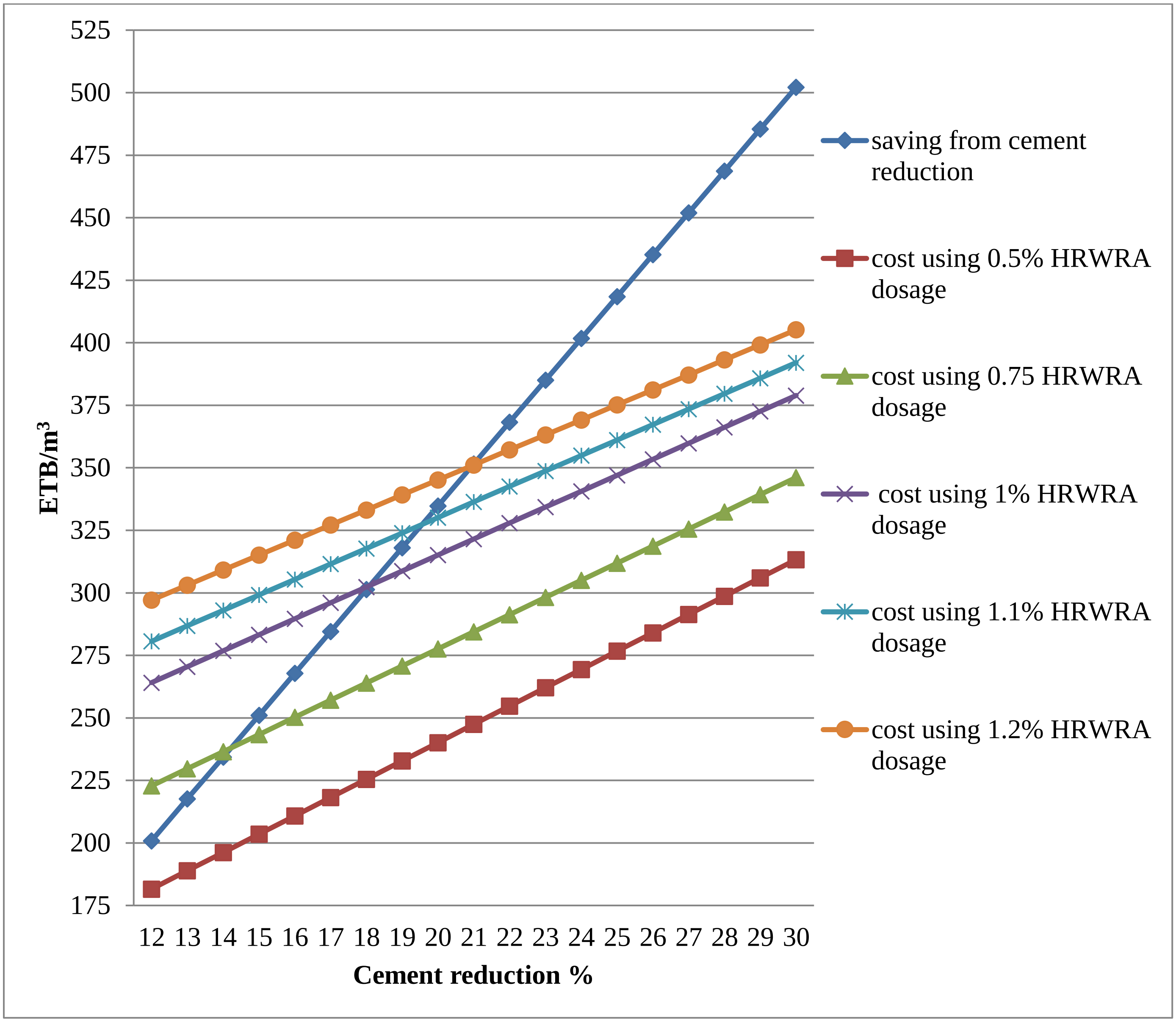

Fig. 4.3.2. Saving from cement reduction and cost of using Type-F HRWRA in C-40 (*The cost analysis is done based on materials cost given on Table 4.3.4.)*

To find the optimum cost of concrete the following steps can be applied:

1. Preparing theoretical mix design based on standards (example ACI 211).
2. Determine the maximum cement reduction from:
   - Water reducing admixture manufacturer technical data sheet recommended water reduction capacity;

- Project and/or standard specification for minimum cement content (example for floors 310 kg/m^3 is the minimum cement content using a 25 mm nominal maximum aggregate size). (45)

3. Determine the minimum cement reduction % from graph ***saving from cement reduction and cost of using HRWRA*** as illustrated in Fig 4.3.1 and Fig. 4.3.2. It is important to note that the above graphs can be used only if the concrete material price assumed is equal to the one used in this research. If not, one should make his/her graph using Equation-4.1 (page-68)
4. Perform trial mix using the maximum cement reduction and using maximum admixture dosage % on breakeven point.

