JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CONSTRUCTION ENGINEERING AND MANAGEMENT CHAIR

Finite Element Modeling of Compressive Characteristics of Concrete Containing Superplasticizing Chemical Admixtures

A Thesis submitted to School of Graduate Studies, Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree Master of Science in Construction Engineering and Management

by

DAWIT KEBEDE WOLE

August, 2022
Jimma, Ethiopia

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Advisor: Dr. Habtamu Melese Zelelew (PhD, PE) ____________________

Co-Advisor: Mr. Mebratu Abera (MSc) ____________________

August, 2022

Jimma, Ethiopia

DECLARATION

I declare that the research entitled "Finite Element Modeling of Compressive Characteristics of Concrete Containing Superplasticizing Chemical Admixtures" is my original work and has not been submitted as a requirement for the award of any degree in Jimma University or anywhere else.

Dawit Kebede Wole		29 August 2022
NAME	SIGNATURE	DATE

As research Adviser, I hereby certify that I have read and evaluated this thesis paper prepared under my guidance, by Dawit Kebede Wole entitled "FINITE ELEMENT MODELING OF COMPRESSIVE CHARACTERISTICS OF CONCRETE CONTAINING SUPERPLASTICIZING CHEMICAL ADMIXTURES" and recommend and would be accepted as a fulfilling requirement for the Degree Master of Science in Construction Engineering and Management.

Advisor: Dr. Habtamu Melese Zelelew (PhD, PE)		4 September 2022
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ABSTRACT

*Concrete is the main constituent material in many structures. This leads to difficulties in simulation and modeling of concrete structures. In this research a 3D model of a concrete cube is prepared using concrete damage plasticity approach. The validation of the model to the desired properties/characteristics under monotonic loading is then discussed. Concrete test of concrete containing Mega Flow SP1, Sikament NN, and SASplastSP60 superplasticizer chemical admixtures at a dosage of 0%,0.5%,1%,1.5%,2% and 2.5%, cubical specimen (15cm*15cm*15cm) was performed in a laboratory through each HRWRAs type.* The results indicate by 2% dosage SASPlast SP60 and MegaFlow SP1almost the same increment but Sikament NN greater than the others, therefore Sikament NN HRWRAs is better designed for 2% dosage. *The results indicate by 2% dosage SASPlast SP60 and MegaFlow SP1almost the same increment but Sikament NN greater than the others, therefore Sikament NN HRWRAs is better designed for 2% dosage The experimental results obtained were then used as input parameters for the numerical solution which were simulated using software. The strength of the concrete depends on a lot of factors including curing time, temperature, water cement ratio, moisture condition etc, and hence the modeling of the concrete specimen should be done carefully. Concrete damaged plasticity model available in ABAQUS software package was used to reflect the characteristics of the concrete model in compression as well as tension. Three-dimensional non-linear finite element model was developed and analyzed by the Quasi-static technique using the ABAQUS standard model. Results show that the model simulated using Finite element method was able to predict the damage properties/characteristics of concrete specimen fairly accurately despite the variable nature of concrete. Hence, finite element analysis is an economical and time efficient method of advanced structural analysis that can be used to study the structural characteristics of concrete. Additionally, 2% superplasticizer admixture has been provided the optimum results on compressive strength of concrete of all the tested superplasticizer types. Finally finite element modeling with experimental validation results the results display a good correlation between these two approaches.*

Key Words: concrete damaged plasticity (CDP), concrete compressive strength, superplasticizer, Finite element Modeling, ABAQUS

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ACRONYMS

AASHTO	American Association of State Highway and Transportation officials
ABAQUS	Software for Finite Element Modeling Analysis
ACI	American Concrete Institute
ASTM	American Society for Testing Material
ANOVA	Analysis of Variance
BS	British Standard
CDP	Concrete Damage Plasticity
ERA	Ethiopian Roads Authority
ES	Ethiopian Standard
FE	Finite Element
HRWRAs	High-Range, Water-Reducing Admixtures or Superplasticizer
Kg	Kilogram
Kg/m3	Kilogram per cubic meter
KN	Kilo Newton
Lit	Liter
Lit/kg	Liter per Kilogram
M^3	Meter Cubic
Max	Maximum
Min	Minimum
Mpa	Mega Pascal
Mpa/s	Mega Pascal per Second
SD	Saturated surface Dry
SMF	Sulfonated Melamine-Formaldehyde condensate
SNF	Sulfonated Naphthalene- Formaldehyde condensate
SP	Superplasticizer
W/C	Water to Cement ratio

1. INTRODUCTION

1.1 Background of the study

Numerical simulations are often used for studying the properties/characteristics of structural elements. It is necessary to select a material model and to identify its constituent parameters thoughtfully. Concrete cracks when it is subjected to tension and crushes when subjected to compression. To model this properties/characteristic, the concrete damaged plasticity (CDP) models was used. In this research, CDP model used to reflect the characteristics of the concrete cubes subjected to compression. The tests of the concrete cubes were a part of the investigation of the properties/characteristics of concrete containing superplasticizing chemical admixtures. And present a 3D nonlinear finite element model to analyze concrete containing superplasticizer admixture cube subjected to compression. Considering the brittle nature of the concrete, standard dynamics analysis procedure was employed using ABAQUS/standard module (1).

Concrete is a composite material composed of fine and coarse aggregate bonded together with a fluid cement (cement paste) that hardens (cures) over time. The days when it was difficult to talk the benefit that admixtures provide have passed. It is now quite clear that admixtures can both solve technical problems and save substantial cost. However, they also have the potential to create technical problems if improperly selected or used. According to Neil and Ravindra (1992), numerous benefits are available through the use of admixtures, such as: improved quality, acceleration or retardation of setting time, coloring, greater concrete strength, increased flow for the same water-to-cement ratio, enhanced frost and sulfate resistance, improved fire resistance, improved workability, cracking control and enhanced finish ability. The specific effects of an admixture generally vary with the type of cement, mix proportion, ambient conditions (particularly temperature) and dosage. (2). It is important to realize both the complexity of the situation and the inaccuracies inherent in any attempt to compare the relative value of different admixtures. Different admixtures can have significantly different relative values when used with different cements or other different conditions. A difference in the time of addition (relative to that of the cement first coming into contact with the water) can substantially affect the performance of an admixture. Different results may be obtained from the same mix and admixtures when mixed in different way (3). In the construction industry a lot of admixtures are used for different purposes to improve different properties of concrete. Generally, admixtures are classified in to two: mineral and chemical admixtures (3).

Water reducing admixture is one type of chemical admixture which provide a wide benefit for concrete in the fresh and hardened sates. Different water reducing admixtures can be available in the market; from those admixtures high range water reducing admixture also known as superplasticizer, type F is the main type of admixture which provide a lot of improvement for concrete properties. This admixture is produced in our country as mega flow SP1, Sikament NN and SASplastSP60 which have a capacity to improve the workability and strength of concrete. However, in our country researches and investigation are not yet done on modeling of compressive properties/characteristics of concrete containing admixtures (4).

Therefore, this research shown the effects of superplasticizing chemical admixture on concrete properties. Laboratory experiments on compression resistance was carried out by adding doses of 0%, 0.5%, 1%, 1.5%, 2% and 2.5% for each super plasticizer product. And finally simulating the damage using models of concrete damaged plasticity (CDP) since this technique has the potential to represent complete inelastic properties/characteristics of concrete both in tension and in compression including damage characteristics (5).

1.2 Statement of the Problem

During Construction of concrete around the world the use of chemical superplasticizer admixture is less recognize. However, concrete technology has reached remarkable successes by the development of admixtures for production of quality concrete. Around the world construction parties that participate in the construction industry have little information and awareness about the uses and effects of admixtures on the production of quality concrete.

Presently, in the developed countries the qualities of being constructed concrete are not as such strong and durable; crack and failure is frequent and the cost incur for construction is very high; this is due to less improvement of construction technology and materials usage. However, super plasticizing admixture can substantially reduce those problems, because they have a potential to reduce the water demand of a concrete mix without reducing workability, allowing to increase early and ultimate strengths without additional cement, reduce concrete permeability and thereby reduce aggressive penetration, like: chloride, carbonation, sulphate, etc. and reduce crack and enhance durability. Nowadays, a great problem for this world is global warming which is caused by depletion of natural resources and emission of gases during cement production. But, superplasticizing admixtures are sensitized or by-product which has ability to save cement consumption with some percentage, this helps to reduces environmental problems caused by too much cement production (6).

Moreover, Portland pozzolana cement (PPC) - CEM grade 32.5R has low initial setting strength than OPC but it hardens over time with proper curing (7), conversely a lack of understanding adding superplasticizer in a concrete mix helps in allowing to increase early and ultimate strengths without additional cement. Additionally, lack of knowledge of the benefits obtained by the use of super plasticizing admixtures to compare the experimental results of concrete test performed on concrete specimens in the laboratory with the numerical results obtained using the finite element analysis of concrete model simulated in ABAQUS software.

1.3 Research Questions

The research question of the study includes;

- What is the effect of concrete containing super plasticizing chemical admixtures on compressive strength of concrete?
- What is the optimum content of superplasticizer?
- How can we utilize finite element modeling in concrete compression properties?

1.4 Objectives

1.4.1 General objective

The general objective of the research is to model compressive properties of concrete containing super plasticizing chemical admixtures using finite element analysis.

1.4.2 Specific objectives

The specific objectives of this research are:

- To evaluate the effects of superplasticizers on concrete mixture and strength properties.
- To identify the optimum content of superplasticizer.
- To model the compressive properties of concrete using Finite Element Method.

1.5 Scope and Limitation of the study

The scope of this experimental research focused on the three selected products of high range water reducer chemical admixtures that are widely available in Ethiopia Construction Industry. Examining with different dosages of HRWRAs of Mega flow SP1, Sikament NN and SASplast SP60 going on compressive strength of concrete. The study involves concrete ingredient quality tests, concrete mix design and concrete cube casting and test for compressive strength then data analysis using Excel, ANOVA and ABAQUS Software for Modeling. This experimental research was limited to Portland-Pozzolan Cement (PPC) Dangote brand, class-32.5 and merely focused on high range water reducer admixtures (HRWRAs) Type-F.

1.6 Significance of the study

The significance of the study includes analyze different high-range water reducer superplasticizer (HRWRAs) products and demonstrate how to increase the compressive strength of concrete of Portland Pozzolana cement (PPC) CEM grade 32.5R at early ages by adding high-range water reducer superplasticizer (HRWRAs). Since the adoption of concrete cube modeling, this kind of research has been a better input for Ethiopian concrete technology. And moreover, answer the question about finite element modeling uses of calculations, models and simulations to predict and understand how an object might behave under concrete compression properties.

1.7 Organization of the report

This research work will have five chapters. The first chapter will be the introduction, in this chapter the background of the study, statement of the problem, research questions, objectives of the study, the scope of the study, the significance of the study, and structure of the research will be explained. In the second chapter, several pieces of literature will be reviewed background information for concrete properties, the classification of different types of admixtures, the mechanism and applications of High Range Water Reducers (HRWRAs) or Superplasticizers. Finally, literature done on

Finite Element Analysis of Concrete Tests with Experimental Validation will be covered. In the third chapter, the research methodology will be described. Details of the experimental program and methods utilized during testing. The analysis of the test results and the evaluation of the concrete containing chemical admixture are provided, Finite element modeling will be discussed. In the fourth chapter, laboratory test result gathered and will be analyzed, and the finite element modeling will be developed. In the last chapter of the research, conclusions will be drawn, and Further future studies will be recommended.

2. LITERATURE REVIEW

2.1 Introduction

Concrete is the most widely used strongest construction material that forms the basis of our modern life. It is used in different structures, such as: dam, building, bridge, tunnels, highway etc. Starting from the past, concrete was produced by the combination of cementing materials, aggregate and water. However, when the concrete technology develops, additional materials known as admixture have produced. This additional material may be added to the basic mix to develop special properties of the concrete in fresh and hardened states (8).

According to ACI 116R and ASTM C 125, admixtures are ingredients other than water, aggregates, hydraulic cement, and fibers that are added to the concrete batch immediately before or during mixing [3]. A proper use of admixtures offers certain beneficial effects to concrete, including: acceleration or retardation of setting time, enhanced strength development, improved workability, improve concrete durability and enhanced finish ability. Basically, two categories of admixtures are available: mineral and chemical admixture (9).

Superplasticizing admixture is a type of high range water reducing chemical admixture, which have a capacity of reducing the mixing water up to 35%. This type of admixture will provide high quality improvement for concrete in both fresh and hardened states. Generally, superplasticizing admixtures improve workability, strength, and permeability of concrete. Therefore, the main discussion of this chapter focus on reviewing admixtures, particularly on superplasticizing admixture used to produce quality concrete.

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" (11).

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" (12).

Classification

The ASTM C494 classifies and defines chemical admixtures in seven 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.

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, HRWRAs 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 (4).

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 (13).

2.3.1 Mechanism

Superplasticizers are effective due to their adsorption on and dispersion of the cement particles in the cement-water system (9). 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 (14).

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). The water reduction effect depends on the dosage level, the sequence of addition, and molecular weight. Mehta et al. stated that the interaction mechanism of superplasticizer is also dependent on the ambient temperature, cement fineness, and composition, especially the C3A, SO3, and alkali contents, which control the rate of ettringite formation, may affect too (16).

2.3.2 Application

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

- enhancing workability without altering the water-to-cement ratio that controls concrete durability and strength;

- decreasing the water cement 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 (17).
- 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 water cement ratio, 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 (4).

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 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 (4). Neville A.M. stated that high cement content leads to high shrinkage and low water to cement ratio resulted using superplasticizer give lower shrinkage (11).

2.4.1 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% (18). 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 C3A, C3S, and alkali contents of the cement (4). 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 (14).

2.4.2 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 (4). 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).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 (11).

2.4.3 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 (12). 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 (4). 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 (13). 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 (19). 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 (20).

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 (14).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 (21).

2.4.4 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. 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 (4).

2.5 Effects of Cement Content on Properties of Hardened Concrete

2.5.1 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/m3) 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 (11)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 (20).

2.6 Effects of HRWRAs on Properties of Hardened Concrete

2.6.1 Compressive Strength

Kosmatka et al. stated that, for concretes of equal cement content, air content, and slump, the 28day compressive strength of a water-reduced concrete containing a water reducer can be 10% to 25% greater than the concrete without the admixture (13). The ACI complements that cement contents can thus be reduced without lowering 28-day strength (4).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 (11).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. 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 (14).

2.7 Optimum content of High Range Water Reducers (HRWRAs) or Superplasticizers

It is reported that, in the production of high-strength concrete is beneficial to increase the dosage of the admixture. This usually provided extra water reduction and typically a delay in setting time and slow early-strength gain. Concrete with slow-early strength gain generally exhibits higher later strengths. Generally, more than two additions are less effective and concrete may lose its workability faster than with a single dose. Re-dosing may result in lower air content, on the order of one to two percentage points for each re-dose. When re-dosages are used, the concrete might have a greater potential for bleeding, segregation, and possible retardation of setting time (22).

2.8 Portland Pozzolana Cement –PPC Cement

2.8.1 Definition

A siliceous or silico-aluminous material that will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties (there are both natural and artificial pozzolans (22).

- PPC has low initial setting strength than OPC but it hardens over time with proper curing.
- PPC has higher strength than OPC over a longer period of time.
- It has higher resistance against alkalis, sulphates, chlorides etc.

2.8.2 Use of Portland Pozzolana Cement (PPC)

The significance of using PPC may include the following among others;

For the construction of hydraulic structures, the construction of massive structures as dams, thick foundations, bridge piers etc (23) and the construction of sewers and sewage disposal works etc.

2.9 Finite Element Analysis of Concrete Tests with Experimental Validation

Finite element analysis is a numerical technique that uses computational power to calculate approximate solution to a given problem. Since this method is based on energy principle, it can be used to solve problems related to solid mechanics, fluid mechanics, heat transfer and electrodynamics. This research compares the experimental results of concrete test performed on concrete specimens in laboratory with the numerical results obtained using the finite element analysis of concrete model simulated in ABAQUS software. Test of Concrete containing superplasticizer chemical admixture concrete cubes, will performed in a laboratory (5). This study compares the real properties/Characteristics of concrete containing superplasticizer chemical admixture with its numerical modeling (24).The damage properties of Concrete containing superplasticizer admixture had not been explored deeply by researchers especially for its continuum damage mechanics and plasticity. This thesis will present the results of compressive tests and finite element analysis of concrete containing superplasticizer admixture cubes. Three dimensional- nonlinear finite element model was developed and analyzed by the aquasi static technique using the ABAQUS standard module. The input parameters of the model were obtained from experimental results. Concrete damaged plasticity was chosen as damaged criteria. Results show that the proposed finite element model is able to predict the damage properties of the superplasticizer concrete cube accurately. Thus, finite element method can be used as an economical tool for studying the structural properties of concrete in compression. And one of the popular and effective numerical solutions for a range of engineering issues is the finite element approach. It has been applied for the past 30 years to numerous problem-solving scenarios. Using either an analytical solution or experimental studies, finite element results are validated Finite element approach tools have seen major advancements recently as a result of advancements in computing technology. Software packages based on finite element analysis are useful for a variety of reasons like; spotting problems early in the design process, lowering the cost of prototyping, understanding phenomena that are difficult to understand through physical testing, etc. (25).

3. RESEARCH MATERIAL AND METHODOLOGY

3.1 Background

This experimental research be present mainly focused on laboratory investigations. It began by material characterization, and then produced control mixes (without superplasticizer); later special mixes with three different Type-F high range water reducer admixture (HRWRAs) or Superplasticizer ; Mega Flow SP1, Sikament NN, and SASplast SP60 each six different phases at dosages of 0, 0.5%, 1%, 1.5%, 2% and 2.5%. Each of this trial batches are casted using 15cm X 15cm X 15cm cube specimen and tested for their 3rd, 7th and 28th day Concrete Compressive strength tests was performed in a laboratory.

After obtaining the laboratory/experimental values, a 3D nonlinear finite element model is presented to analyze control mixes and special mixes concrete cube specimen subjected to 28th day compression load to obtain its ultimate compressive strength using FEA. Considering the brittle nature of the concrete material, standard analysis procedure was employed using ABAQUS/Standard module. The concrete damaged plasticity (CDP) model was used to simulate the control mix and concrete containing each type of HRWRAs. Then it uses stress-strain relationships obtained using experimental methods to correlate parameters for relative concrete damage for both tension and compression. The concrete damaged plasticity model in Abaqus.

3.2 Sampling Size

Three cubic trial samples are prepared for each batch. Each of these trial batches are casted and tested for their 3rd, 7th and 28th day concrete strength therefore for the sixteen trials 144 concrete cubes are casted and tested. For this experiment cement 174.9kg, coarse aggregate 506.5kg and Fine aggregate 342.2kg are used.

3.3 Material Preparation

The type of material was used to prepare concrete trial mixes shown in the table 3-1 below.

Table 3-1 Type of concrete ingredients used

Material	Type
Cement	Pozzolana Portland Cement (PPC) 32.5R Grade Cement
Fine Aggregate	River sand
Coarse Aggregate	Crushed basalt stone
Superplasticizer Admixture	Sulphonated naphthalene formaldehyde-based, Type-F according to ASTM C 494 classification
Water	Tap water

Before mix proportioning the following tests were conducted to characterize aggregate properties. Table 3-2 below shows applied test methods of the concrete ingredients: The sieve analysis determines the gradation (the distribution of aggregate particles, by size, within a given sample) in order to determine compliance with design, production control requirements, and verification specifications. Specific gravity test of aggregates is done to measure the strength or quality of the material while water absorption test determines the water holding capacity of the coarse and fine aggregates. The main objective of these test is to, to measure the strength or quality of the material. The bulk density or unit weight is the weight per unit volume (mass per unit volume or density). Voids in unit volume of aggregate are the space between particles in an aggregate mass not occupied by solid minerals.

Table 3-2 Test methods used to characterize concrete ingredients

Laboratory Test	Test method
Sieve analysis of fine and coarse aggregates	ASTM C 136
Relative density (Specific gravity) and absorption of aggregate	ASTM C127 and ASTM C128
Bulk density (unit weight) and voids in aggregate	ASTM C 29

3.3.1 Cement Used for the Experiment

Ordinary Pozzolana cement (PPC) produced as per CEM-32.5 grade produced by Dangote Cement PLC was used throughout the experiment. The reason to select PPC cement is to check parallel to is this type of cement can attain the required strength at an early age with addition of high range water reducer or Superplasticizer (HRWRAs), since PPC cement is more produced throughout the cement factory.

3.3.2 Aggregate Used for the Experiment

Aggregates are materials basically used as filler with binding material in the production of concrete. Aggregates form the body of the concrete, reduce the shrinkage and affect economy. Therefore, it is significantly important to obtain right type and quality of aggregates on site. They should be clean, hard, strong, and durable and graded in size to achieve utmost economy from the paste. Therefore, to judge the quality of the aggregate physical characteristic's tests have to be conducted. So, in this research the all-necessary physical testes are performed on the properties of fine and coarse aggregate.

3.3.3 Water Used for the Experiment

Mixing water used in this research was drinkable water supplied by Addis Ababa Water and Sewerage Authority found in the laboratory area.

3.3.4 High Range Water Reducers (HRWRAs) or Superplasticizers Used for the Experiment

For this research three types of high range water reducer admixture (HRWRAs) or superplasticizers are used which is complying with ASTM C494 Type F. All taken from the Sika Chemicals Manufacturing PLC. Table 3-7 shown below the HRWRAs types and their chemical bases.

Table 3-3 Superplasticizers chemical bases

HRWRAs or Superplasticizer Type	Chemical base
MegaFlow SP1 or Muraplast SP1	Sulphonated naphthalene polymers
Sikament NN	Naphthalene formaldehyde sulphonate
SASplast SP60	Naphthalene sulphonate

3.3.5 Concrete Mix Design and Materials Proportion

The ACI Method of concrete mix design was used to design C-25 concrete grade (Cubical).The target mean strength was 34N/mm2 and the water cement ratio is 0.5.In addition the slump was 25 to 75mm.The quantity of concrete materials was calculated by using the physical properties of the materials for one cubic meter for C25 grade concrete. It began by material characterization, and then produced control mixes (without superplasticizer); later special mixes with three different Type-F high range water reducer admixture (HRWRAs) or Superplasticizer; Mega Flow SP1 (Muraplast), Sikament NN, and SASplast SP60 each six different phases at dosages of 0, 0.5%, 1%, 1.5%, 2% and 2.5%. The standard cast iron molds of size 15cm x15cm x 15cm are used. The mix design details attached in the Appendix C.

3.3.6 Concrete Production Process

The concrete moulds and mixer were cleaned from all dust and coated with releasing agent (oil) to smooth the surface and to prevent sticking of mixed concrete with the mold and mixer. The ingredients, such as; cement, fine aggregate (sand), coarse aggregate water and admixture were measured by weight balance. After that the weighted coarse aggregate was first added to the mixer and the cement was added after the coarse aggregate and then the fine aggregate is added next to cement and dry mixed for a minute. Then, water and admixture was added to the dry mixed concrete ingredients mixture and thoroughly mixed for two more minute. The mixed concrete was checked for workability by filling the standard slump cone with three layers by rodding each layer with 25 times. Then, after checked the slump the mixed concrete was placed in the mould and was well compacted in two layers with the help of a table vibrator for 45 and 30 seconds for double and single cast iron moulds respectively. The concrete moulds are kept for 24 hours and then the casted concrete cubes were removed from the mould and placed inside water for curing to take place until the testing age was reached.