For example to find the optimum mix proportion of C-30 type of concrete with project specified minimum cement content 300 kg/m^3. In the case, there is no such minimum cement requirement it is possible to reduce cement based on the recommended water reduction capacity of the admixture and "Saving from cement reduction and cost of using HRWRA" graph and do trial mixes.

Step1- based on the material properties used in this study 378 kg/m^3 of cement is required according to ACI 211 mix-proportioning method;

Step2- the maximum allowable cement content reduction % considering specified minimum cement content (300 kg/m^3) is

$$= 378 - 300 = 78 \text{ kg} = 78/378 = 20.63\%;$$

Step3- according to graph Fig. 4.3.1., to achieve cost-saving from 20% cement reduction the maximum dosage of admixture has to be less than 1.2%; This dosage can be lower or higher for combination of particular concrete ingredients based on their price at that time. The best way is to make similar graph based on their materials price.

Step4- perform trial mix with 1.1% HRWRA and 20% cement reduction, gave 40.57 MPa 28th day strength, and 5.5 birr/m^3 cost reduction. If the additional strength (10.57 MPa) is not needed, prepare another trial mix with reduced HRWRA dosage.

Cement price fluctuates from time to time. Sometimes in Addis Ababa, the price escalation gets more than 500 Birr/quintal. The cost-saving made by using HRWRAs also increases when cement price increases. For instance, if the cement price assumed in this study becomes 400 instead of 360 Birr/Qt, the cost-saving made from using concrete mixes with HRWRAs will also increase by more than 35 Birr/m^3 in C30-concrete and 45 Birr/m^3 in C40-concrete.

Moreover, finding the optimum concrete mix for specified materials and project requirements may require doing many trial mixes based on the price of concrete ingredients at a given time.

Chapter- Five

Conclusions and Recommendations

5.1. Conclusions

In this section summary of the conclusions is presented based on the study findings. The hypothesis that guided this study is that significant cost reduction can be achieved by using HRWRAs without sacrificing the desired workability and strength properties of concrete. Accordingly,

1. On average 98 to 152 Birr/m^3 of concrete cost saving was achieved using Type-F HRWRA at a dosage of 1.2% and 25% cement reduction with poor slump retention.
2. Using 1.5% Type-G HRWRA 118 to 131 Birr/m^3 cost saving was achieved with up to 2 hours slump retention and a 90 mm higher initial slump.
3. Despite the significant cost-saving made using HRWRAs, more than 15 MPa at 7^{th} day and 8 MPa at 28^{th} day increase in compressive strengths were recorded compared to the reference mixes. This may enable additional cost-saving from early age form removal.
4. Adding more HRWRA above the optimum dosage did not improve slump.

5.2. Recommendations for further study

1. Using PCE and SNF based HRWRAs to optimize concrete mixes
2. Using supplementary cementitious materials to optimize the cost of concrete
3. Study on durability property of optimized concrete mixtures with minimum cement content

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Annex

Technical datasheet for superplasticizers

Construction

Sikament® NNG

Superplasticizer / High range water-reducer

Product Description

Sikament® NNG is a highly effective admixture for concrete especially suitable for the production of free flowing concrete and for the production of high strengths concrete, especially in hot climatic conditions.

Uses

Sikament® NNG acting as superplasticizer or as high range water-reducer, promotes a very high plasticity and good slump keeping properties to concrete.

Sikament® NNG is mainly used for the following applications:

- Concrete with strong fluidity.
- High quality concrete.
- Concrete applied in precast.
- Concrete submitted to long transportation, delayed placing and high temperatures.
- Concrete with high water reduction while maintaining favorable consistency enabling good early strength development.

Characteristics/ Advantages

Sikament® NNG provides the following properties:

As superplasticizer

- Workability is greatly improved.
- Increase place ability in slender components with densely packed reinforcement.
- Enables easy placing, less vibration needed.
- Good slump keeping effect.

As high range water-reducer

- Up to 25% of water reduction.
- Pronounced increase of final strengths.
- 16 hours compressive strengths increased by up to 100% (depend on dosage).
- Reduced permeability for water.

Tests / Standards

Complies with EN 934-2

Product Data

Appearance/ Colours

Dark brown liquid.

Packaging

200 liter drum; 1000 liter container; bulk.

Storage conditions/ Shelf-life

12 months minimum from production date if stored in undamaged and unopened, original sealed packaging, in dry conditions at temperatures between +5 and +35 ºC. Protect from direct sunlight.

Technical Data

Chemical base

Naphthalene formaldehyde sulphonate.

Construction

Density	1.2 ± 0.02 kg/liter.
pH (23 ± 2ºC)	8 ± 1.
Chloride content	< 0.1% (EN934-2).

System information

Application details

Consumption/ Dosage	According to the main goal we recommend the following dosages: ■ 0.5 – 3.0% by weight of cement. It is advisable to carry out trial mixes to establish the exact dosage rate required.
Mixing / Dispensing	Sikament® NNG can be added to the mixing water prior to its addition to the aggregates or directly to the freshly mixed concrete (the plasticizing effect is more pronounced). Never add Sikament® NNG directly to dry cement or aggregates (efficiency reduction). Sikament® NNG can also be added to the concrete immediately prior to discharge and after further mixing has taken place for at least three more minutes.
Aplication method/ Tools	Sikament® NNG allows the production of high performance concrete, as long as the composition is well design and standard rules of good concreting practice are followed (production as well as placing). Fresh concrete must be cured properly and as early as possible especially in hot climatic conditions in order to prevent plastic and drying shrinkage.
Cleaning of tools	Clean all tools and application equipment with water immediately after use.
Notes on application/ Limitations	■ We recommend previous tests to determine the correct dosage of the admixture and whenever concrete composition is changed. ■ When accidental overdosing occurs, the set retarding effect increases. During this period the concrete must be kept moist in order to prevent premature drying out. ■ For further details contact our Technical Department.
Value base	All technical data stated in this Product Data Sheet are based on laboratory tests. Actual measured data may vary due to circumstances beyond our control.
Health and Safety Information	For information and advice on the safe handling, storage and disposal of chemical products, users shall refer to the most recent Material Safety Data Sheet containing physical, ecological, toxicological and other safety related data.

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PRODUCT DATA SHEET

Sikament® NNR

SUPERPLASTICIZER / HIGH RANGE WATER-REDUCER

DESCRIPTION

Sikament® NNR is a highly effective admixture for concrete especially suitable for the production of free flowing concrete and for the production of high strengths concrete, especially in hot climatic conditions.

USES

Sikament® NNR acting as superplasticizer or as high range water-reducer, promotes a very high plasticity and good slump keeping properties to concrete.
Sikament® NNR is mainly used for the following applications:
- Concrete with strong fluidity.
- High quality concrete.
- Concrete submitted to long transportation, delayed placing and high temperatures.
- Concrete with high water reduction while maintaining favourable consistency enabling good early strength development.

CHARACTERISTICS / ADVANTAGES

Sikament® NNR provides the following properties:
As superplasticizer :
- Workability is greatly improved.
- Increase place ability in slender components with densely packed reinforcement.
- Enables easy placing, less vibration needed.
- Good slump keeping effect.

As high range water-reducer :
- Up to 25% of water reduction.
- Pronounced increase of final strengths.
- Reduced permeability for water.

APPROVALS / CERTIFICATES

Complies with ASTM C 494 type G and EN 934-2 Table 11.1 and11.2

PRODUCT INFORMATION

Composition	Based on naphthalene formaldehyde sulphonate
Packaging	▪ 1000 litres IBC ▪ 200 litres Drum ▪ 20 and 25 litres Keg
Appearance / Colour	Dark Brown Liquid
Shelf life	12 months minimum from production date if stored in undamaged and unopened, original sealed packaging, in dry conditions at temperatures between +5 and +35 ºC.
Storage conditions	Store in a dry area between 5ºC and 35ºC. Protect from direct sunlight.
Density	1.20 ± 0.015
pH-Value	8.5 ± 1

Total Chloride Ion Content	< 0.1%
Equivalent Sodium Oxide	< 2 %
Recommended Dosage	0.4 – 3.0 % by weight of cement, depending on the requested performance of the concrete. Usual dosage : 0.5 - 2.0 % by weight of cement. It is advisable to carry out trial mixes to establish the exact dosage rate required
Dispensing	Sikament® NNR is added to the gauging water or can be added separately to the freshly mixed concrete. In this case, further mixing should take place for at least one minute per cubic meter. Sikament® NNR can also be added to the concrete immediately prior to discharge and after further mixing has taken place for at least five more minutes.

APPLICATION INSTRUCTIONS

Sikament® NNR allows the production of high performance concrete, as long as the composition is well design and standard rules of good concreting practice are followed (production as well as placing).
Fresh concrete must be cured properly and as early as possible especially in hot climatic conditions in order to prevent plastic and drying shrinkage.

- We recommend previous tests to determine the correct dosage of the admixture and whenever concrete composition is changed.
- When accidental overdosing occurs, the set retarding effect increases. During this period the concrete must be kept moist in order to prevent premature drying out.
- For further details contact our Technical Department.

BASIS OF PRODUCT DATA

All technical data stated in this Data Sheet are based on laboratory tests. Actual measured data may vary due to circumstances beyond our control.

LOCAL RESTRICTIONS

Note that as a result of specific local regulations the declared data and recommended uses for this product may vary from country to country. Consult the local Product Data Sheet for the exact product data and uses.

ECOLOGY, HEALTH AND SAFETY

For information and advice on the safe handling, storage and disposal of chemical products, users shall refer to the most recent Safety Data Sheet (SDS) containing physical, ecological, toxicological and other safety-related data.

LEGAL NOTES

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