3.4 Finite Element Analysis

The finite element method (FEM) is a numerical technique used to perform finite elements analysis (FEA) of any given physical phenomenon. It is necessary to use mathematics to comprehensively understand and quantify any physical phenomena, such as structural of fluid properties thermal transport, wave propagation, and the growth of biological cells. Most of these processes are described using partial differential equations. However, for a computer to solve these partial differential equations have been developed like Abaqus Software one of the most prominent todays is the finite element method. The finite element method started with significant promise in the modeling of several mechanical applications related to civil engineering.

3.4.1 Material Properties

A 3D nonlinear finite element model was developed using ABAQUS/Standard module to study the Properties/Characteristics of concrete containing superplasticizer admixture of concrete cube under compression. Material properties of the concrete obtained from the experiment were used to calculate the concrete damage plasticity parameters as input to the model. The parameters were calculated based on the stress-strain relations under uniaxial tension and compression loading.

3.4.2 Input Parameters for Finite Element Analysis (FEA)

Damage Plasticity Constitutive Model

The isotropic damaged elasticity and the isotropic tensile and compressive plasticity were used in the concrete damaged plasticity model to study the properties/characteristics of concrete in a non-elastic manner. The total strain tension ε was comprised of the elastic part ε el and the plastic part ε pl. (27). The shape of the compressive branch in the inelastic range and is computed according to Carreia and Chu (1985) as equation below where the unit of σ_{cu} is MPa (28)

$$\beta = \left(\frac{\sigma_{cu}}{30.6}\right)^2 + 2.19$$

Furthermore, in order to quantify the effect of compressive strength on a strain of peak ε_o and on the initial tangential modulus, E_{it}. A regression analysis is performed to establish a relationship between the compressive strength and these parameters whose values can be determined as equations according to Hsu and Hsu (1994), and the unit of MPa is considered (28)

$$\varepsilon_o = (0.01291\sigma_{cu} + 2.114)10^{-3}$$

The stress-strain relation in tension is adopted from the research of Aslani and Jowkarmeimandi (2012) as demonstrated in Figure. A complete relation is composed of two regimes, a linear is captured until the failure stress of concrete is achieved and the descending branch is denoted by equation (28)

$$\sigma_t = \sigma_{to}\left(\frac{\varepsilon_{to}}{\varepsilon_t}\right)^{0.85}$$

The tensile strength of concrete in modulus of rapture is a more variable property than the compressive strength and it's about 10 to 15 percent of the compressive strength of concrete in flexure is neglected in strength design. In this study the tensile strength value is adjusted as per American Concrete Institute (ACI) ACI 318-14 A complete relation is (30)

$f_t = 0.56\ (f_c)^{0.5}$

The mechanical properties of concrete of Poisson's ratio for concrete material is 0.18 according to (28).

The modulus of elasticity of concrete Ec adopted in modified form by the ACI code 318-19 can be calculated by the formula given below (30) Ec= 4700√fcu' MPa in SI units

Where Ec= modulus of elasticity of concrete in MPa

fcu = specified 28th day compressive strength of concrete in (MPa)

Concrete used most widely in structural engineering is of density varying from 2.2 to 2.4 t/m^3 according to Guo (2014).In this study, the density of concrete is set from the experimental result. (28)

Analytical expressions to estimate the parameters of proposed equations β parameter equation is used to generate a set of compressive stress-strain curves at different β values while other parameters are kept constant (29)

$$\beta = \left(\frac{f_c'}{9.46}\right)^3 + 2.59$$

Where f_c' is the compressive strength of concrete in Kip/in^2

Uniaxial Compressive Properties/Characteristics

In concrete damage plasticity models, the plastic hardening strain in compression $\varepsilon_t^{in,h}$ played a key role in finding the relation between the damage parameters and the compressive strength of concrete as follows (27)

$$\varepsilon_t^{in,h} = \varepsilon_t - \frac{\sigma_t}{E_0}$$

Cyclic properties/characteristics continued to concrete behavior. This was defined by effective parameters, including damage in tension. Compression damage (d_c) was based on inelastic hardening strain in compression $\varepsilon_t^{in,h}$ that controlled the unloading curve slope. Given dc increased with respect to an increase in $\varepsilon_t^{in,h}$,it could be expressed as follows: (27),(28)

$$d_c = 1 - \frac{\sigma_c}{\sigma_{cu}}$$

Uniaxial Tensile Properties/Characteristics

In concrete damage plasticity models, the plastic hardening strain in tension $\varepsilon_c^{pl,h}$ was derived as follows (28)

$$\varepsilon_c^{pl,h} = \varepsilon_{tc} - \frac{\sigma_t}{E_0} \qquad \varepsilon_t^{ck,h} = \varepsilon_t - \frac{\sigma_t}{E_0}$$

The hardening cracking strain, $\varepsilon_t^{ck,h}$the tension damage continued to increase, and this could be expressed as follows (27), (28)

$$d_t = 1 - \frac{\sigma_t}{\sigma_{t0}}$$

The concepts and properties of the concrete damage plasticity model using inferential reasoning and analysis. Computational techniques were used to determine the plastic factors for the concrete damage in ABAQUS.

4. RESULTS AND DISCUSSIONS

In this chapter, the study findings are reported, analyzed, and discussed based on the laboratory test results of 234 concrete mixtures having different dosages of HRWRAs superplasticizer 0%, 0.5, 1%, 1.5%, 2% and 2.5% by weight of cementitious material. This study aimed to investigate Finite Element Modeling of Compressive Properties/Characteristics of Concrete Containing Super Plasticizing Chemical Admixtures. The tests results are used to draw conclusions on the Finite Element modeling of 3D nonlinear finite element model to analyze concrete containing superplasticizer admixture cube subjected to compression load. Therefore, the compressive strength properties of the trial concrete mixtures are discussed and numerical stimulation by using Finite element method.

4.1 Properties of Aggregate

Aggregates are materials basically used as filler with binding material in the production of concrete. Aggregates form the body of the concrete, reduce the shrinkage and affect economy. Therefore, it is significantly important to obtain right type and quality of aggregates on site. They should be clean, hard, strong, and durable and graded in size to achieve utmost economy from the paste. Therefore, to judge the quality of the aggregate physical characteristic's tests have to be conducted. So, in this research the following physical testes are performed on the properties of fine and coarse aggregate.

4.1.1 Properties of Fine Aggregate

The term fine aggregate is used to describe natural sand, crushed rock, crushed gravel or other material all fine aggregate which retain on 9.5mm sieve size were no longer relevant, and all the passing fine aggregate were used for experimentation. For the case of this research Koka River sand used as a sample, which is found in Oromia region about 120km from Addis Ababa, was used to prepare the concrete samples. Then, the following tests were conducted for fine aggregates.

Sieve Analysis

According to ASTM-33, the gradation test result of the sampled sand is within the range. Particle size distribution of fine aggregate tests were conducted on the samples to assess the quality. The comparison of laboratory test results with the corresponding specifications is illustrated in table 4-1 below and the fine aggregate particle size distribution test result confirms within the required specification requirement for concrete work based on ASTM-33.

Table 4-1: The particle size distribution for fine aggregate

Sieve size (mm)	Weight retained (gm)	Cumulative weight retained (gm)	% Retained	% Passing	Cumulative % Retained	ASTM-33	
9.5	0.0	0.0	0.0	100.0	0.0	100	
4.75	76.1	76.1	5.4	94.6	5.4	95	100
2.36	133.9	210.0	9.4	85.2	14.8	80	100
1.18	196.0	406.0	13.8	71.4	28.6	50	85
0.6	352.0	758.0	24.8	46.6	53.4	25	60
0.3	414.8	1172.9	29.2	17.3	82.7	10	30
0.15	154.9	1327.8	10.9	6.4	93.6	2	10
Pan	90.8	1418.6	6.4		100.0		

The fineness modulus of fine aggregate (FM) = ∑ cumulative coarser (%)/100

Fineness Modules = (5.4+14.8+28.6+53.4+82.7+93.6)/100 = 2.79

This can be interpreted that the third sieve, i.e., 0.6mm is the average size. However, depending upon their size, sand can be classified as coarse sand when a fineness modulus is between 2.90 to 3.20; medium sand with a fineness modulus of 2.60 to 2.90 and; fine sand with a fineness Modulus of 2.20 to 2.60. So, the sample was classified as medium sand. The gradation results for the fine aggregate source are plotted with the specified envelope as shown in figure 4-1. And the test result illustrations within the required specification requirement for fine aggregate based on ASTM-33.

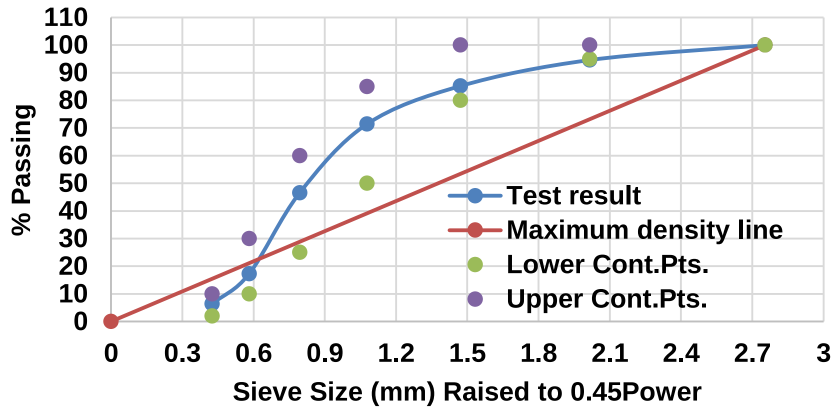


Figure 4-1 Fine aggregate gradation chart

Material Finer than 75mm, AASHTO T 11

According to the Ethiopian Standard it is recommended to wash the sand or reject if the silt content exceeds a value of 6% (26). From the test result obtained, the silt content of the sand used for this experiment before washing was 4.8 %, which is below the maximum requirement of Ethiopian standard. For this reason, it was not washed.

Specific Gravity and Absorption Capacity of fine Aggregates

Since aggregates generally contain pores, both permeable and impermeable, the meaning of the term specific gravity has to be carefully defined, and there are indeed different types of specific gravity, like: apparent specific gravity and bulk specific gravity. Bulk specific gravity refers to total volume of the solid including pores of the aggregate, and Apparent specific gravity refers to the volume of the solid is consider to include the impermeable pores but not the capillary ones. The bulk specific gravity, bulk specific gravity (saturated- surface dry) and apparent specific gravity results obtained from the experiment are 2.32, 2.42 and 2.57 respectively. And, the absorption capacity was 4.17%.

Moisture Content of Aggregates

The moisture content of fine aggregate was determined by Oven dry 500gm of fine aggregate (sand) for about 24hrs with a temperature of 105 °C to 110 °C and cool for an hour. Then, dividing the weight difference by oven dry weight and multiplying by hundred provide the moisture content. Therefore, the moisture content of the sample fine aggregate was 1.5 %. The summarized test results for fine aggregate and tests were conducted on the samples to assess the quality. The laboratory test results is illustrated in table 4-2 below

Table 4-2 Summarized test results for fine aggregate (Sand)

Physical test for fine aggregate		Results
Fineness modulus		2.78
Specific gravity	Bulk specific gravity	2.32
	Specific gravity (SSD)	2.42
	Apparent specific gravity	2.37
Absorption capacity		4.17%
Moisture content		1.50%
Material Finer than 75mn,AASHTO T 11		4.8
Sand Equivalent, AASHTO T 021		89
Organic Impurities, AASHTO T 021		Standard No. 2
Clay Lumps and Friable Particles, AASHTO T 112		3.20%

From the result obtained, all the test results within the required specification requirement fine aggregate for concrete work as per ASTM and AASHTO and ERA 2013 manuals.

4.1.2 Properties of coarse aggregate

The term Coarse aggregate is used to describe materials such as crushed rock, crushed gravel or natural gravel most of which retained on a 5mm BS sieve. As aggregate form the bulk of the volume of concrete, the selection of suitable material is important. For an aggregate to be used in construction there are essential requirements such as being Strong and Durable i.e. it should be stronger than the required strength, not contain materials which are likely to undergo in to undesirable reaction with the cement, Decompose (change in volume) when exposed to weather, or affect the reinforcement and be resistant to weathering action.

For the case of this research the available Kality sub-city, locally known as "Worku sefer" stone quarry source coarse aggregate is used. In this study a Nominal maximum aggregate size of 25 mm was used in all the concrete mix design. The value of coarse aggregate grading are shown in Table 4-3 and Figure 4-2 below were X-value Sieve size in (mm) and Y- value Percent Pass (%).

Table 4-3 Sieve analysis for coarse aggregate

Sieve size (mm)	Weight (Retained (gm)	Cumulative weight retained (gm)	% Retained	% Passing	Cumulative % Retained	ASTM-33	
37.5	0	0	0	100	0	100	100
25	48.9	48.9	0.50	99.50	0.50	100	100
19	850	898.9	8.63	90.88	9.12	90	100
9.5	5104	6002.9	51.80	39.08	60.92	20	55
4.75	3200	9202.9	32.47	6.61	93.39	0	10
2.36	632.5	9835.4	6.42	0.19	99.81	0	5
Pan	18.5	9853.9	0.19		100		

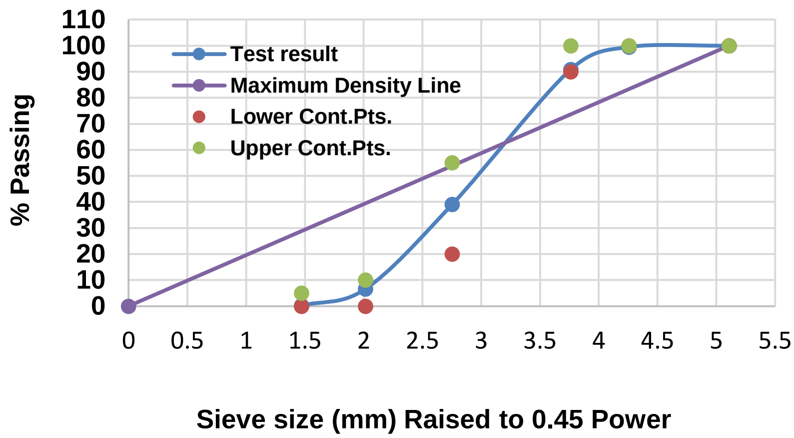


Figure 4-2 Coarse aggregate gradation chart

The summarized test results for coarse aggregate and tests were conducted on the samples to assess the quality. The laboratory test results is illustrated in table 4-4 below

Table 4-4: Summarized test results for coarse aggregate

No	Physical test for fine aggregate		Results
1	Unit weight	Compacted unit weight	1540 Kg/m^3
		Loose unit weight	1480 Kg/m^3
2	Specific gravity	Bulk specific gravity	2.63
		Bulk Specific Gravity (SSD)	2.69
		Apparent specific gravity	2.80
3	Absorption capacity		2.30%
4	Moisture content		1.10%

From the result gotten, all the test comes about inside the specified detail necessity for concrete coarse aggregate as per ASTM and AASHTO and ERA 2013 manuals.

4.1.3 Water Used For the Experiment

Mixing water used in this research was drinkable water supplied by Addis Ababa Water and Sewerage Authority found in the laboratory area.

4.1.4 Properties of High Range Water Reducers (HRWRAs) or Superplasticizers

For this research three types of high range water reducer admixture (HRWRAs) or superplasticizers are used which is complying with ASTM C494 Type F. All taken from the Sika Chemicals Manufacturing PLC. Table 4-5 shown below the HRWRAs types and their chemical bases. The properties are attached on the Annex.

Table 4-5 Superplasticizers chemical bases

HRWRAs or Superplasticizer Type	Chemical base
MegaFlow SP1 or Muraplast SP1	Sulphonated naphthalene polymers
Sikament NN	Naphthalene formaldehyde sulphonate
SASplast SP60	Naphthalene sulphonate

4.2 Compressive strength properties of a concrete mixture

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 different compressive strength regarding the dosage of HRWRAs and types.

4.2.1 Summary of trial batches to be tested for strength

Table 4-6 Summary of trial batches to be tested for strength

Proportioning Concrete Mixtures				Admixture dosage by weight of cementations material (%)
Water (Kg/m^3)	Cement (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Fine Aggregate (Kg/m^3)	
180	360	1030	694	0%,0.5%,1%,1.5%,2%,2.5%

4.2.2 Summary of test results of the concrete 3, 7 and 28 days

Table 4-7 Compressive Strength test results of Reference Mix without containing admixture

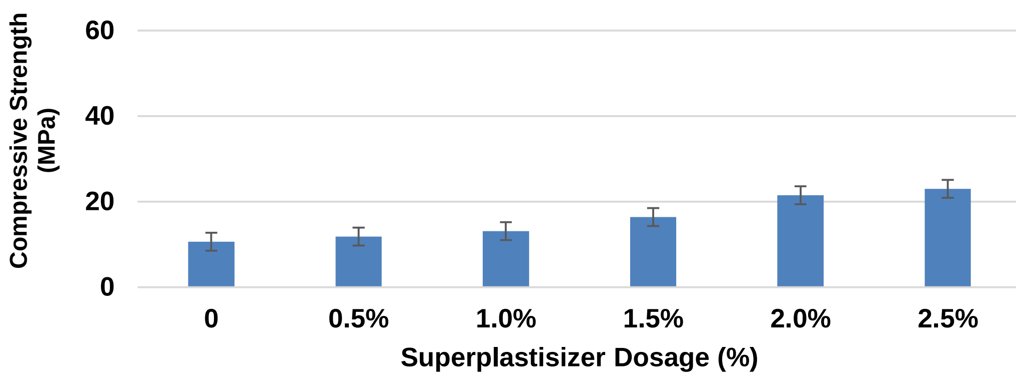
Admixture dosage (%)	Slump (mm)	3rd days		Average Comp. strength (Mpa)	7th days		Average Comp. strength (Mpa)	28th days		Average Comp. strength (Mpa)
		Failure Load (KN)	Comp. Strength (Mpa)		Failure Load (KN)	Comp. Strength (Mpa)		Failure Load (KN)	Comp. Strength (Mpa)	
0	50	237.7	10.5	10.6	342.8	15.2	14.7	574.9	25.5	27.1
		238.6	10.5		329.5	14.6		626.9	27.8	
		243.5	10.8		322.5	14.3		628.2	27.9	

Table 4-8: Compressive Strength test results of SAS plast SP60 with different dosage

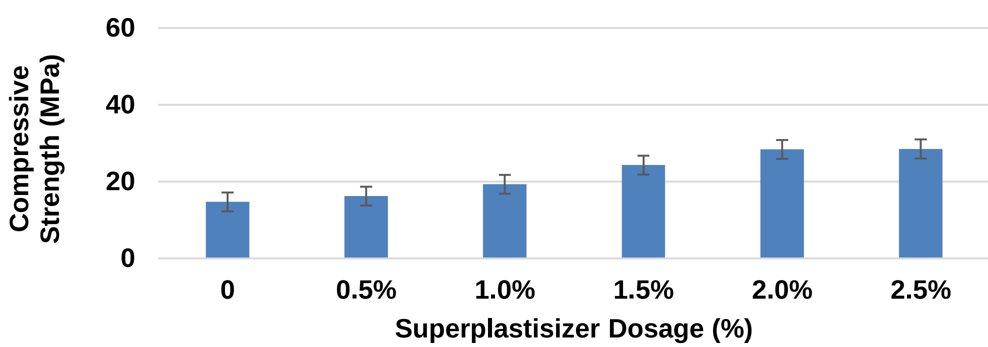
Admixture dosage (%)	Slump (mm)	3rd days		Average Comp. strength (Mpa)	7th days		Average Comp. strength (Mpa)	28th days		Average Comp. strength (Mpa)
		Failure Load (KN)	Comp. Strength (Mpa)		Failure Load (KN)	Comp. Strength (Mpa)		Failure Load (KN)	Comp. Strength (Mpa)	
0.5%	50	264.1	11.7	11.8	364.2	16.2	16.2	649.9	28.9	28.9
		269.3	12.0		358.6	15.9		652.2	29.0	
		265.3	11.8		369.3	16.4		646.2	28.7	
1%	52	297.3	13.2	13.1	418.1	18.5	19.3	715.6	31.7	31.5
		295.3	13.1		439.9	19.5		706.1	31.3	
		293.0	13.0		448.3	19.9		713.3	31.6	
1.5%	50	368.2	16.3	16.4	565.4	25.1	24.3	853.2	37.9	37.7
		372.1	16.5		526.6	23.3		826.9	36.7	

Admixture dosage (%)	Slump (mm)	3rd days		Average Comp. strength (Mpa)	7th days		Average Comp. strength (Mpa)	28th days		Average Comp. strength (Mpa)
		Failure Load (KN)	Comp. Strength (Mpa)		Failure Load (KN)	Comp. Strength (Mpa)		Failure Load (KN)	Comp. Strength (Mpa)	
		371.1	16.5		551.1	24.4		866.3	38.4	
2%	51	483.7	21.5	21.5	628.8	27.9	28.4	970.8	43.1	42.9
		475.8	21.1		633.4	28.2		959.6	42.6	
		489.4	21.7		653.6	29.1		970.8	43.2	
2.5%	51	511.5	22.7	23.0	650.4	28.9	28.5	901.2	40.1	39.7
		524.8	23.3		642.4	28.5		893.9	39.7	
		519.2	23.1		632.2	28.1		886.5	39.4	

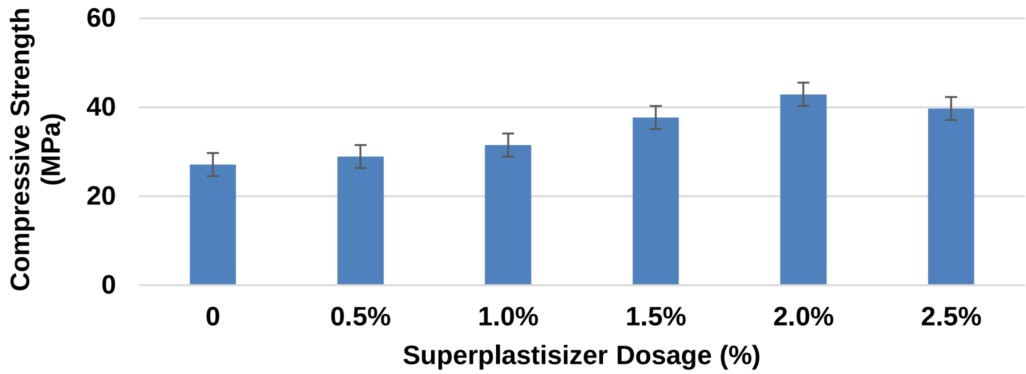
The bellow Figure (a) (b) and (c) shows the 3rd, 7th and 28th days of the concrete compressive strength test results of concrete containing SASplastSP60 HRWRAs or superplasticizer with different dosages.



(a)



(b)



(c)

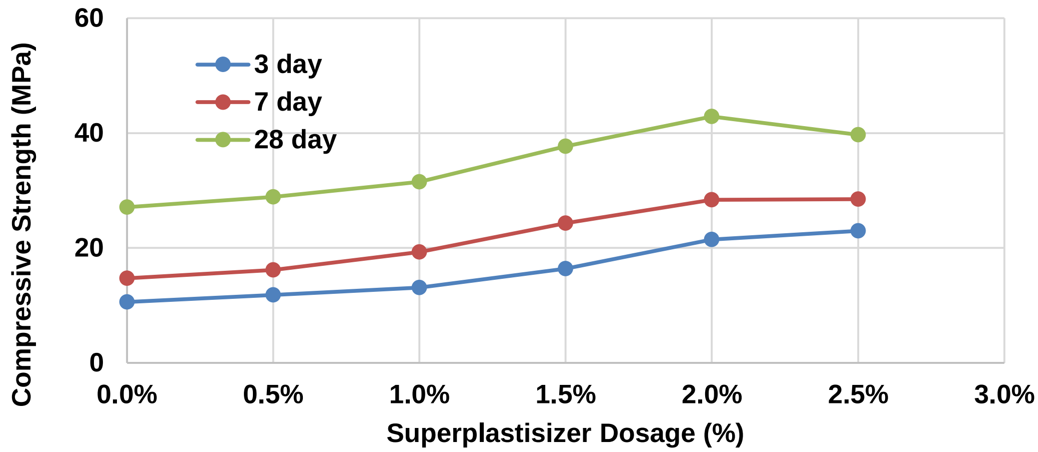


Figure 4-3 Compressive Strength test result of Concrete with and Without SAS plast SP60 HRWRAs

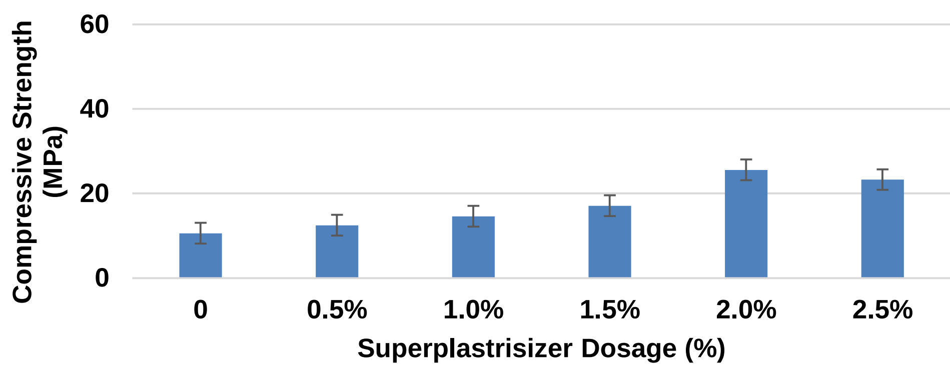
Table 4-9: The percentage increment (%) to the control mix of the compressive strength of the concrete. For HRWRAs or Superplasticizer of SASplastSP60

Dosage of HRWRAs or Superplasticizer	3 day	7 day	28 day
0	-	-	-
0.5	11.3	10.2	6.64
1	23.6	31.3	16.2
1.5	54.7	65.3	39.1
2	102.8	93.2	58.3
2.5	116.9	93.8	46.5

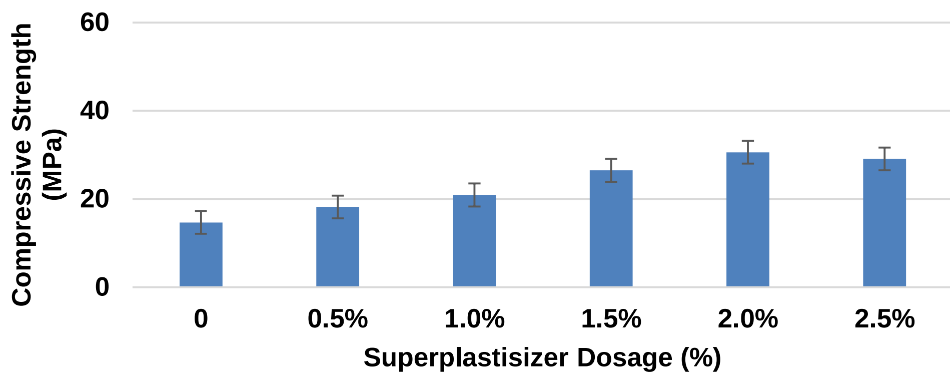
Table 4-10: Compressive Strength test results of MegaFlow SP1 with different dosage

Admixture dosage (%)	Slump (mm)	3rd days		Average Comp. strength (Mpa)	7th days		Average Comp. strength (Mpa)	28th days		Average Comp. strength (Mpa)
		Failure Load (KN)	Comp. Strength (Mpa)		Failure Load (KN)	Comp. Strength (Mpa)		Failure Load (KN)	Comp. Strength (Mpa)	
0.5%	50	278.6	12.4	12.5	420.2	18.7	18.2	712.8	31.7	32.2
		295.7	13.1		402.5	17.9		735.9	32.7	
		270.2	12.0		408.2	18.1		726.3	32.3	
1%	52	326.6	14.5	14.6	460.9	20.4	20.9	788.3	35.1	34.7
		335.6	14.9		453.9	20.1		792.1	35.1	
		324.0	14.0		502.8	22.3		762.3	33.8	
1.5%	50	401.1	17.8	17.1	605.4	26.8	26.5	901.2	40.1	40.4
		377.1	16.7		592.1	26.2		938.2	41.6	
		376.8	16.7		596.3	26.4		890.1	39.5	
2%	51	581.6	25.8	25.6	687.4	30.5	30.6	975.4	43.4	43.0
		570.4	25.4		688.2	30.5		959.7	42.7	
		574.8	25.6		689.6	30.7		966.4	42.9	
2.5%	51	524.5	23.3	23.3	659.2	29.2	29.1	915.1	40.7	40.4
		520.4	23.1		648.6	28.8		907.1	40.2	
		526.2	23.4		652.4	28.9		903.6	40.2	

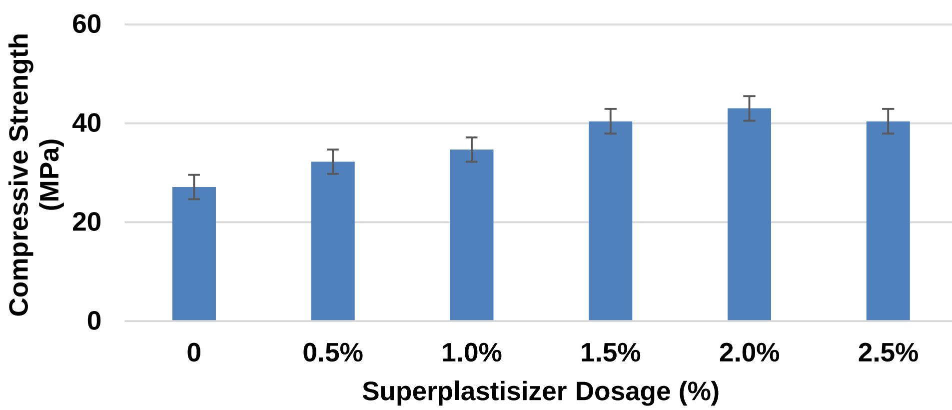
The bellow figure (a) (b) and (c) shows the 3rd, 7th and 28th days of the concrete compressive strength test results respectively of concrete containing MegaFlowSP1 HRWRAs or superplasticizer with different dosages.



(a)



(b)



(c)

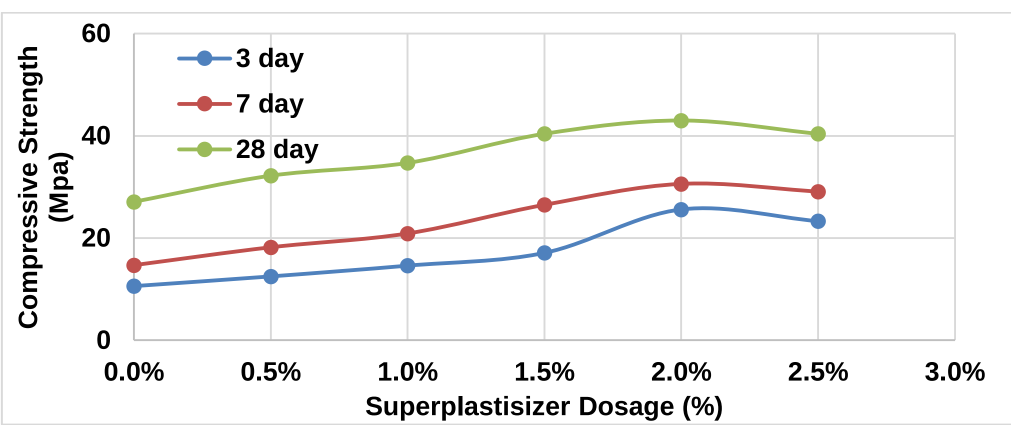


Figure 4-4 Compressive Strength test result of Concrete with and Without MegaFlow SP1 HRWRAs

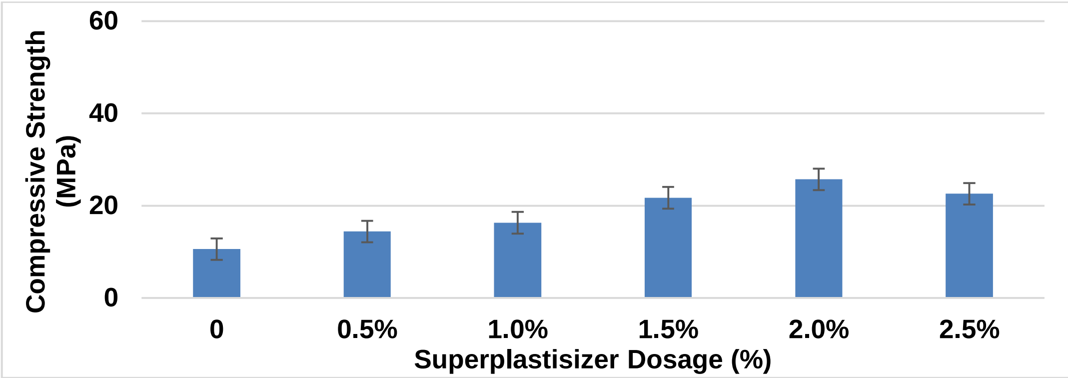
Table 4-11: The percentage increment to the control mix of the compressive strength of the concrete. For HRWRAs or Superplasticizer of MegaFlowSP1

Dosage of HRWRAs or Superplasticizer	3 day	7 day	28 day
0	-	-	-
0.5	17.9	23.8	18.8
1	37.7	42.1	28.0
1.5	61.3	80.3	49.1
2	141.5	108.2	58.7
2.5	119.8	97.9	49.1

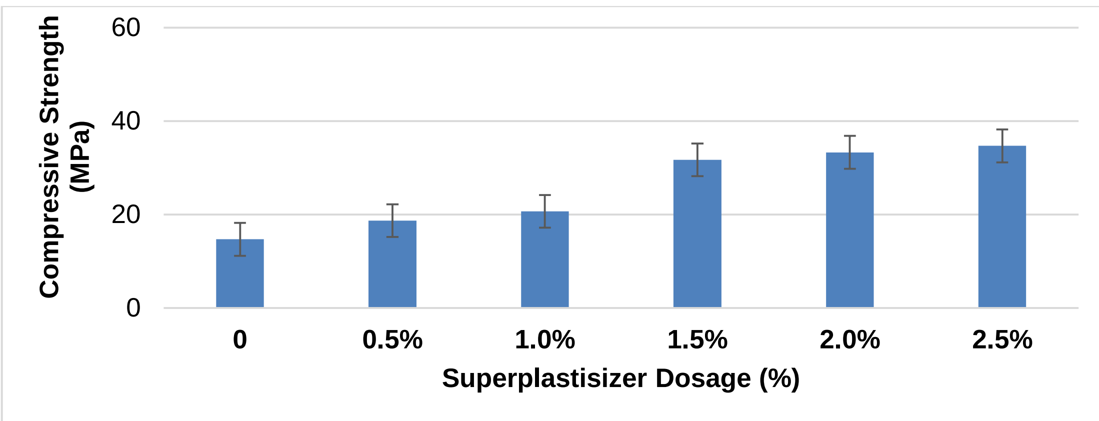
Table 4-12: Compressive Strength test results of Sikament NN with different dosage

Admixture dosage (%)	Slump (mm)	3rd days		Average Comp. strength (Mpa)	7th days		Average Comp. strength (Mpa)	28th days		Average Comp. strength (Mpa)
		Failure Load (KN)	Comp. Strength (Mpa)		Failure Load (KN)	Comp. Strength (Mpa)		Failure Load (KN)	Comp. Strength (Mpa)	
0.5%	50	324.8	14.4	14.4	425.6	18.9	18.7	728.4	32.4	32.8
		332.8	14.7		409.6	18.2		741.3	32.9	
		319.7	14.2		428.4	19.0		743.1	33.0	
1%	52	375.9	16.6	16.3	463.1	20.5	20.7	784.4	34.8	34.7
		360.6	16.1		466.1	20.7		766.6	34.0	
		370.1	16.4		474.7	21.0		796.6	35.3	
1.5%	50	480.2	21.3	21.7	716.9	31.8	31.7	1041.5	46.2	46.4
		493.7	21.9		655.6	29.5		1064.7	47.2	
		494.7	22.0		745.1	33.9		1034.4	45.9	
2%	51	574.8	25.5	25.7	743.6	13.2	33.3	1101.4	48.9	48.2
		581.6	25.8		727.9	32.4		1063.1	47.3	
		577.1	25.6		775.1	34.5		1090.1	48.5	
2.5%	51	504.8	22.4	22.6	702.6	31.2	34.7	929.5	41.2	41.0
		510.2	22.6		698.9	31.1		916.2	40.7	
		514.3	22.8		712.5	31.7		923.8	41.1	

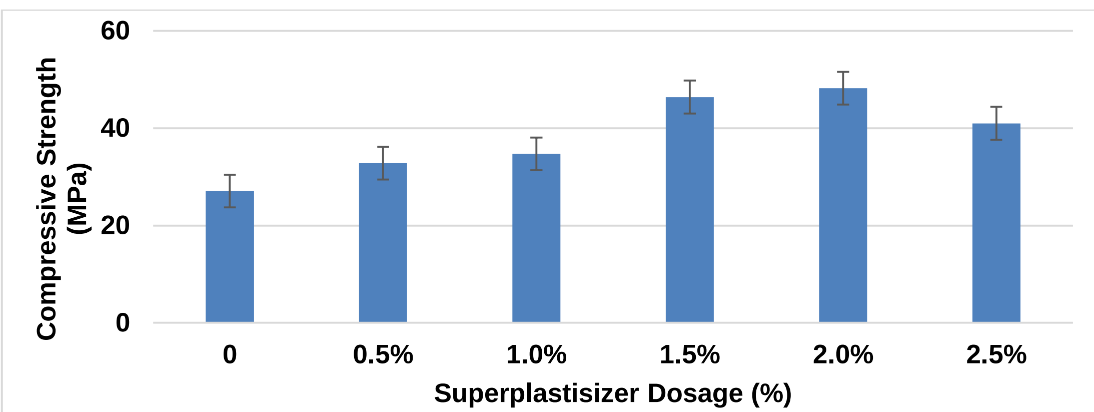
The bellow figure (a) (b) and (c) shows the 3rd, 7th and 28th days of the concrete compressive strength test results respectively of concrete containing SikamentNN HRWRAs or superplasticizer with different dosages.


Compressive Strength (MPa)
60
40
20
0
0
0.5%
1.0%
1.5%
2.0%
2.5%
Superplastisizer Dosage (%)

(a)


Compressive Strength (MPa)
60
40
20
0
0
0.5%
1.0%
1.5%
2.0%
2.5%
Superplastisizer Dosage (%)

(b)


Compressive Strength (MPa)
60
40
20
0
0
0.5%
1.0%
1.5%
2.0%
2.5%
Superplastisizer Dosage (%)

(c)

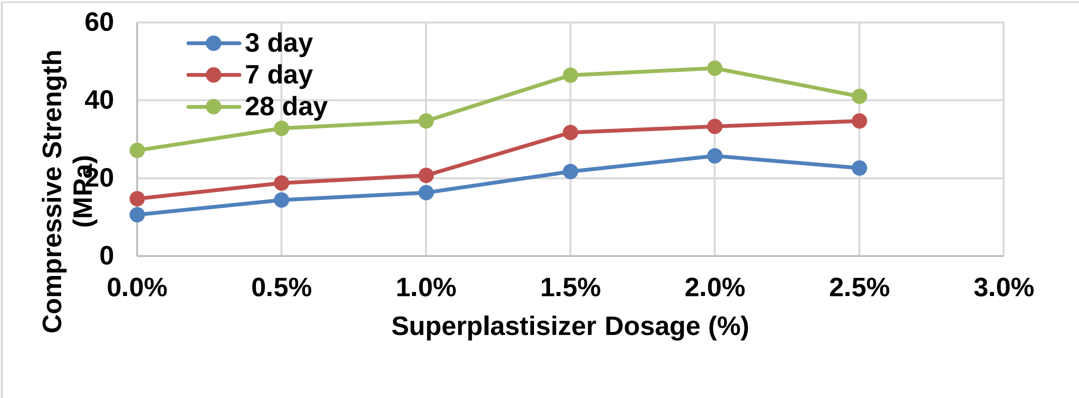


Figure 4-5 Compressive Strength of Concrete with and Without Sikament NN Superplasticizer

Table 4-13: The percentage increment to the control mix of the compressive strength of the concrete. For HRWRAs or Superplasticizer of Sikament NN

Dosage of HRWRAs or Superplasticizer	3 day	7 day	28 day
0	-	-	-
0.5	35.8	27.2	21.0
1	53.7	40.8	28.1
1.5	104.7	115.6	71.2
2	142.5	126.5	77.8
2.5	113.2	136.1	51.2

As revealed on the above tables and Figures the 28^{th} day compressive strength value of C-25-reference mix laboratory outcomes 27.1 MPa where the concrete mix with 0.5% Type-F HRWRAs of SASPlast SP60, MegaFlow SP1, Sikament NN gave 28.9 MPa, 32.2 MPa and 32.8 MPa respectively for an equal slump of 52 mm and w/c of 0.52. Which is 6.64%, 18.8%, and 21.03% greater than the reference mix. The result indicates that even if all the three selected HRWRAs in the same group of Type-F SASPlast SP60 has smaller increment comparing with the other HRWRAs. And all are not complying the target mean strength, therefore, this dosage is not advised for C-25 concrete grade and by PPC cement.

The 28^{th} day compressive strength of C-25- reference mix is 27.1 MPa where concrete mix with 1% Type-F HRWRA of SASPlast SP60,MegaFlow SP1,Sikament NN gave 31.5 MPa,34.7MPa and 34.7MPa respectively for an equal slump of 52 mm and w/c of 0.52.which is 16.2%,28.0%,28.0% increment from the reference mix which is 27.1MPa. The results indicate via 1% dosage and MegaFlow SP1 and Sikament NN are almost the same increment and both comply the target mean strength which is 33.3 MPa but SASPlast SP60 less than the target mean strength, therefore Sikament NN and MegaFlow SP1 HRWRAs is better designed for 1% dosage.

.The 28th day compressive strength of C-25- reference mix is 27.1 MPa where concrete mix with 1.5% Type-F HRWRA of SASPlast SP60,MegaFlow SP1,Sikament NN gave 37.7 MPa,40.4 and 46.4 respectively for an equal slump of 52 mm and w/c of 0.52.which is 39.1%,49.1%,71.2% increment from the reference mix. The results indicate through 1.5% dosage Sikament NN greater than MegaFlow SP1 and SASPlast SP60 are stood 2nd and 3rd therefore these HRWRAs better designed for 1.5% dosage succession of.

The 28th day compressive strength of C-25- reference mix is 27.1 MPa where concrete mix with 2% Type-F HRWRA of SASPlast SP60,MegaFlow SP1,Sikament NN gave 42.9 MPa,43.0 and 48.2 respectively for an equal slump of 52 mm and w/c of 0.52.which is 58.3%,58.7%,77.9% increment from the reference mix. The results indicate by 2% dosage SASPlast SP60 and MegaFlow SP1almost the same increment but Sikament NN greater than the others, therefore Sikament NN HRWRAs is better designed for 2% dosage.

The 28th day compressive strength of C-25- reference mix is 27.1 MPa where concrete mix with 2.5% Type-F HRWRA of SASPlastSP60,MegaFlow SP1, Sikament NN gave 39.7 MPa,40.4 and 41.0 respectively for an equal slump of 52 mm and w/c of 0.52.which is 46.5%,49.1%,51.2% increment from the reference mix which is 27.1MPa.From this in conclusion by 2.5% dosage all HRWRAs almost the same increment from the reference mix but it decrease from 2% dosage compressive strength value ,therefore, HRWRAs for C25 concrete mix 2% is the optimum dosage.

4.3 Optimum content of High Range Water Reducing Admixture (HRWRAs) or Superplasticizer

In the production of high-strength concrete is beneficial to increase the dosage of the admixture. This usually provided extra water reduction and typically a delay in setting time and slow early-strength gain. Concrete with slow-early strength gain generally exhibits higher later strengths. Generally, more than two additions are less effective and concrete may lose its workability faster than with a single dose. Re-dosing may result in lower air content, on the order of one to two percentage points for each re-dose. When re-dosages are used, the concrete might have a greater potential for bleeding, segregation, and possible retardation of setting time. Experimental studies confirmed after 2% HRWRAs addition on the mix the 28th day compressive strength dropped by 7.5%, 6.1% and 14.9% SASplast SP60, MegaFlowSp1 and Sikament NN respectively.

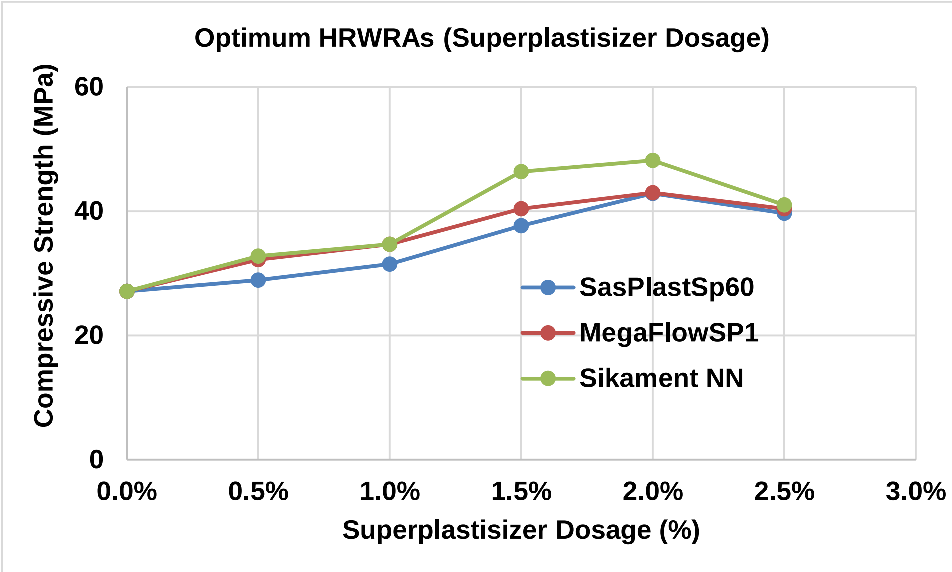


Figure 4-6 Optimum content of 28th day Compressive strength with different dosage and Type of HRWRAs

4.4 Finite Element Analysis of Concrete Specimen

Concrete is brittle in nature and its strength depends on a lot of factors including curing time, temperature, water cement ratio, moisture condition etc. Hence the modelling of the concrete specimen should be done carefully. ABAQUS software provides the capability of simulating the damage using concrete damaged plasticity (CDP) model. CDP model has the potential to represent complete inelastic properties/characteristics of concrete both in tension and in compression including damage characteristics.

4.4.1 Material Properties

A 3D nonlinear, quasi-static finite element model was developed using ABAQUS/Standard module to study the properties/characteristics of the concrete cube containing HRWRAs under compression. Material properties required to calculate the concrete damage parameters as input variable to the FE model were obtained from the stress-strain relations under uniaxial tension and compression loading.

4.4.1.1 Application of CDP Parameters in FE Programs

The dilation angle was equal to volume strain over shear strain. The dilation angle for concrete was usually 20^0 to 40^0, for this research assume to take 27^0, the default flow potential eccentricity was $\varepsilon = 0.1$, The ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress was given by fb0/fc0 and its default value was 1.16 and null velocity parameter based on the Abaqus software for normal concrete.

According to the experiment and the aforementioned damage plasticity formulation derived in the chapter Three, without adding HRWRAs 0% and for each type of HRWRAs adding 0.5%, 1%, 1.5%, 2% and 2.5% in the concrete mix the 28th day compressive and tensile strength as well as Modulus of Elasticity and Mass density values revealed on the table below

Table 4-14 Compressive Strength plus Modulus of elasticity and Mass density values

HRWRAs (Superplasticizer) Dosage	HRWRAs (Superplasticizer) Type	Average 28th day Compressive strength value (Mpa)	Tensile strength Value Ft=0.56(fc)^0.5 (ACI 318-14)	Youngus Modulus (Mpa) ACI 318-19 (4700(fc^0.5) (Comp.Str.)	Compressive strength of 28th day (Kip/in^2)	Mass Density (Kg/m^3)
0%	Control Mix	27.1	2.9	21884.04	3.92	2360.3
0.5%	Sikament NN	32.8	3.2	24075.75	4.76	2366.8
	SasPlastSP60	28.9	3.0	22599.13	4.18	2359.6
	MegaFlowSp1	32.2	3.2	23854.53	4.67	2346.3
1.0%	Sikament NN	34.7	3.3	24763.25	5.03	2343.8
	SasPlastSP60	31.5	3.1	23593.81	4.57	2354.7
	MegaFlowSp1	34.7	3.3	24763.25	5.03	2353.7
1.5%	Sikament NN	46.4	3.8	28635.31	6.73	2402.2
	SasPlastSP60	37.7	3.4	25811.52	5.46	2353.7
	MegaFlowSp1	40.4	3.6	26719.82	5.86	2408.5
2.0%	Sikament NN	48.2	3.9	29185.45	6.99	2378.2
	SasPlastSP60	42.9	3.7	27534.14	6.22	2360.6
	MegaFlowSp1	43.0	3.7	27566.21	6.23	2376.4
2.5%	Sikament NN	41.0	3.6	26917.50	5.94	2339.5
	SasPlastSP60	39.7	3.5	26487.33	5.76	2315.8
	MegaFlowSp1	40.4	3.6	26719.82	5.86	2313.6

The parameters were implemented within the framework in tabular format, that is shown in, Annex "A" Accordingly, the hardening and softening rule as well as the evolution of the scalar damage variable for compression and tension were presented for all 28th day compressive and Tensile strength concrete values including without adding any HRWRAs which value is 27.1MPa. The general framework of the damage plasticity formulation was clearly stated.

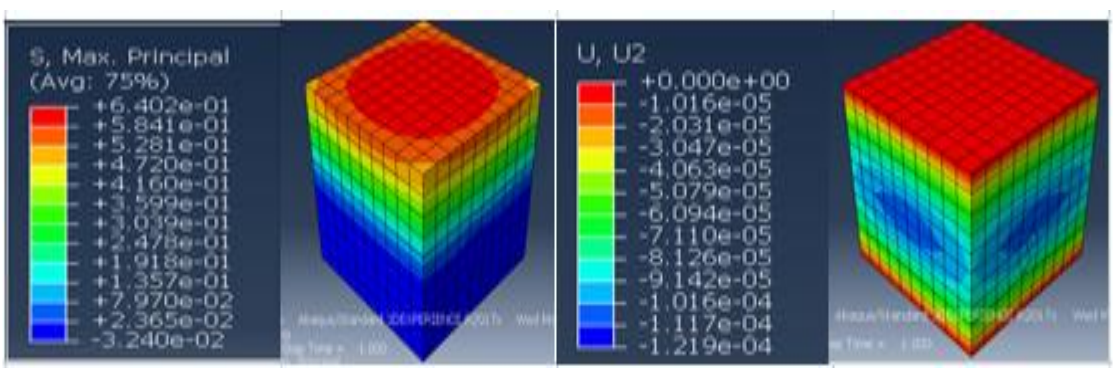
4.4.1.2 Concrete without containing HRWRAs (0% superplasticizer) Model

The Model

A concrete cube of size 150mm is modeled in ABAQUS using C3D8 element. The average compressive stress, fc=27.1MPa, ultimate strain, ε_{cu} =0.0047, and the strain at pick stress, ε_{0}=0.0024 Since the Non-linear Geometric Analysis has been selected, it refers to nonlinear strain component which in this case is logarithmic Strain. If the plastic characteristics of

material in properties module is selected and during deformation, the material has passed yielding point (by comparing maximum principal stress and yield stress of the experiment).
Three key features, including damage in compression, tension, max principal stress maximum displacement, were recorded and compared to determine the effect of the CDP method. The results were plotted to interpret the effect of the CDP method on the aforementioned HRWRAs or superplasticizer dosage in consort with type's. Model figure (a) and (b) displayes the FEM Load and figure (c) and (d) displacement. The contour of horizontal stress during the peak vertical load are shown in the above figures. The tensile stress is generated inside samples between up and down loading strips, in the middle of the sample, the cracks first occurs due to the existence of tensile stress concentration, and then it develops to both ends, eventually leads to splitting failure of samples (the CDP model reflects the development of cracks in ABAQUS by tensile damage and compression damage changes).The lateral strain firstly increases slowly with increasing vertical displacement. Once the loading process approach to peak point, the lateral strain increases sharply which indicates that cracks are emerging in the region of sample.

The damage in compression and tension, stress distribution, and mid-point deformation of concrete cube are shown in Figure. 4–7 (a), (b), (c) and (d) for C25 concrete without adding HRWRAs. As demonstrated in these figures, the stressed concrete cube failed when the damage in compression strain reached 0.001202.

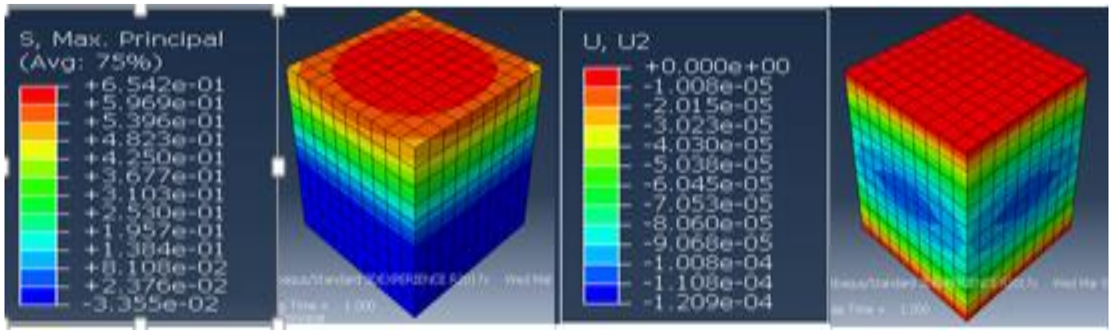


(a) (b) (c) (d)

Figure 4-7: The concrete mesh Model of without adding HRWRAs or superplasticizer

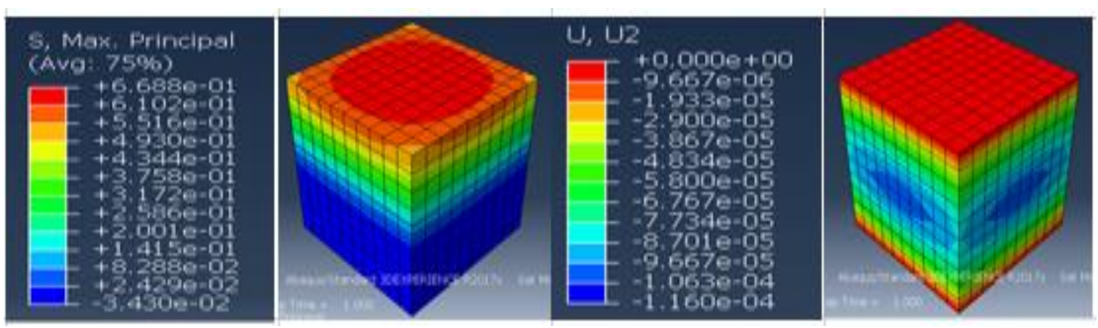
4.4.1.3 Concrete Containing HRWRAs (Superplasticizer) of 0.5 % dosage Model

A concrete cube of size 150mm is modeled in ABAQUS using C3D8 element. The concrete mesh model of s max principal and U2 of the average compressive stress, fc=28.9MPa, ultimate strain, ε_{cu} =0.004515, and the strain at pick stress, ε_{0}=0.001221 when containing SasplastSP60 as shown the below Figure 4-8 (a), (b), (c) and (d). The average compressive stress, fc=32.8MPa, ultimate strain, ε_{cu} =0.004589, and the strain at pick stress, ε_{0}=0.001158 when containing Sikament NN. The average compressive stress, fc=28.9MPa, ultimate strain, ε_{cu} =0.004599, and the strain at pick stress, ε_{0}=0.001170 when containing MegaFlowSP1. as shown the below Figure 4-8,Figure 4-9 and Figure 4-10 (a),(b),(c) and (d). As demonstrated in these figures, the stressed concrete cube failed when the damage in compression strain reached 0.001202, 0.001158 and 0.001170 respectively.



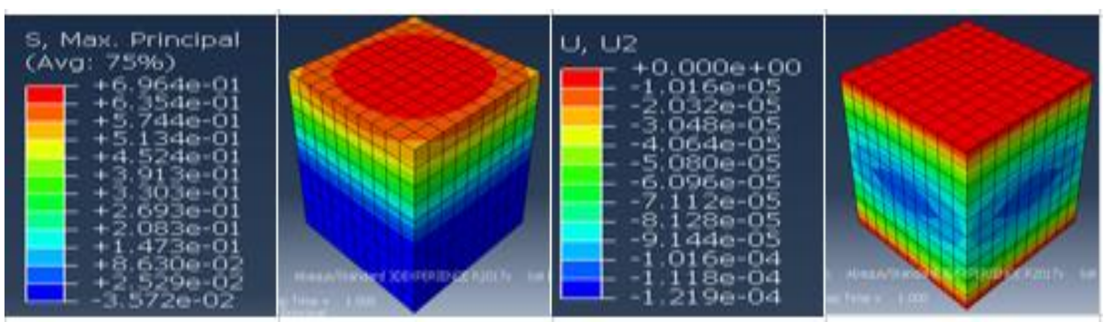
(a) (b) (c) (d)

Figure 4-8: The concrete mesh Model of SasplastSp60 HRWRAs (Superplasticizer) 0.5%



(a) (b) (c) (d)

Figure 4-9: The concrete mesh Model of Sikament NN HRWRAs (Superplasticizer) 0.5%



(a) (b) (c) (d)

Figure 4-10 : The concrete mesh Model of MegaFlowSP1 HRWRAs (Superplasticizer) 0.5%

The below table at column one shows the experimental result of the average 28th day failer load in use from the above indicated Table 4-8,Table 4-10 and Table 4-12; SASplastSP60,MegaFlowSP1 and Sikament NN respectively which concrete contained

0.5% of HRWRAs or superplastisizer dosage.However,column four failur load taken from abaqus software output after processing and modeling the compressive strength.

CDP Models	Failure Load (KN)	Compressive stress (MPa) Experment	Failure Load (KN) FEM	Compressive stress (MPa) FEM	Error (MPa)
Normal (0%)	610	27.1	640	28.44	1.34
Sikament NN	737	32.8	668	29.69	-3.11
MegaFlowSP1	725	32.2	696	30.93	-1.27
SasplastSP60	649	28.9	654	29.07	0.17

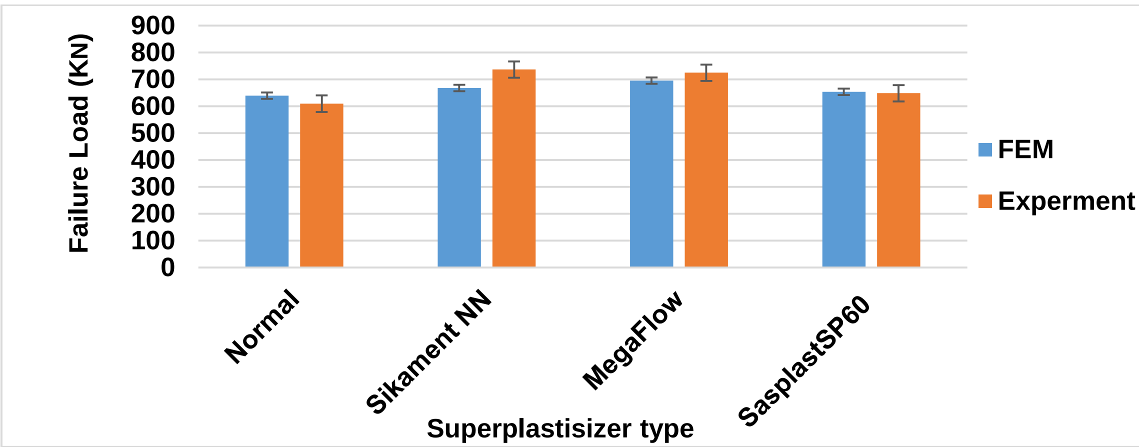
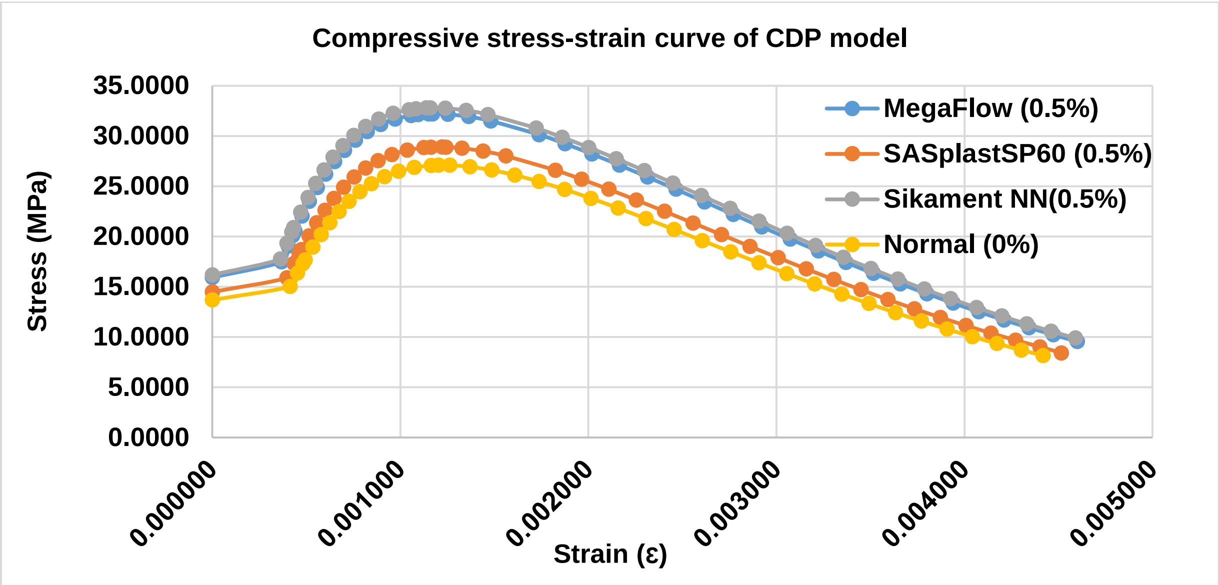
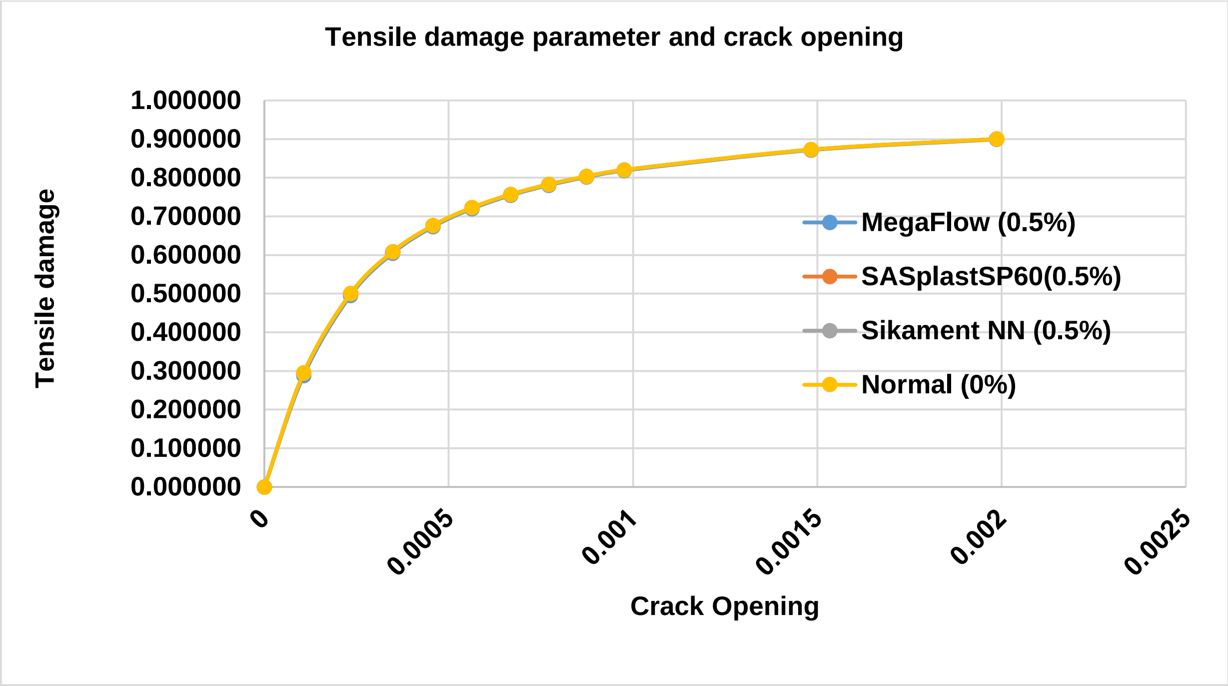


Figure 4-11 Failure Load of FEM and Experiment of 0.5 % HRWRAs (Superplasticizer) dosage

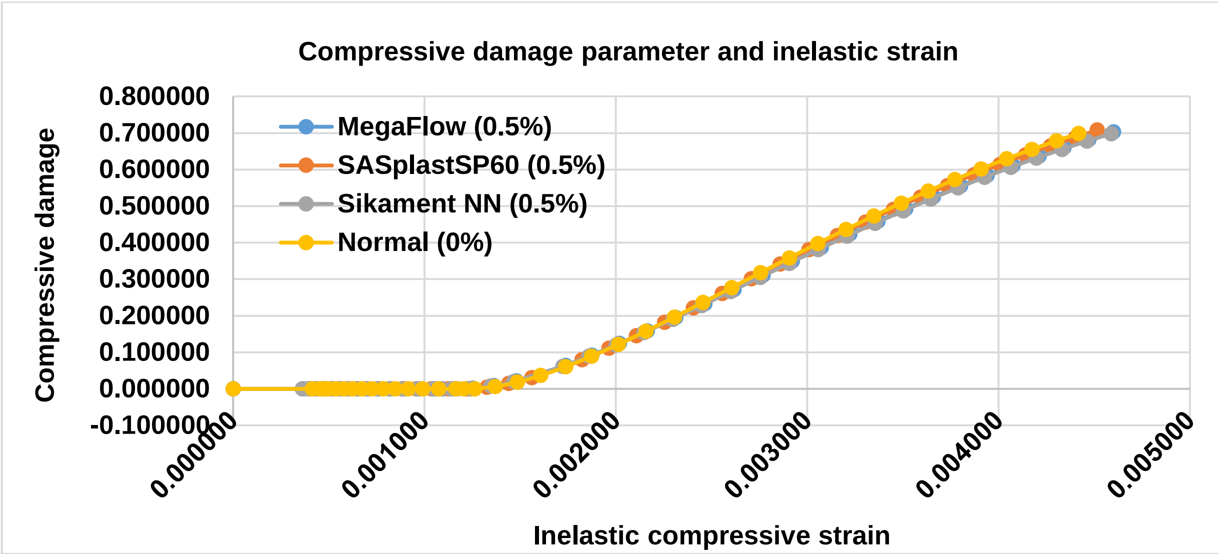
Through respect to the results obtained and summarized in the above table and figure 4-11 is observed that the compressive stress values of the available concrete damage plasticity models and experment had good agreement. Compressive and tensile stress-strain curve, tensile damage parameter and crack opening curve, compressive damage parameter and inelastic strain curves of CDP model are illustrated the below figures. Compressive stress-strain curve of CDP model of (0.5%) HRWRAs dosage are shown in Figure 4-12 (a),(b) and (c).In Figure 4-12 (a) Compressive and tensile stress-strain curve.Then, as shown in Figure 4-12(b) Tensile damage parameter and crack opening and then Figure 4-12 (c) Compressive damage parameter and inelastic strain curves of CDP model.


Compressive stress-strain curve of CDP model
Stress (MPa)
35.0000
30.0000
25.0000
20.0000
15.0000
10.0000
5.0000
0.0000
0.000000
0.001000
0.002000
0.003000
0.004000
0.005000
Strain (ε)
MegaFlow (0.5%)
SASplastSP60 (0.5%)
Sikament NN(0.5%)
Normal (0%)

(a)


Tensile damage parameter and crack opening
Tensile damage
1.000000
0.900000
0.800000
0.700000
0.600000
0.500000
0.400000
0.300000
0.200000
0.100000
0.000000
0
0.0005
0.001
0.0015
0.002
0.0025
Crack Opening
MegaFlow (0.5%)
SASplastSP60(0.5%)
Sikament NN (0.5%)
Normal (0%)

(b)

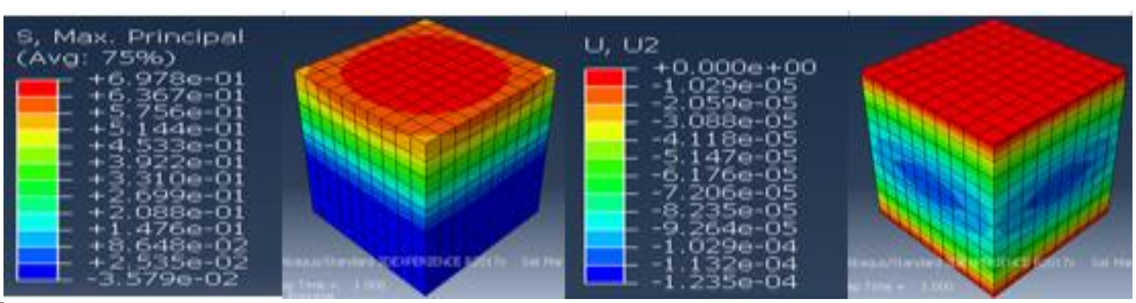


(c)

Figure 4-12: Compressive stress-strain curve of CDP model of (0.5%) HRWRAs dosage

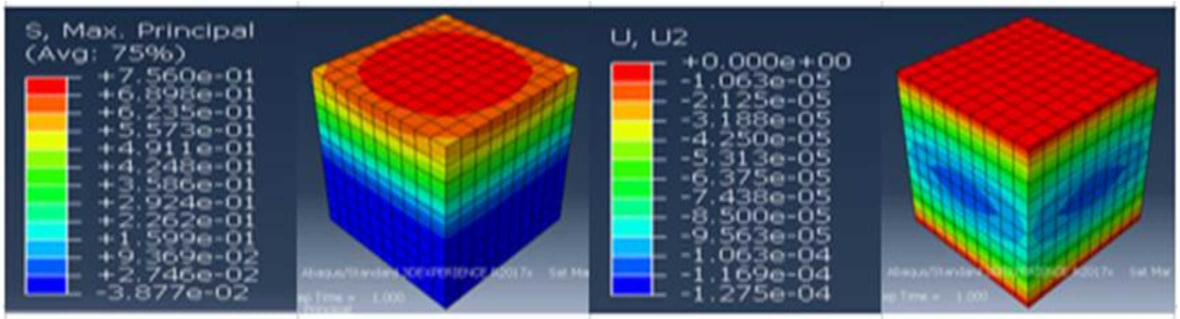
4.4.1.4 Concrete Containing HRWRAs (Superplasticizer) of 1 % dosage Model

A concrete cube of size 150mm is modeled in ABAQUS using C3D8 element. The concrete mesh model of s max principal and U2 of the average compressive stress, fc=31.5MPa, ultimate strain, $\mathcal{E}_{cu}$ =0.004611, and the strain at pick stress, $\mathcal{E}_{0=}$0.001195 when containing SasplastSP60. The average compressive stress, fc=32.8MPa, ultimate strain, fc=34.7MPa, ultimate strain, $\mathcal{E}_{cu}$ =0.004683, and the strain at pick stress, $\mathcal{E}_{0=}$0.001199 when containing Sikament NN. The average compressive stress, fc=28.9MPa, ultimate strain, fc=34.7MPa, ultimate strain, $\mathcal{E}_{cu}$ =0.004683, and the strain at pick stress, $\mathcal{E}_{0=}$0.001199 when containing MegaFlowSP1.As shown the below Figure 4-13, Figure 4-14, and Figure 4-15 (a), (b), (c) and d) demonstrated in these figures, the stressed concrete cube failed when the damage in compression strain reached 0.001195, 0.001199 and 0.001199 respectively.



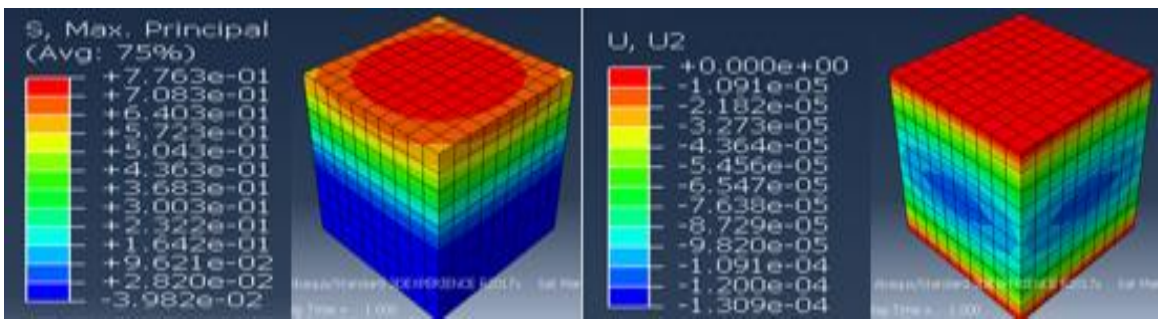
(a) (b) (c) (d)

Figure 4-13: The concrete mesh Model of SasplastSp60 HRWRAs (Superplasticizer) 1%



(a) (b) (c) (d)

Figure 4-14: The concrete mesh Model of Sikament NN HRWRAs (Superplasticizer) 1%



(a) (b) (c) (d)

Figure 4-15: The concrete mesh Model of MegaFlow SP1 HRWRAs (Superplasticizer) 1%

The underneath table at column one appears the test result of the normal 28th day failure stack in utilize from the over shown Table 4-8, Table 4-10 and Table 4-12; SASplastSP60, MegaFlowSP1 and Sikament NN separately which concrete contained 1% of HRWRAs or superplasticizer dosage. However, column four failure stack taken from abaqus program yield after handling and modeling the compressive quality.

CDP Models	Failure Load (KN)	Compressive stress (MPa) Experment	Failure Load (KN) FEM	Compressive stress (MPa) FEM	Error (MPa)
Normal (0%)	610	27.1	640	28.44	1.34
Sikament NN	783	32.8	756	33.60	-1.1

MegaFlowSP1	725	32.2	776	34.49	-0.1
SasplastSP60	649	28.9	697	30.98	-0.72

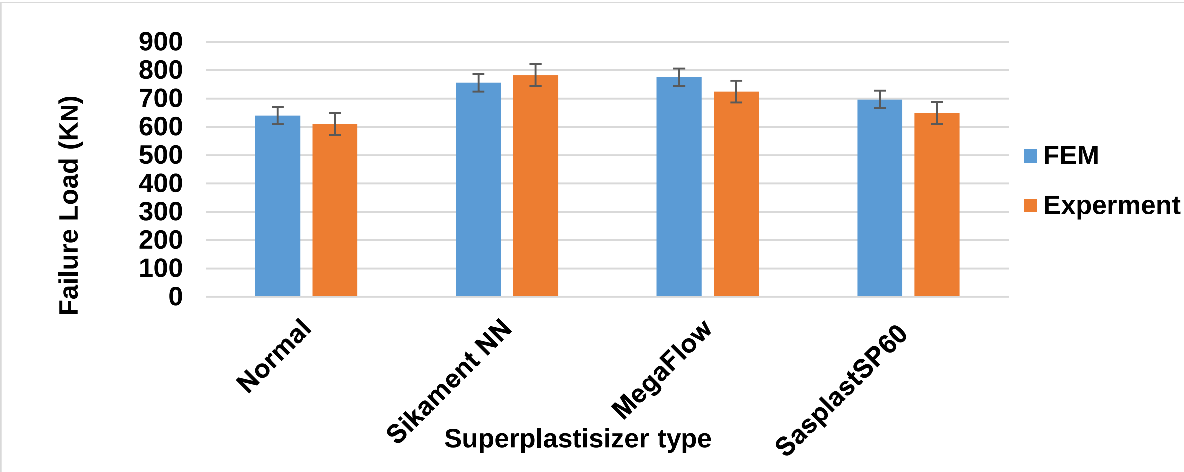
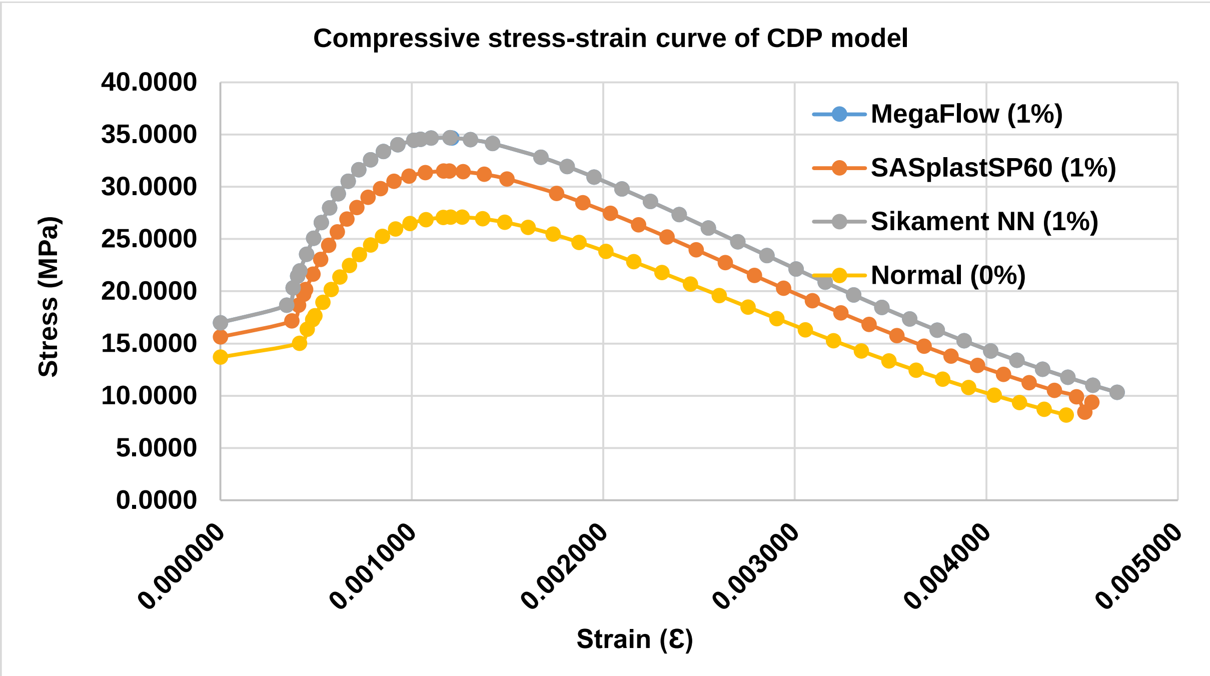
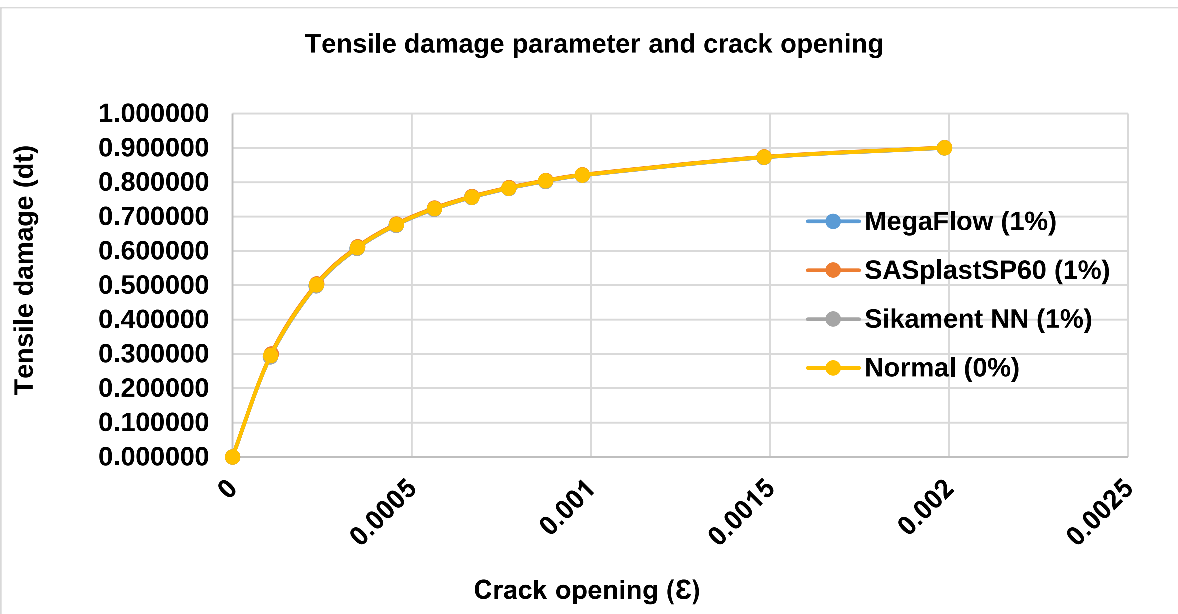


Figure 4-16: Failure Load of FEM and Experiment of 1% HRWRAs (Superplasticizer) dosage

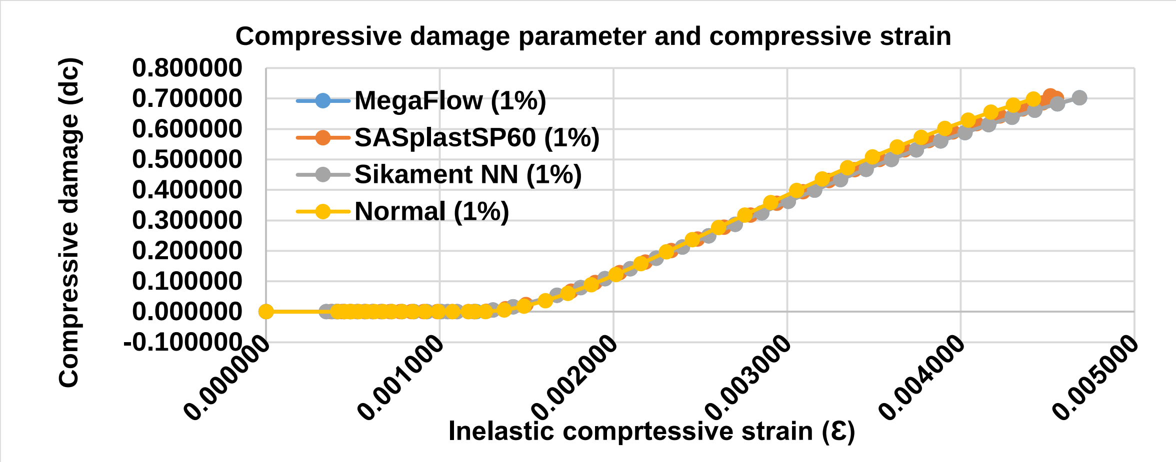
The lateral strain increases sharply which indicates that cracks are emerging in the region of the sample with respect to the results obtained and summarized in the above table and figure it was observed that the compressive stress values of the available concrete damage plasticity models and experiment had good agreement. Compressive stress-strain curve of CDP model of (1%) HRWRAs dosage are shown in Figure 4-17 (a),(b) and (c).In Figure 4-17 (a) Compressive and tensile stress-strain curve.Then, as shown in Figure 4-17 (b) Tensile damage parameter and crack opening and then Figure 4-17 (c) Compressive damage parameter and inelastic strain curves of CDP model.


Compressive stress-strain curve of CDP model
Stress (MPa)
40.0000
35.0000
30.0000
25.0000
20.0000
15.0000
10.0000
5.0000
0.0000
0.000000
0.001000
0.002000
0.003000
0.004000
0.005000
Strain (Ɛ)
MegaFlow (1%)
SASplastSP60 (1%)
Sikament NN (1%)
Normal (0%)

(a)


Tensile damage parameter and crack opening
Tensile damage (dt)
1.000000
0.900000
0.800000
0.700000
0.600000
0.500000
0.400000
0.300000
0.200000
0.100000
0.000000
0
0.0005
0.001
0.0015
0.002
0.0025
Crack opening (Ɛ)
MegaFlow (1%)
SASplastSP60 (1%)
Sikament NN (1%)
Normal (0%)

(b)

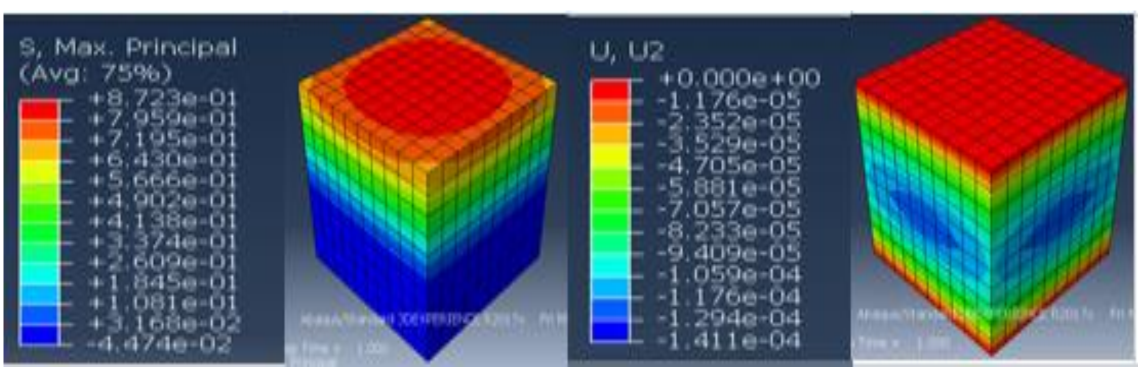


(c)

Figure 4-17: Compressive stress-strain curve of CDP model of (1%) HRWRAs dosage

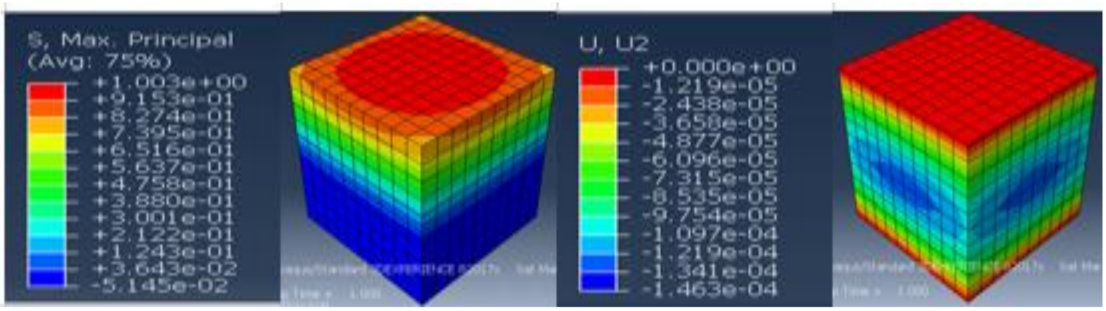
4.4.1.5 Concrete Containing HRWRAs (Superplasticizer) of 1.5 % dosage Model

A concrete cube of size 150mm is modeled in ABAQUS using C3D8 element. The concrete mesh model of s max principal and U2 of the average compressive stress, fc=37.7MPa, ultimate strain, ε_{cu} =0.004551, and the strain at pick stress, ε_0=0.001139 when containing SasplastSP60. The average compressive stress, fc=46.4MPa, ultimate strain, ε_{cu} =0.005233, and the strain at pick stress, $\varepsilon_{0=}$0.001080 when containing Sikament NN. The average compressive stress, fc=40.4MPa, ultimate strain, ε_{cu} =0.004881, and the strain at pick stress, $\varepsilon_{0=}$0.001098 when containing MegaFlowSP1. As shown the below Figure 4-18, Figure 4-19, and Figure 4-20 (a), (b), (c) and d) demonstrated in these figures, the stressed concrete cube failed when the damage in compression strain reached 0.001139, 0.001199 and 0.001199 respectively.



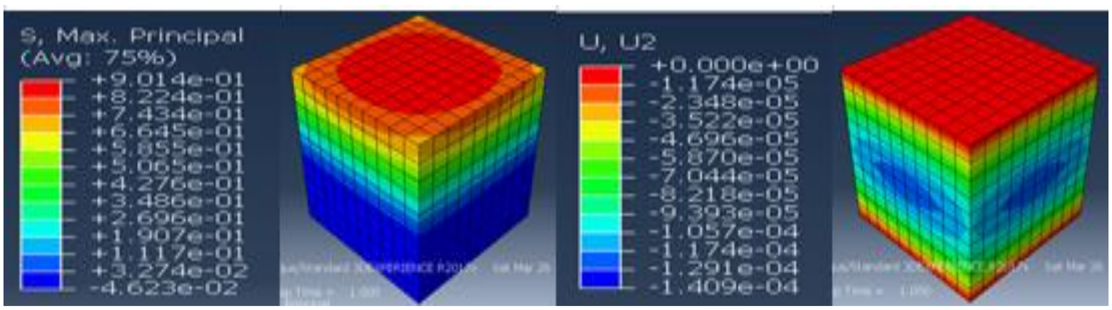
(a) (b) (c) (d)

Figure 4-18: The concrete mesh Model of SasplastSp60 HRWRAs (Superplasticizer) 1.5%



(a) (b) (c) (d)

Figure 4-19 : The concrete mesh Model of Sikament NN HRWRAs (Superplasticizer) 1.5%



(a) (b) (c) (d)

Figure 4-20: The concrete mesh Model of MegaFlowSP1 HRWRAs (Superplasticizer) 1.5%

The underneath table at column one shows up the test result of the typical 28th day failure stack in utilize from the over appeared Table 4-8,Table 4-10 and Table 4-12; SASplastSP60,MegaFlowSP1 and Sikament NN independently which concrete contained 1.5% of HRWRAs or superplasticizer dosage. However, column four failure stack taken from abaqus program surrender after dealing with and modeling the compressive quality.

CDP Models	Failure Load (KN)	Compressive stress (MPa) Experment	Failure Load (KN) FEM	Compressive stress (MPa) FEM	Error (MPa)
Normal (0%)	610	27.1	640	28.44	1.34
Sikament NN	1046.9	46.4	1003	44.6	-1.8
MegaFlowSP1	909.8	40.4	901	40.3	-0.1
SasplastSP60	848.8	37.7	872	38.8	-1.1

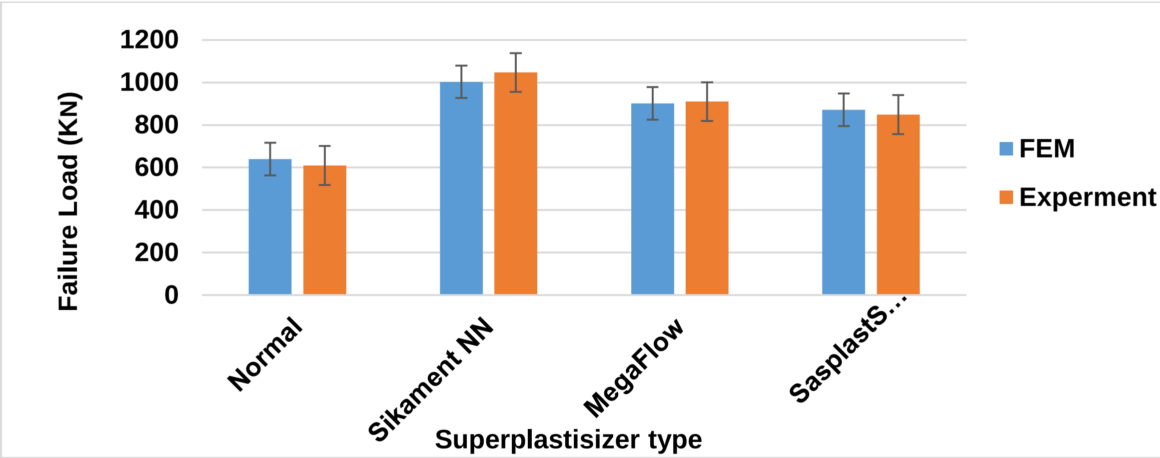
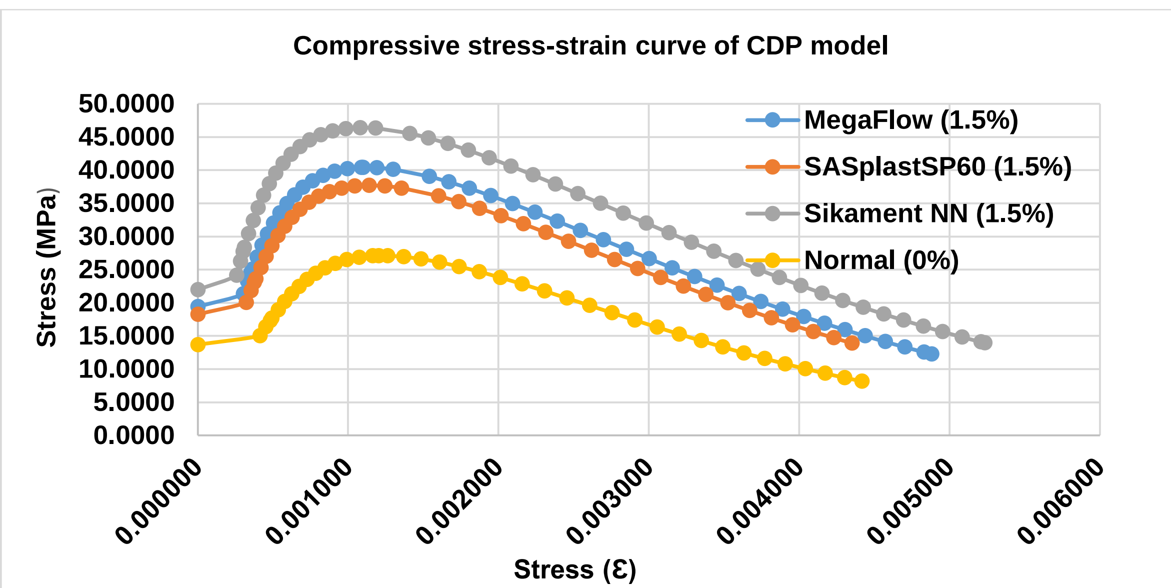
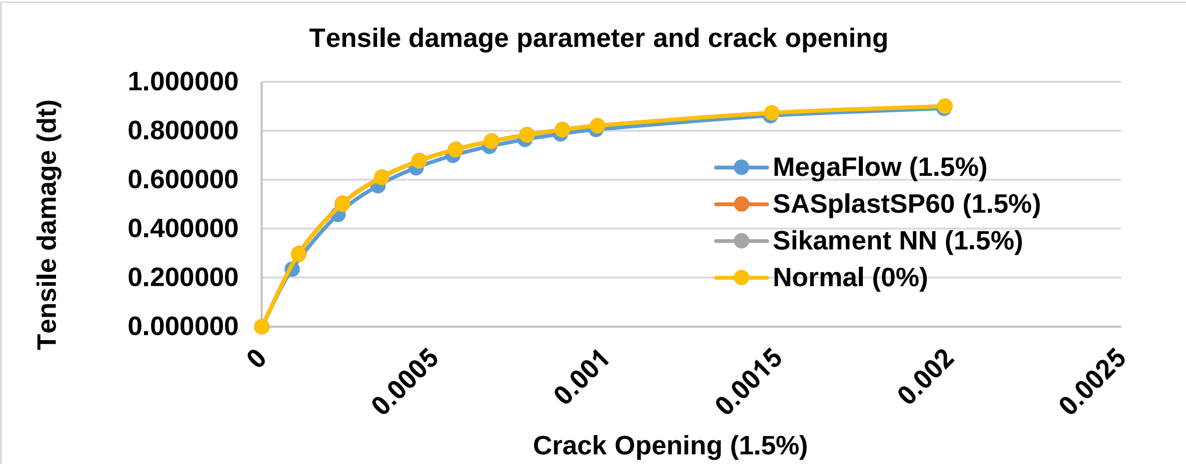


Figure 4-21: Failure Load of FEM and Experiment of 1.5 % HRWRAs (Superplasticizer) dosage

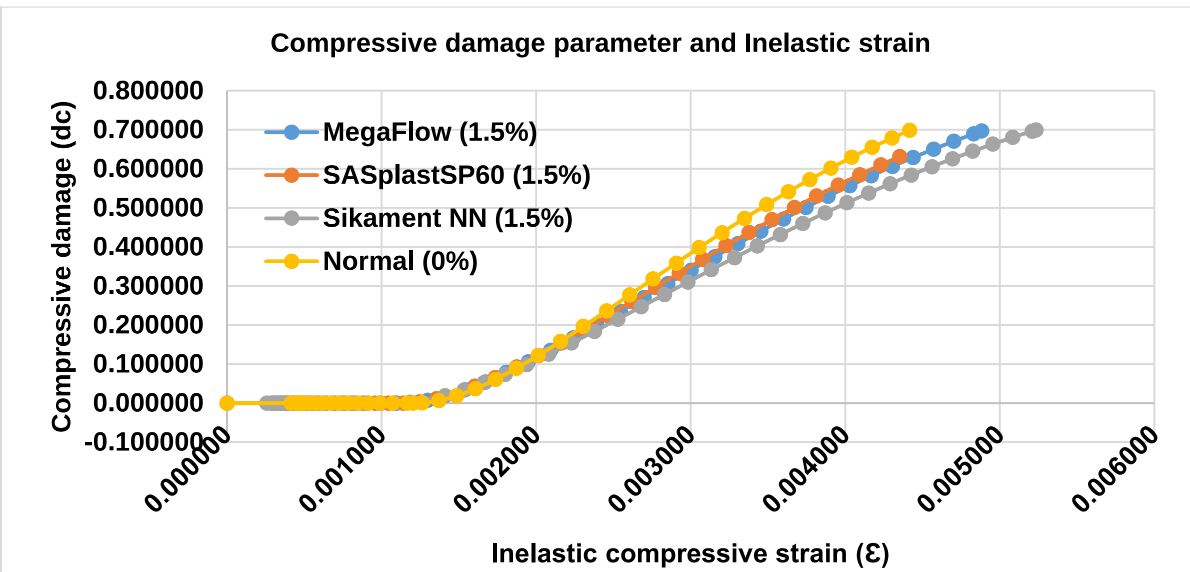
The horizontal strain increments strongly which demonstrates that breaks are rising within the locale of the test with regard to the results obtained and summarized within the over table and figure it was watched that the compressive push values of the accessible concrete harm versatility models and explore had great understanding.Compressive stress-strain curve of CDP model of (1.5%) HRWRAs dosage are shown in Figure 4-22 (a),(b) and (c).In Figure 4-22 (a) Compressive and tensile stress-strain curve.Then, as shown in Figure 4-22 (b) Tensile damage parameter and crack opening and then Figure 4-22 (c) Compressive damage parameter and inelastic strain curves of CDP model.



(a)



(b)

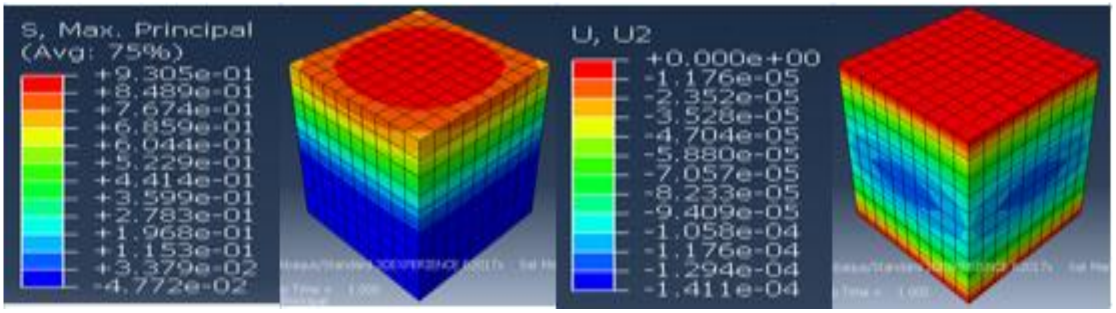


(c)

Figure 4-22 : Compressive stress-strain curve of CDP model of (1.5%) HRWRAs dosage

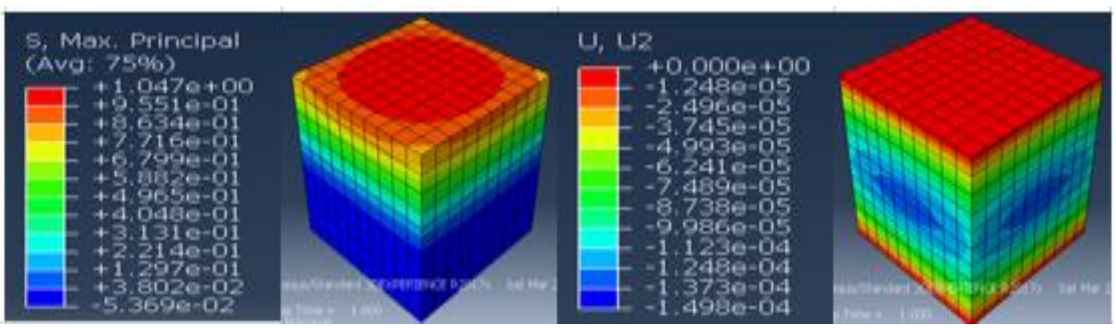
4.4.1.6 Concrete Containing HRWRAs (Superplasticizer) of 2 % dosage Model

A concrete cube of size 150mm is modeled in ABAQUS using C3D8 element. The concrete mesh model of s max principal and U2 of the average compressive stress, fc=42.9MPa, ultimate strain, Ɛcu =0.005033, and the strain at pick stress, Ɛ0=0.001142 when containing SasplastSP60. The average compressive stress, fc=48.2MPa, ultimate strain, Ɛcu =0.005354, and the strain at pick stress, Ɛ0=0.001079 when containing Sikament NN. The average compressive stress, fc=43.0MPa, ultimate strain, Ɛcu =0.005031, and the strain at pick stress, Ɛ0=0.001052 when containing MegaFlowSP1. As shown the below Figure 4-23, Figure 4-24, and Figure 4-25 (a), (b), (c) and d) demonstrated in these figures, the stressed concrete cube failed when the damage in compression strain reached 0.001142, 0.000869 and 0.001052 respectively.



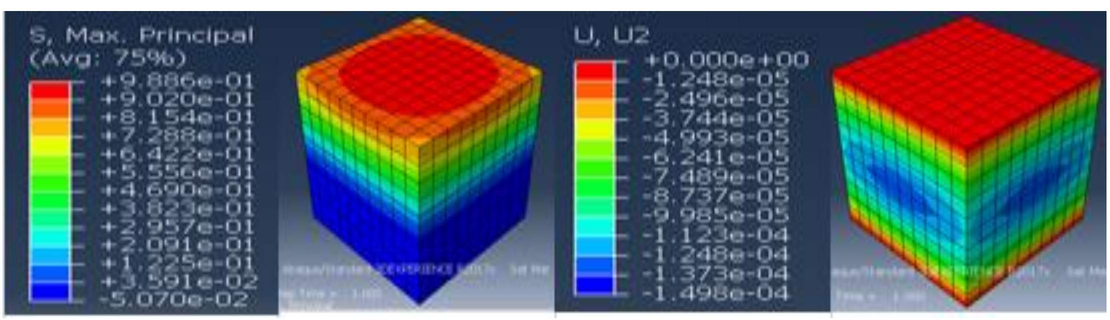
(a) (b) (c) (d)

Figure 4-23 : The concrete mesh Model of SasplastSp60 HRWRAs (Superplasticizer) 2%



(a) (b) (c) (d)

Figure 4-24: The concrete mesh Model of Sikament NN HRWRAs (Superplasticizer) 2%



(a) (b) (c) (d)

Figure 4-25: The concrete mesh Model of MegaFlowSP1 HRWRAs (Superplasticizer) 2%

The below table at column one shows up the test result of the typical 28th day failure stack in utilize from the over appeared Table 4-8,Table 4-10 and Table 4-12;

SASplastSP60,MegaFlowSP1 and Sikament NN independently which concrete contained 2% of HRWRAs or superplasticizer dosage. However, column four failure stack taken from abaqus program surrender after dealing with and modeling the compressive quality.

CDP Models	Failure Load (KN)	Compressive stress (MPa) Experment	Failure Load (KN) FEM	Compressive stress (MPa) FEM	Error (MPa)
Normal (0%)	610	27.1	640	28.44	1.34
Sikament NN	1084.9	48.2	1047	46.5	-1.7
MegaFlowSP1	967.1	43.0	988	43.9	-0.9
SasplastSP60	967.1	43.0	930	41.3	1.7

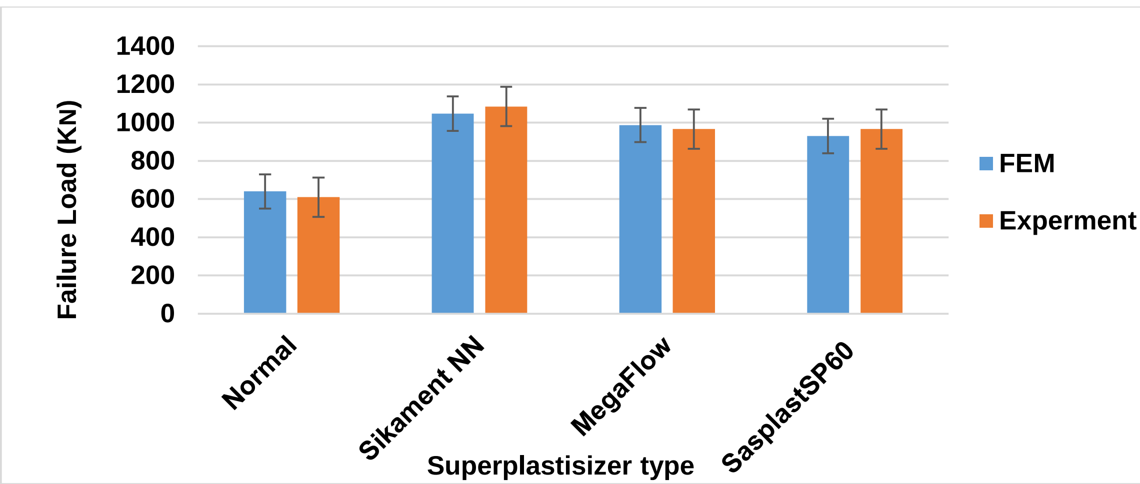
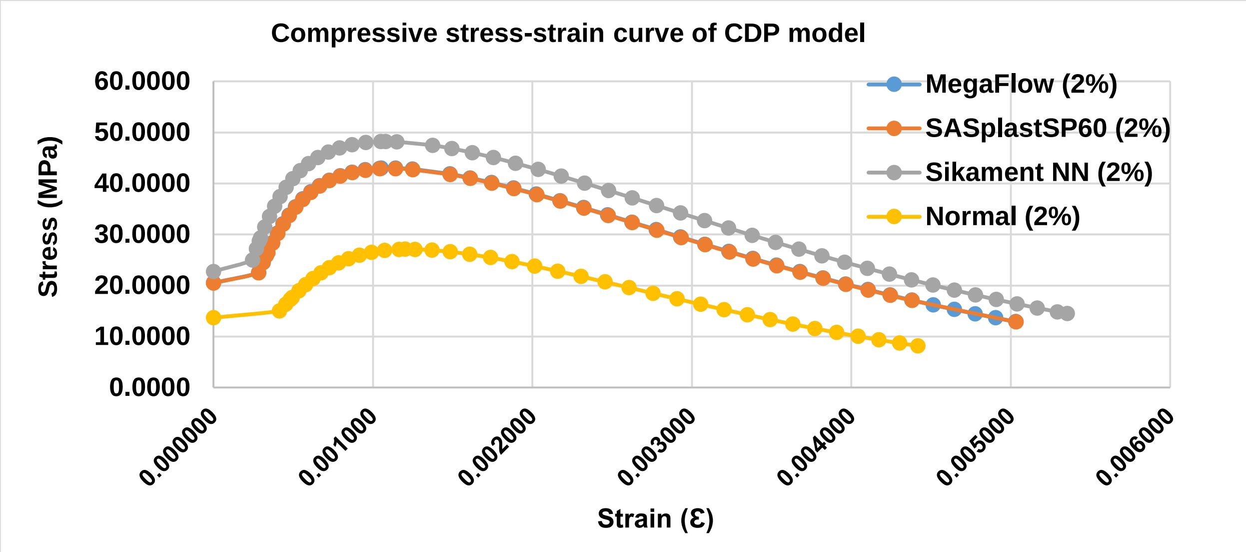
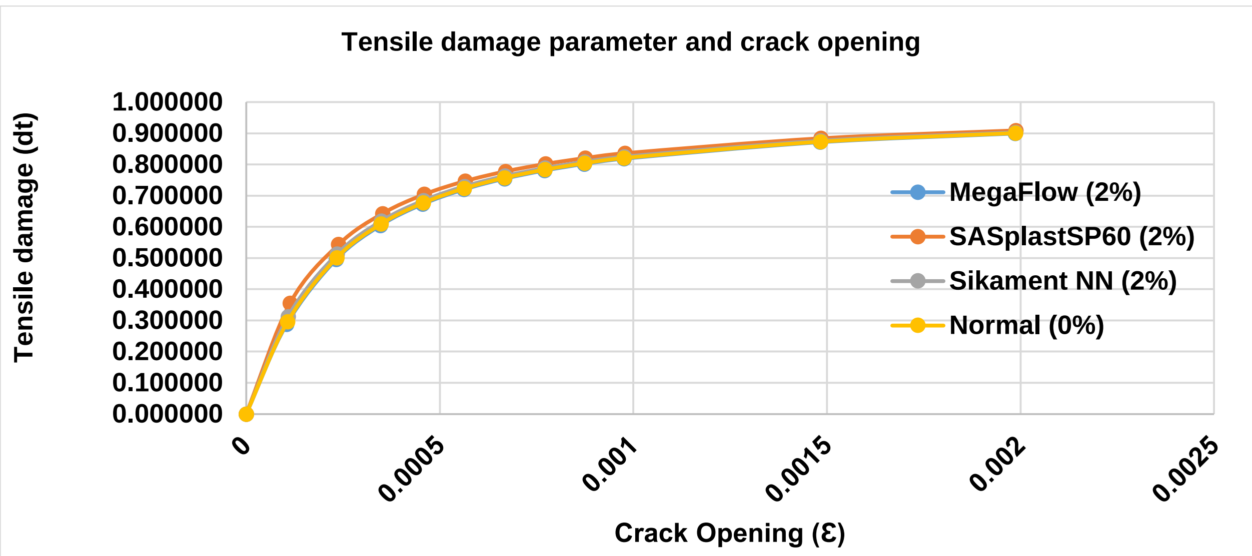


Figure 4-26 : Failure Load of FEM and Experiment of 2 % HRWRAs (Superplasticizer) dosage

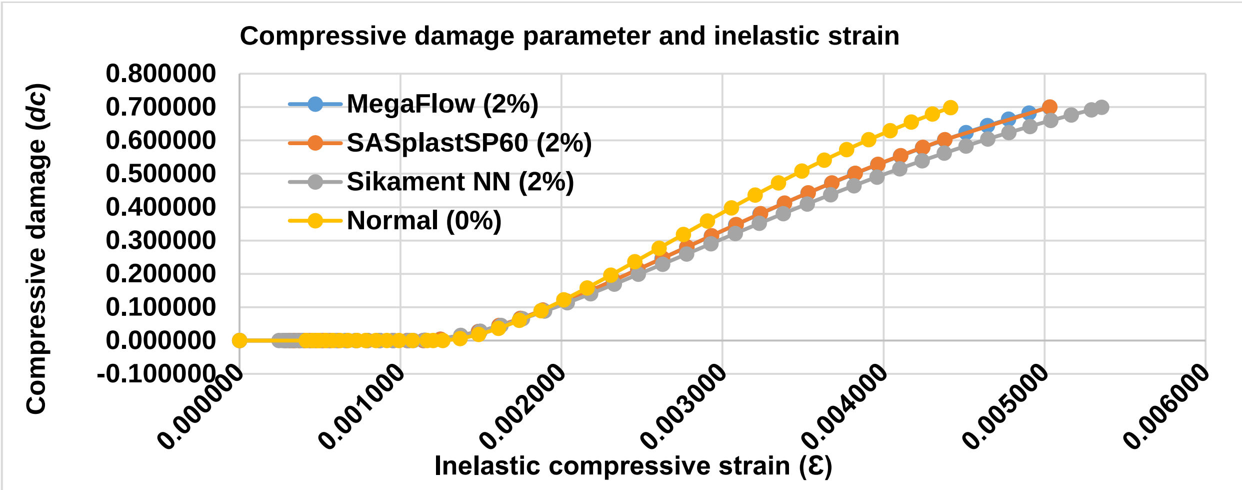
The even strain increases emphatically which illustrates that breaks are rising inside the region of the test with respect to the comes about gotten and summarized inside the over table and figure it was observed that the compressive thrust values of the open concrete hurt flexibility models and investigate had extraordinary understanding.Compressive stress-strain curve of CDP model of (2%) HRWRAs dosage are shown in Figure 4-27 (a),(b) and (c).In Figure 4-20 (a) Compressive and tensile stress-strain curve.Then, as shown in Figure 4-27 (b) Tensile damage parameter and crack opening and then Figure 4-27 (c) Compressive damage parameter and inelastic strain curves of CDP model.


Compressive stress-strain curve of CDP model
Stress (MPa)
60.0000
50.0000
40.0000
30.0000
20.0000
10.0000
0.0000
0.000000
0.001000
0.002000
0.003000
0.004000
0.005000
0.006000
Strain (Ɛ)
MegaFlow (2%)
SASplastSP60 (2%)
Sikament NN (2%)
Normal (2%)

(a)


Tensile damage parameter and crack opening
Tensile damage (dt)
1.000000
0.900000
0.800000
0.700000
0.600000
0.500000
0.400000
0.300000
0.200000
0.100000
0.000000
0
0.0005
0.001
0.0015
0.002
0.0025
Crack Opening (Ɛ)
MegaFlow (2%)
SASplastSP60 (2%)
Sikament NN (2%)
Normal (0%)

(b)

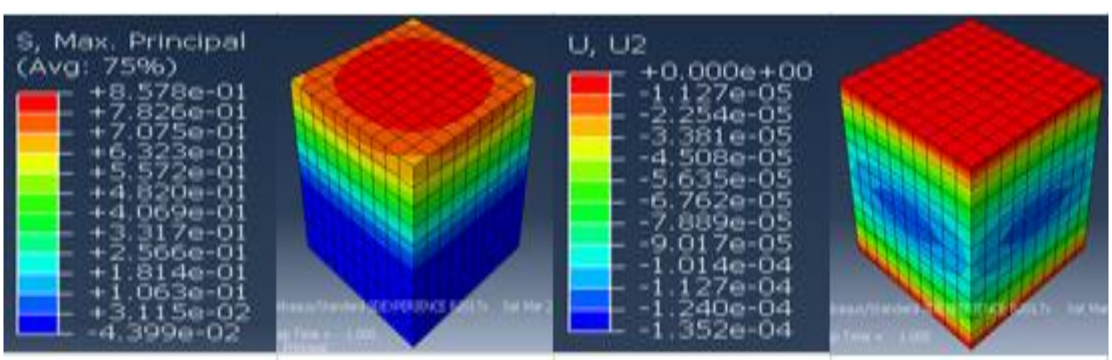


(c)

Figure 4-27: Compressive stress-strain curve of CDP model of (2%) HRWRAs dosage

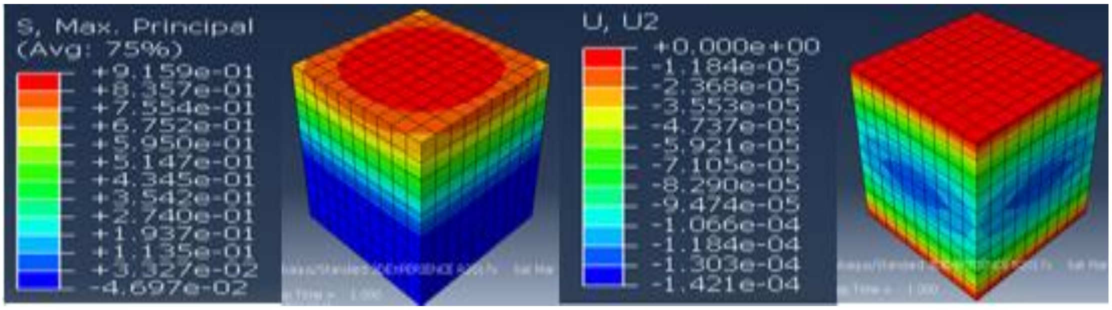
4.4.1.7 Concrete Containing HRWRAs (Superplasticizer) of 2.5 % dosage Model

A concrete cube of size 150mm is modeled in ABAQUS using C3D8 element. The concrete mesh model of s max principal and U2 of the average compressive stress, fc=39.7MPa, ultimate strain, Ɛcu =0.004870, and the strain at pick stress, Ɛ0=0.001101 when containing SasplastSP60. The average compressive stress, fc=41.0MPa, ultimate strain, Ɛcu =0.004933, and the strain at pick stress, Ɛ0=0.001097 when containing Sikament NN. The average compressive stress, fc=40.1MPa, ultimate strain, Ɛcu =0.004900, and the strain at pick stress, Ɛ0=0.001129 when containing MegaFlowSP1. As shown the below Figure 4-28, Figure 4-29, and Figure 4-30 (a), (b), (c) and d) demonstrated in these figures, the stressed concrete cube failed when the damage in compression strain reached 0.001101, 0.001097and 0.001129 respectively.



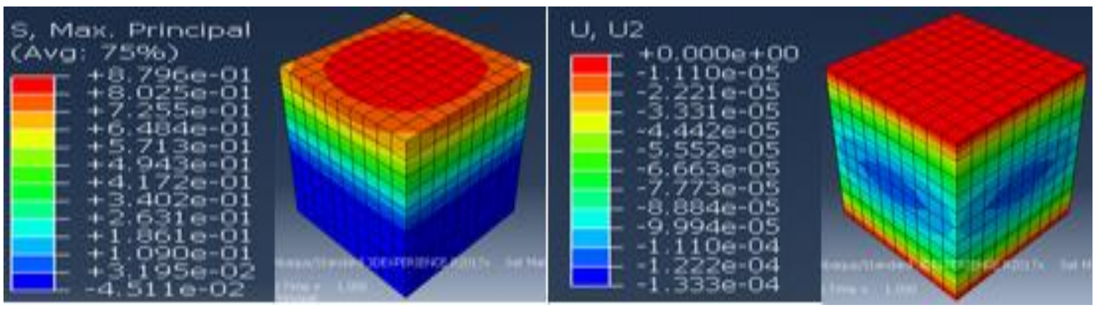
(a) (b) (c) (d)

Figure 4-28 : The concrete mesh Model of SasplastSp60 HRWRAs (Superplasticizer) 2.5%



(a) (b) (c) (d)

Figure 4-29: The concrete mesh Model of Sikament NN HRWRAs (Superplasticizer) 2.5%



(a) (b) (c) (d)

Figure 4-30: The concrete mesh Model of MegaFlow SP1 HRWRAs (Superplasticizer) 2.5%

The underneath table at column one shows up the test result of the ordinary 28th day failure stack in utilize from the over appeared up Table 4-8,Table 4-10 and Table 4-12; SASplastSP60,MegaFlowSP1 and Sikament NN independently which concrete contained 2.5% of HRWRAs or superplasticizer dosage. However, column four failure stack taken from abaqus program abdicate after overseeing with and modeling the compressive quality.

CDP Models	Failure Load (KN)	Compressive stress (MPa) Experment	Failure Load (KN) FEM	Compressive stress (MPa) FEM	Error (MPa)
Normal (0%)	610	27.1	640	28.44	1.34
Sikament NN	923.2	41.0	915	40.7	0.3
MegaFlowSP1	908.6	40.4	879	39.1	1.3
SasplastSP60	893.9	39.7	857	38.0	1.7

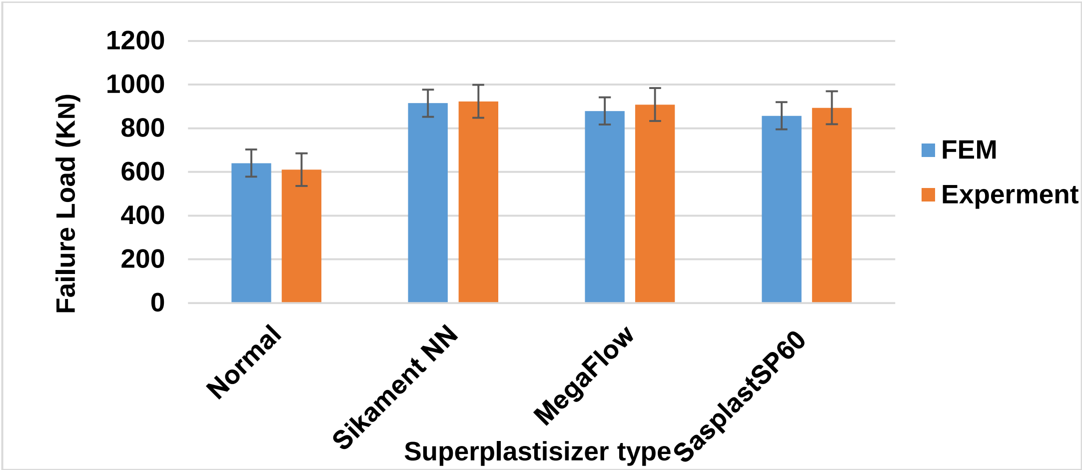
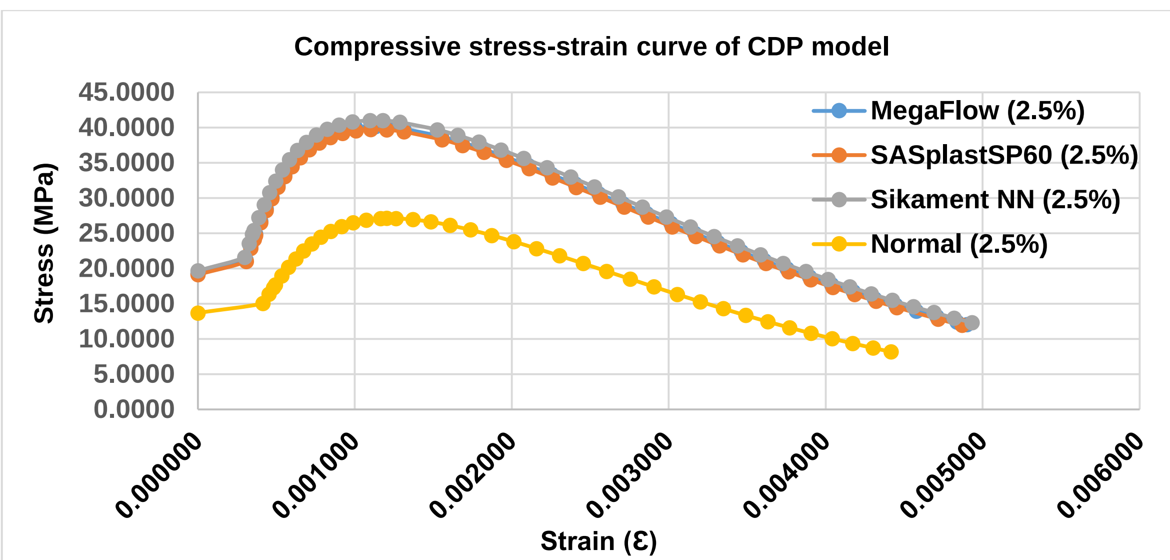
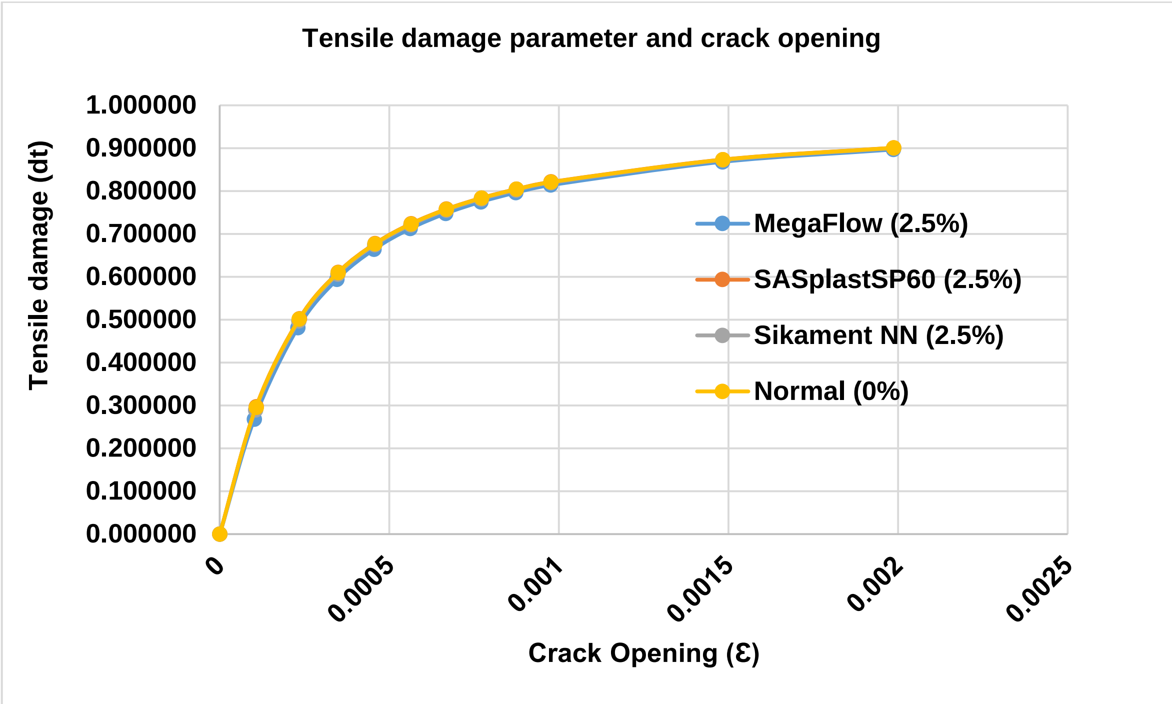


Figure 4-31 Failure Load of FEM and Experiment of 2.5 % HRWRAs (Superplasticizer) dosage

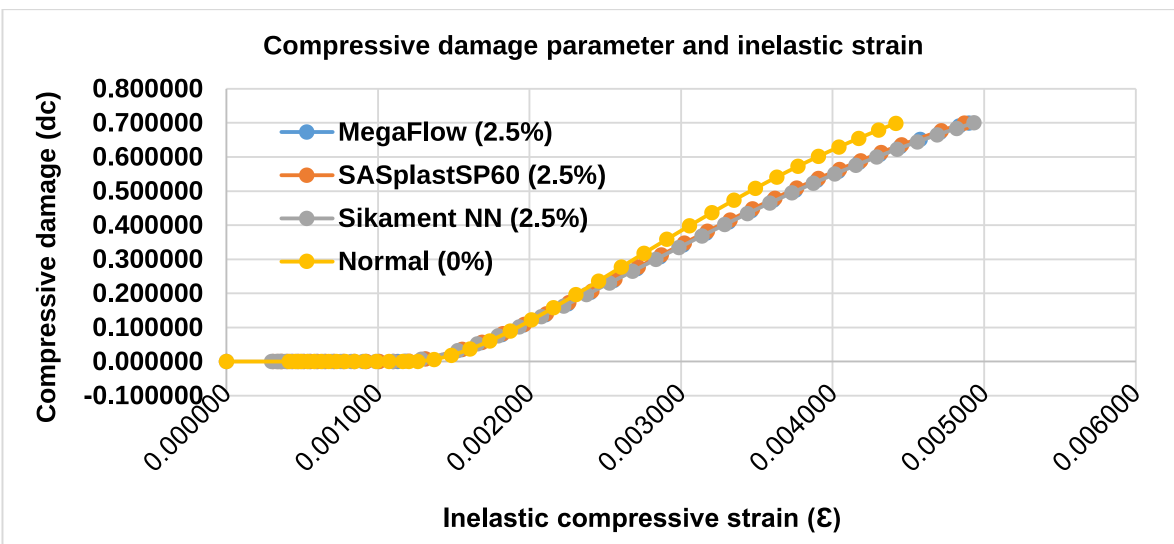
The indeed strain increments decidedly which outlines that breaks are rising interior the locale of the test with regard to the comes almost gotten and summarized interior the over table and figure it was watched that the compressive pushed values of the open concrete harmed adaptability models and explore had exceptional understandingCompressive stress-strain curve of CDP model of (2.5%) HRWRAs dosage are shown in Figure 4-32 (a),(b) and (c).In Figure 4-32 (a) Compressive and tensile stress-strain curve.Then, as shown in Figure 4-32(b) Tensile damage parameter and crack opening and then Figure 4-32 (c) Compressive damage parameter and inelastic strain curves of CDP model.



(a)



(b)

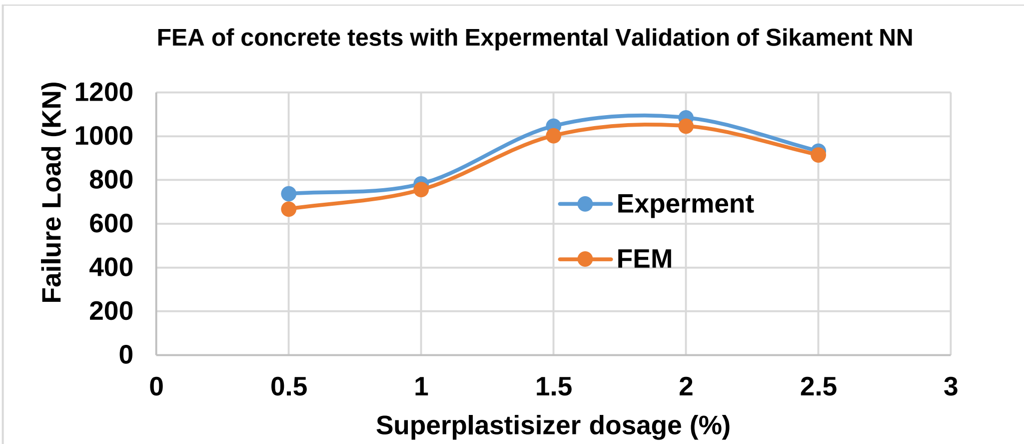


(c)

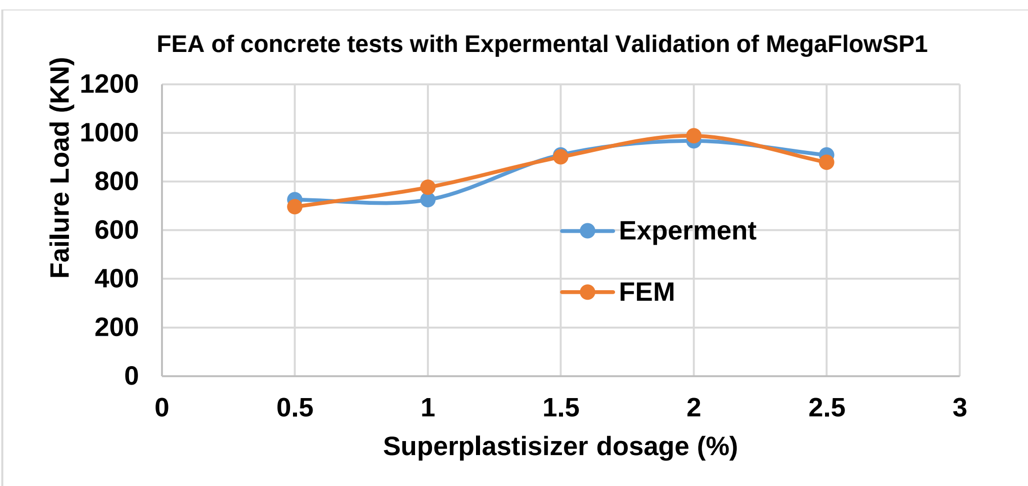
Figure 4-32: Compressive stress-strain curve of CDP model of (2%) HRWRAs dosage

4.5 Finite Element Analysis of Concrete tests with Expermental Validation

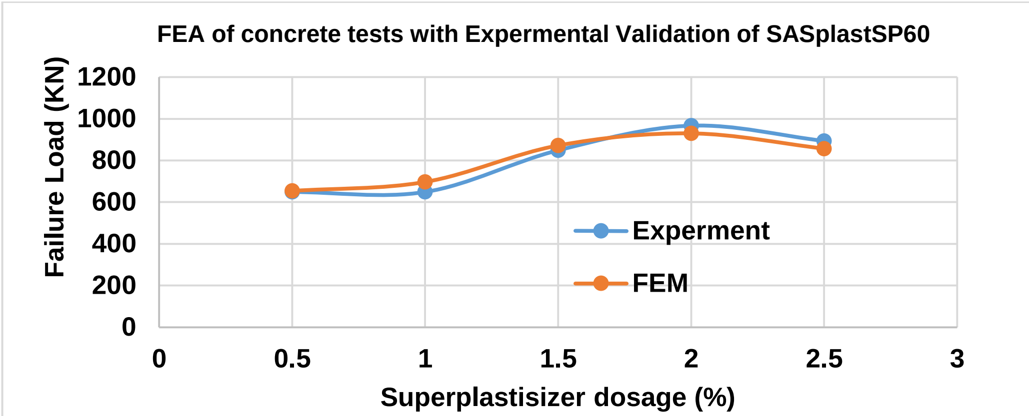
Validation of the finite element concrete damage plasticity model comparing with the laboratory result with that presented in this research. Figure 4-33 (a), (b) and (c) shows Finite element modeling with experimental validation results. The results show a good correlation between these two approaches for whole types of HRWRAs; SikamentNN, MegaFlowSP1, SASplastSp60 respectively.



(a)



(b)



(c)

Figure 4-33: Finite element modeling with experimental validation

4.6 Statistical Analysis of Compressive strength result using ANOVA

Made a statistical technique that can compare samples and depict how different these samples are from one another. Such a technique, which compares the samples based on their means is called analysis of variance (commonly abbreviated as ANOVA).Testing of the hypothesis is done: at 0.05 level of significance. Five groups of independent variables i.e. 0.5%, 1%, 1.5%, 2%, 2.5% for each type of HRWRAs (Superplasticizer), were considered in this research. Details of ANOVA hypothesis testing detail analysis results are presented in Appendix D. 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 five design HRWRAs dosage. This statistical method of concrete mix optimization was less precise because of the variation in material characteristics of aggregates and types of Superplasticizer (HRWRAs). The ANOVA test results are shown below;

Table 4:15 Results of Statistical analysis (ANOVA)

HRWRAs (Superplastsizer) Type	HRWRAs (Dosage)	F-Value	P-Value	F-Critical	Null Hypothesis
Sikament NN,SasplastSP60 ,MegaFlowSP1	0.5%	1765.62	1.27205E-11	4.066181	Reject
	1.0%	1422.05	3.01815E-11	4.066181	Reject
	1.5%	1342.70	3.79553E-11	4.066181	Reject
	2.0%	2661.05	2.47085E-12	4.066181	Reject
	2.5%	3308.11	1.03542E-12	4.066181	Reject

5. CONCLUSION 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 concrete compressive strength can be achieved by using HRWRAs without sacrificing the desired workability and strength properties of concrete. Accordingly, adding more HRWRA above the optimum dosage did not improve the compressive strength of the concrete.

Testing for concrete compressive strength of a proportion designed for C-25 is obtained at its 28th day. This end result indicates concrete containing without HRWRAs cannot satisfy the target mean strength of 33.5MPa. However, via adding HRWRAs or superplasticizer with a dosage of 1% Sikament NN and MegaFlowSP1 satisfy the strength which is each 34.7MPa, however, SASplastSP60 31.5Mpa it is underneath the required strength and considered necessary extra dosage this displays even though the identical type of HRWRAs used the first-rate likely will vary.

The complete failures of concrete containing superplasticizer chemical admixture cube the concrete damage plasticity model using numerical simulation illustrated that the damaged parameters responded well to the experiment's results. The model presenting in this research can be considered as a reference model with different grade concrete cube. The model realistically described the transition from tensile to compressive failure. This finding was achieved through the introduction of two separate isotropic damage variables for tension and compression. This study compares the real characteristics of concrete with its numerical modeling. The adopted 3D model captured the response of the concrete cube subjected to compression fairly well. The failure mechanism from the FEA corresponds to the experiment.

5.2 Recommendations

The following recommendations are drawn based on the finite element analysis results of this study.

- The results presented here in this study are based on finite element analysis. Therefore, validating the results with field tests is needed to confirm whether finite element analysis results are similar to the actual condition.

- Even if PPC cement is highly resistant to sulphate attacks and hence used in construction dams, foundations and buildings and marine constructions and have high durability later strength, but due to it has higher setting time not usually adopted in our country, therefore by adding HRWRAs can improve the setting time and need further study.

5.3 Future study

- Modeling of concrete for linear and nonlinear analysis using Finite Element Analysis
- Finite element analysis of concrete cylinders subjected to compression
- Identification of parameters of concrete damage plasticity constative model
- Further studies also required to determine the effect of the stress components at integration points, spatial displacement at nodes, strain components at integration points.

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APPINDIX A: Material parameters used in the CDP model for the concrete subjected to compression and Tension

27.1 MPa (0%)

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	21894.13	0.18

Dilatation Angle	*Eccentrically*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	0.1	1.16	0.67	0

Concrete compression hardening		Concrete compression damage		Concrete tension stiffening		Concrete tension damage	
Yield Stress (Mpa)	Inelastic Strain	Damage Parameter, D	Inelastic Strain	Yield Stress (Mpa)	Cracking Strain	Damage Parameter, D	Cracking Strain
13.6877	0.000000	0	0.000000	2.9000	0.000000	0	0
15.0321	0.000413	0	0.000413	2.0431	0.000107	0.2955	0.000107
16.3604	0.000453	0	0.000453	1.4475	0.000234	0.5009	0.000234
17.2772	0.000481	0	0.000481	1.1335	0.000348	0.6092	0.000348
17.6661	0.000493	0	0.000493	0.9376	0.000457	0.6767	0.000457
18.9411	0.000535	0	0.000535	0.8030	0.000563	0.7231	0.000563
20.1752	0.000579	0	0.000579	0.7044	0.000668	0.7571	0.000668
21.3567	0.000625	0	0.000625	0.6288	0.000771	0.7832	0.000771
22.4717	0.000674	0	0.000674	0.5689	0.000874	0.8038	0.000874
23.5049	0.000726	0	0.000726	0.5202	0.000976	0.8206	0.000976
24.4398	0.000784	0	0.000784	0.3685	0.001483	0.8729	0.001483
25.2591	0.000846	0	0.000846	0.2886	0.001987	0.9005	0.001987
25.9457	0.000915	0	0.000915				
26.4839	0.000990	0	0.000990				
26.8599	0.001073	0	0.001073				
27.0633	0.001164	0	0.001164				
27.1000	0.001202	0	0.001202				
27.0882	0.001263	0.0004	0.001263				
26.9337	0.001370	0.0061	0.001370				
26.6041	0.001485	0.0183	0.001485				
26.1092	0.001607	0.0366	0.001607				

25.4638	0.001737	0.0604	0.001737				
24.6862	0.001872	0.0891	0.001872				
23.7980	0.002013	0.1218	0.002013				
22.8220	0.002158	0.1579	0.002158				
21.7813	0.002305	0.1963	0.002305				
20.6982	0.002455	0.2362	0.002455				
19.5933	0.002605	0.2770	0.002605				
18.4846	0.002756	0.3179	0.002756				
17.3878	0.002906	0.3584	0.002906				
16.3155	0.003055	0.3980	0.003055				
15.2775	0.003202	0.4363	0.003202				
14.2813	0.003348	0.4730	0.003348				
13.3321	0.003491	0.5080	0.003491				
12.4330	0.003632	0.5412	0.003632				
11.5858	0.003771	0.5725	0.003771				
10.7906	0.003907	0.6018	0.003907				
10.0470	0.004041	0.6293	0.004041				
9.3535	0.004173	0.6549	0.004173				
8.7082	0.004302	0.6787	0.004302				
8.1668	0.004417	0.6986	0.004417				

28.9 MPa (0.5%)

SASplastSp60

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	22599.13	0.18

Dilatation Angle	*Eccentrically*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		Concrete compression damage		Concrete tension stiffening		Concrete tension damage	
Yield Stress (Mpa)	Inelastic Strain	Damage Parameter,D	Inelastic Strain	Yield Stress (Mpa)	Cracking Strain	Damage Parameter,D	Cracking Strain

14.4818	0.000000	0	0.000000	3.0000	0.000000	0	0
15.9047	0.000396	0	0.000396	2.1175	0.000106	0.2942	0.000106
17.3111	0.000434	0	0.000434	1.5002	0.000234	0.4999	0.000234
18.2822	0.000461	0	0.000461	1.1747	0.000348	0.6084	0.000348
18.6943	0.000473	0	0.000473	0.9718	0.000457	0.6761	0.000457
20.0459	0.000513	0	0.000513	0.8323	0.000563	0.7226	0.000563
21.3557	0.000555	0	0.000555	0.7301	0.000668	0.7566	0.000668
22.6116	0.000599	0	0.000599	0.6517	0.000771	0.7828	0.000771
23.7996	0.000647	0	0.000647	0.5896	0.000874	0.8035	0.000874
24.9042	0.000698	0	0.000698	0.5391	0.000976	0.8203	0.000976
25.9083	0.000754	0	0.000754	0.3820	0.001483	0.8727	0.001483
26.7944	0.000814	0	0.000814	0.2991	0.001987	0.9003	0.001987
27.5449	0.000881	0	0.000881				
28.1432	0.000955	0	0.000955				
28.5751	0.001036	0	0.001036				
28.8291	0.001124	0	0.001124				
28.8792	0.001162	0	0.001162				
28.9	0.001221	0	0.001221				
28.8899	0.001242	0.0004	0.001242				
28.7810	0.001326	0.0041	0.001326				
28.4803	0.001440	0.0145	0.001440				
28.0051	0.001561	0.0310	0.001561				
26.5912	0.001823	0.0799	0.001823				
25.6917	0.001963	0.1110	0.001963				
24.6942	0.002107	0.1455	0.002107				
23.6221	0.002255	0.1826	0.002255				
22.4987	0.002404	0.2215	0.002404				
21.3456	0.002555	0.2614	0.002555				
20.1822	0.002707	0.3017	0.002707				
19.0253	0.002858	0.3417	0.002858				
17.8888	0.003008	0.3810	0.003008				
16.7841	0.003157	0.4192	0.003157				
15.7195	0.003304	0.4561	0.003304				
14.7012	0.003449	0.4913	0.003449				
13.7335	0.003592	0.5248	0.003592				
12.8185	0.003733	0.5565	0.003733				
11.9572	0.003871	0.5863	0.003871				
11.1495	0.004007	0.6142	0.004007				
10.3944	0.004140	0.6403	0.004140				

9.6900	0.004271	0.6647	0.004271				
9.0343	0.004400	0.6874	0.004400				
8.4250	0.004515	0.7085	0.004515				

32.8 MPa (0.5%)

Sikament NN

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	24075.75	0.18

Dilitation Angle	*Eccentricaly*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		Concrete compression damage		Concrete tension stiffening		Concrete tension damage	
Yield Stress (Mpa)	Inelastic Strain	Damage Parameter,D	Inelastic Strain	Yield Stress (Mpa)	Cracking Strain	Damage Parameter,D	Cracking Strain
16.1775	0.000000	0	0.000000	3.2000	0.000000	0	0
17.7677	0.000362	0	0.000362	2.2610	0.000106	0.2934	0.000106
19.3402	0.000397	0	0.000397	1.6019	0.000233	0.4994	0.000233
20.4267	0.000422	0	0.000422	1.2544	0.000348	0.6080	0.000348
20.8879	0.000432	0	0.000432	1.0377	0.000457	0.6757	0.000457
22.4023	0.000470	0	0.000470	0.8887	0.000563	0.7223	0.000563
23.8727	0.000508	0	0.000508	0.7796	0.000668	0.7564	0.000668
25.2866	0.000550	0	0.000550	0.6959	0.000771	0.7825	0.000771
26.6297	0.000594	0	0.000594	0.6296	0.000874	0.8032	0.000874
27.8858	0.000642	0	0.000642	0.5757	0.000976	0.8201	0.000976
29.0377	0.000694	0	0.000694	0.4079	0.001483	0.8725	0.001483
30.0670	0.000751	0	0.000751	0.3194	0.001987	0.9002	0.001987
30.9555	0.000814	0	0.000814				
31.6857	0.000884	0	0.000884				
32.2420	0.000961	0	0.000961				
32.6117	0.001045	0	0.001045				
32.7052	0.001082	0	0.001082				

32.7860	0.001138	0	0.001138				
32.8	0.001158	0	0.001158				
32.7609	0.001239	0.0012	0.001239				
32.5378	0.001349	0.0080	0.001349				
32.1235	0.001466	0.0206	0.001466				
30.7734	0.001722	0.0618	0.001722				
29.8746	0.001859	0.0892	0.001859				
28.8561	0.002001	0.1202	0.002001				
27.7420	0.002148	0.1542	0.002148				
26.5565	0.002297	0.1903	0.002297				
25.3229	0.002448	0.2280	0.002448				
24.0626	0.002601	0.2664	0.002601				
22.7949	0.002753	0.3050	0.002753				
21.5363	0.002905	0.3434	0.002905				
20.3005	0.003057	0.3811	0.003057				
19.0987	0.003207	0.4177	0.003207				
17.9391	0.003355	0.4531	0.003355				
16.8281	0.003501	0.4869	0.003501				
15.7698	0.003645	0.5192	0.003645				
14.7665	0.003787	0.5498	0.003787				
13.8193	0.003926	0.5787	0.003926				
12.9282	0.004063	0.6058	0.004063				
12.0922	0.004198	0.6313	0.004198				
11.3098	0.004330	0.6552	0.004330				
10.5789	0.004461	0.6775	0.004461				
9.89720	0.004589	0.6983	0.004589				

32.2 MPa (0.5%)

MegaFlowSp1

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	23854.53	0.18

Dilitation Angle	***Eccentricaly***	***Initial biaxial/uniaxial ratio,***	***K***	***Viscosity***
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		Concrete compression damage		Concrete tension stiffening		Concrete tension damage	
Yield Stress (Mpa)	Inelastic Strain	Damage Parameter,D	Inelastic Strain	Yield Stress (Mpa)	Cracking Strain	Damage Parameter,D	Cracking Strain
15.9187	0.000000	0	0.000000	3.2000	0.000000	0	0
17.4833	0.000367	0	0.000367	2.2789	0.000104	0.2879	0.000106
19.0305	0.000402	0	0.000402	1.6145	0.000232	0.4955	0.000233
20.0994	0.000427	0	0.000427	1.2643	0.000347	0.6049	0.000348
20.5532	0.000438	0	0.000438	1.0458	0.000456	0.6732	0.000457
22.0428	0.000476	0	0.000476	0.8957	0.000562	0.7201	0.000563
23.4888	0.000515	0	0.000515	0.7857	0.000667	0.7545	0.000668
24.8787	0.000557	0	0.000557	0.7014	0.000771	0.7808	0.000771
26.1982	0.000602	0	0.000602	0.6346	0.000873	0.8017	0.000874
27.4313	0.000650	0	0.000650	0.5802	0.000976	0.8187	0.000976
28.5607	0.000703	0	0.000703	0.4111	0.001483	0.8715	0.001483
29.5681	0.000760	0	0.000760	0.3219	0.001987	0.8994	0.001987
30.4355	0.000824	0	0.000824				
31.1453	0.000894	0	0.000894				
31.6823	0.000972	0	0.000972				
32.0337	0.001057	0	0.001057				
32.1203	0.001093	0	0.001093				
32.1913	0.001151	0	0.001151				
32.2	0.001170	0	0.001170				
32.1511	0.001252	0.0015	0.001252				
31.9149	0.001362	0.0089	0.001362				
31.4897	0.001480	0.0221	0.001480				
30.1262	0.001737	0.0644	0.001737				
29.2252	0.001875	0.0924	0.001875				
28.2077	0.002018	0.1240	0.002018				
27.0978	0.002164	0.1585	0.002164				
25.9196	0.002313	0.1950	0.002313				
24.6961	0.002465	0.2330	0.002465				
23.4487	0.002617	0.2718	0.002617				
22.1962	0.002770	0.3107	0.002770				
20.9547	0.002922	0.3492	0.002922				
19.7377	0.003073	0.3870	0.003073				
18.5558	0.003222	0.4237	0.003222				
17.4171	0.003370	0.4591	0.003370				

16.3274	0.003516	0.4929	0.003516				
15.2907	0.003659	0.5251	0.003659				
14.3089	0.003800	0.5556	0.003800				
13.3831	0.003939	0.5844	0.003939				
12.5130	0.004075	0.6114	0.004075				
11.6975	0.004210	0.6367	0.004210				
10.9349	0.004342	0.6604	0.004342				
10.2231	0.004471	0.6825	0.004471				
9.55969	0.004599	0.7031	0.004599				

31.5 MPa (1%)

SasplastSP60

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	23593.81	0.18

Dilitation Angle	*Eccentricaly*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		**Concrete compression damage**		**Concrete tension stiffening**		**Concrete tension damage**	
Yield Stress (Mpa)	**Inelastic Strain**	**Damage Parameter,D**	**Inelastic Strain**	**Yield Stress (Mpa)**	**Cracking Strain**	**Damage Parameter,D**	**Cracking Strain**
15.6163	0.000000	0	0.000000	3.1000	0.000000	0	0
17.1512	0.000373	0	0.000373	2.1690	0.000108	0.3003	0.000108
18.6688	0.000409	0	0.000409	1.5367	0.000235	0.5043	0.000235
19.7171	0.000434	0	0.000434	1.2033	0.000349	0.6118	0.000349
20.1621	0.000445	0	0.000445	0.9954	0.000458	0.6789	0.000458
21.6227	0.000484	0	0.000484	0.8525	0.000564	0.7250	0.000564
23.0400	0.000523	0	0.000523	0.7478	0.000668	0.7588	0.000668
24.4018	0.000566	0	0.000566	0.6676	0.000772	0.7846	0.000772
25.6936	0.000611	0	0.000611	0.6040	0.000874	0.8052	0.000874
26.8997	0.000660	0	0.000660	0.5523	0.000977	0.8219	0.000977
28.0026	0.000713	0	0.000713	0.3913	0.001483	0.8738	0.001483

28.9844	0.000772	0	0.000772	0.3064	0.001987	0.9012	0.001987
29.8269	0.000836	0	0.000836				
30.5130	0.000907	0	0.000907				
31.0273	0.000985	0	0.000985				
31.3576	0.001071	0	0.001071				
31.4958	0.001165	0	0.001165				
31.5	0.001195	0	0.001195				
31.4384	0.001268	0.0020	0.001268				
31.1875	0.001378	0.0099	0.001378				
30.7504	0.001497	0.0238	0.001497				
29.3731	0.001755	0.0675	0.001755				
28.4706	0.001893	0.0962	0.001893				
27.4555	0.002036	0.1284	0.002036				
26.3518	0.002183	0.1634	0.002183				
25.1834	0.002333	0.2005	0.002333				
23.9731	0.002484	0.2389	0.002484				
22.7419	0.002636	0.2780	0.002636				
21.5082	0.002788	0.3172	0.002788				
20.2878	0.002940	0.3559	0.002940				
19.0935	0.003091	0.3939	0.003091				
17.9356	0.003240	0.4306	0.003240				
16.8218	0.003387	0.4660	0.003387				
15.7575	0.003532	0.4998	0.003532				
14.7462	0.003675	0.5319	0.003675				
13.7899	0.003816	0.5622	0.003816				
12.8891	0.003954	0.5908	0.003954				
12.0435	0.004090	0.6177	0.004090				
11.2517	0.004223	0.6428	0.004223				
10.5121	0.004354	0.6663	0.004354				
9.8892	0.004471	0.6861	0.004471				
8.4250	0.004515	0.7085	0.004515				
9.37960	0.004551	0.7003	0.004551				

34.7 MPa (1%)

Sikament NN

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	24763.25	0.18

Dilitation Angle	***Eccentricaly***	***Initial biaxial/uniaxial ratio,***	***K***	***Viscosity***
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		**Concrete compression damage**		**Concrete tension stiffening**		**Concrete tension damage**	
Yield Stress (Mpa)	**Inelastic Strain**	**Damage Parameter,D**	**Inelastic Strain**	**Yield Stress (Mpa)**	**Cracking Strain**	**Damage Parameter,D**	**Cracking Strain**
16.9911	0.000000	0	0.000000	3.3000	0.000000	0	0
18.6614	0.000346	0	0.000346	2.3369	0.000106	0.2919	0.000106
20.3134	0.000380	0	0.000380	1.6556	0.000233	0.4983	0.000233
21.4550	0.000404	0	0.000404	1.2965	0.000348	0.6071	0.000348
21.9398	0.000414	0	0.000414	1.0725	0.000457	0.6750	0.000457
23.5319	0.000450	0	0.000450	0.9185	0.000563	0.7217	0.000563
25.0790	0.000487	0	0.000487	0.8057	0.000667	0.7558	0.000667
26.5683	0.000527	0	0.000527	0.7193	0.000771	0.7820	0.000771
27.9854	0.000570	0	0.000570	0.6507	0.000874	0.8028	0.000874
29.3142	0.000616	0	0.000616	0.5950	0.000976	0.8197	0.000976
30.5369	0.000667	0	0.000667	0.4215	0.001483	0.8723	0.001483
31.6353	0.000722	0	0.000722	0.3301	0.001987	0.9000	0.001987
32.5907	0.000784	0	0.000784				
33.3855	0.000852	0	0.000852				
34.0036	0.000927	0	0.000927				
34.4318	0.001010	0	0.001010				
34.5476	0.001045	0	0.001045				
34.6606	0.001100	0	0.001100				
34.7	0.001199	0	0.001199				
34.5059	0.001307	0.0056	0.001307				
34.1285	0.001422	0.0165	0.001422				
32.8280	0.001674	0.0539	0.001674				
31.9403	0.001810	0.0795	0.001810				
30.9230	0.001951	0.1088	0.001951				
29.8001	0.002097	0.1412	0.002097				
28.5961	0.002245	0.1759	0.002245				
27.3345	0.002396	0.2123	0.002396				
26.0377	0.002549	0.2496	0.002549				
24.7258	0.002702	0.2874	0.002702				
23.4165	0.002854	0.3252	0.002854				
22.1245	0.003007	0.3624	0.003007				
20.8621	0.003158	0.3988	0.003158				

19.6389	0.003307	0.4340	0.003307				
18.4621	0.003454	0.4680	0.003454				
17.3367	0.003600	0.5004	0.003600				
16.2659	0.003743	0.5312	0.003743				
15.2516	0.003884	0.5605	0.003884				
14.2943	0.004023	0.5881	0.004023				
13.3935	0.004159	0.6140	0.004159				
12.5480	0.004293	0.6384	0.004293				
11.7561	0.004425	0.6612	0.004425				
11.0155	0.004555	0.6825	0.004555				
10.3240	0.004683	0.7025	0.004683				

34.7 MPa (1%)

MegaFlowSP1

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	24763.25	0.18

Dilitation Angle	*Eccentricaly*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		**Concrete compression damage**		**Concrete tension stiffening**		**Concrete tension damage**	
Yield Stress (Mpa)	**Inelastic Strain**	**Damage Parameter,D**	**Inelastic Strain**	**Yield Stress (Mpa)**	**Cracking Strain**	**Damage Parameter,D**	**Cracking Strain**
16.9911	0.000000	0	0.000000	3.3000	0.000000	0	0
18.6614	0.000346	0	0.000346	2.3369	0.000106	0.2919	0.000106
20.3134	0.000380	0	0.000380	1.6556	0.000233	0.4983	0.000233
21.4550	0.000404	0	0.000404	1.2965	0.000348	0.6071	0.000348
21.9398	0.000414	0	0.000414	1.0725	0.000457	0.6750	0.000457
23.5319	0.000450	0	0.000450	0.9185	0.000563	0.7217	0.000563
25.0790	0.000487	0	0.000487	0.8057	0.000667	0.7558	0.000667
26.5683	0.000527	0	0.000527	0.7193	0.000771	0.7820	0.000771
27.9854	0.000570	0	0.000570	0.6507	0.000874	0.8028	0.000874
29.3142	0.000616	0	0.000616	0.5950	0.000976	0.8197	0.000976
30.5369	0.000667	0	0.000667	0.4215	0.001483	0.8723	0.001483
31.6353	0.000722	0	0.000722	0.3301	0.001987	0.9000	0.001987

32.5907	0.000784	0	0.000784				
33.3855	0.000852	0	0.000852				
34.0036	0.000927	0	0.000927				
34.4318	0.001010	0	0.001010				
34.5476	0.001045	0	0.001045				
34.6606	0.001100	0	0.001100				
34.7	0.001199	0	0.001199				
34.6764	0.001210	0.0007	0.001210				
34.5059	0.001307	0.0056	0.001307				
34.1285	0.001422	0.0165	0.001422				
32.8280	0.001674	0.0539	0.001674				
31.9403	0.001810	0.0795	0.001810				
30.9230	0.001951	0.1088	0.001951				
29.8001	0.002097	0.1412	0.002097				
28.5961	0.002245	0.1759	0.002245				
27.3345	0.002396	0.2123	0.002396				
26.0377	0.002549	0.2496	0.002549				
24.7258	0.002702	0.2874	0.002702				
23.4165	0.002854	0.3252	0.002854				
22.1245	0.003007	0.3624	0.003007				
20.8621	0.003158	0.3988	0.003158				
19.6389	0.003307	0.4340	0.003307				
18.4621	0.003454	0.4680	0.003454				
17.3367	0.003600	0.5004	0.003600				
16.2659	0.003743	0.5312	0.003743				
15.2516	0.003884	0.5605	0.003884				
14.2943	0.004023	0.5881	0.004023				
13.3935	0.004159	0.6140	0.004159				
12.5480	0.004293	0.6384	0.004293				
11.7561	0.004425	0.6612	0.004425				
11.0155	0.004555	0.6825	0.004555				
10.3240	0.004683	0.7025	0.004683				

37.7 MPa (1.5%)

SasplastSP60

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	25811.52	0.18

Dilitation Angle	*Eccentricaly*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		**Concrete compression damage**		**Concrete tension stiffening**		**Concrete tension damage**	
Yield Stress (Mpa)	**Inelastic Strain**	**Damage Parameter,D**	**Inelastic Strain**	**Yield Stress (Mpa)**	**Cracking Strain**	**Damage Parameter,D**	**Cracking Strain**
18.2662	0.000000	0	0.000000	3.4000	0.000000	0	0
20.0616	0.000323	0	0.000323	2.3841	0.000108	0.2988	0.000108
21.8375	0.000354	0	0.000354	1.6890	0.000235	0.5032	0.000235
23.0651	0.000376	0	0.000376	1.3226	0.000349	0.6110	0.000349
23.5865	0.000386	0	0.000386	1.0941	0.000458	0.6782	0.000458
25.2995	0.000420	0	0.000420	0.9371	0.000564	0.7244	0.000564
26.9656	0.000455	0	0.000455	0.8220	0.000668	0.7582	0.000668
28.5718	0.000493	0	0.000493	0.7338	0.000772	0.7842	0.000772
30.1036	0.000534	0	0.000534	0.6639	0.000874	0.8047	0.000874
31.5445	0.000578	0	0.000578	0.6070	0.000976	0.8215	0.000976
32.8769	0.000626	0	0.000626	0.4300	0.001483	0.8735	0.001483
34.0822	0.000680	0	0.000680	0.3368	0.001987	0.9010	0.001987
35.1418	0.000739	0	0.000739				
36.0377	0.000804	0	0.000804				
36.7534	0.000876	0	0.000876				
37.2752	0.000956	0	0.000956				
37.5927	0.001044	0	0.001044				
37.7	0.001139	0	0.001139				
37.5962	0.001243	0.0028	0.001243				
37.2856	0.001355	0.0110	0.001355				
36.0862	0.001602	0.0428	0.001602				
35.2300	0.001735	0.0655	0.001735				
34.2301	0.001874	0.0920	0.001874				
33.1099	0.002017	0.1218	0.002017				
31.8935	0.002164	0.1540	0.002164				
30.6050	0.002314	0.1882	0.002314				
29.2672	0.002466	0.2237	0.002466				
27.9014	0.002619	0.2599	0.002619				

26.5266	0.002772	0.2964	0.002772				
25.1592	0.002925	0.3326	0.002925				
23.8131	0.003077	0.3684	0.003077				
22.4994	0.003228	0.4032	0.003228				
21.2269	0.003378	0.4370	0.003378				
20.0023	0.003525	0.4694	0.003525				
18.8302	0.003670	0.5005	0.003670				
17.7135	0.003814	0.5301	0.003814				
16.6539	0.003955	0.5583	0.003955				
15.6517	0.004094	0.5848	0.004094				
14.7064	0.004230	0.6099	0.004230				
13.9035	0.004351	0.6312	0.004351				
9.8892	0.004471	0.6861	0.004471				
8.4250	0.004515	0.7085	0.004515				
9.3796	0.004551	0.7003	0.004551				

46.4 MPa (1.5%)

Sikament NN

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	28635.31	0.18

Dilitation Angle	*Eccentricaly*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		Concrete compression damage		Concrete tension stiffening		Concrete tension damage	
Yield Stress (Mpa)	**Inelastic Strain**	**Damage Parameter,D**	**Inelastic Strain**	**Yield Stress (Mpa)**	**Cracking Strain**	**Damage Parameter,D**	**Cracking Strain**
21.9718	0.000000	0	0.000000	3.8000	0.000000	0	0
24.1260	0.000257	0	0.000257	2.6814	0.000106	0.2944	0.000106
26.2554	0.000283	0	0.000283	1.8997	0.000234	0.5001	0.000234
27.7268	0.000302	0	0.000302	1.4876	0.000348	0.6085	0.000348
28.3516	0.000310	0	0.000310	1.2306	0.000457	0.6762	0.000457
30.4045	0.000338	0	0.000338	1.0539	0.000563	0.7227	0.000563
32.4024	0.000368	0	0.000368	0.9245	0.000668	0.7567	0.000668

34.3318	0.000401	0	0.000401	0.8253	0.000771	0.7828	0.000771
36.1777	0.000437	0	0.000437	0.7467	0.000874	0.8035	0.000874
37.9238	0.000476	0	0.000476	0.6827	0.000976	0.8203	0.000976
39.5527	0.000519	0	0.000519	0.4837	0.001483	0.8727	0.001483
41.0464	0.000567	0	0.000567	0.3788	0.001987	0.9003	0.001987
42.3871	0.000620	0	0.000620				
43.5575	0.000679	0	0.000679				
44.5420	0.000745	0	0.000745				
45.3270	0.000817	0	0.000817				
45.9019	0.000897	0	0.000897				
46.2599	0.000985	0	0.000985				
46.4	0.001080	0	0.001080				
46.3181	0.001182	0.0018	0.001182				
45.5312	0.001410	0.0187	0.001410				
44.8485	0.001534	0.0334	0.001534				
43.9947	0.001664	0.0518	0.001664				
42.9894	0.001799	0.0735	0.001799				
41.8538	0.001938	0.0980	0.001938				
40.6097	0.002082	0.1248	0.002082				
39.2791	0.002228	0.1535	0.002228				
37.8832	0.002377	0.1836	0.002377				
36.4420	0.002527	0.2146	0.002527				
34.9740	0.002679	0.2463	0.002679				
33.4955	0.002830	0.2781	0.002830				
32.0211	0.002982	0.3099	0.002982				
30.5629	0.003133	0.3413	0.003133				
29.1312	0.003283	0.3722	0.003283				
27.7344	0.003431	0.4023	0.003431				
26.3789	0.003579	0.4315	0.003579				
25.0697	0.003725	0.4597	0.003725				
23.8104	0.003868	0.4868	0.003868				
22.6031	0.004011	0.5129	0.004011				
21.4493	0.004151	0.5377	0.004151				
20.3494	0.004289	0.5614	0.004289				
19.3031	0.004426	0.5840	0.004426				
18.3096	0.004561	0.6054	0.004561				
17.36771	0.004693	0.6257	0.004693				
16.47593	0.004825	0.6449	0.004825				
15.63245	0.004954	0.6631	0.004954				
14.83534	0.005082	0.6803	0.005082				
14.08255	0.005208	0.6965	0.005208				
13.93712	0.005233	0.6996	0.005233				

40.4 MPa (1.5%)

MegaFlowSp1

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	26719.82	0.18

Dilitation Angle	*Eccentricaly*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		Concrete compression damage		Concrete tension stiffening		Concrete tension damage	
Yield Stress (Mpa)	**Inelastic Strain**	**Damage Parameter,D**	**Inelastic Strain**	**Yield Stress (Mpa)**	**Cracking Strain**	**Damage Parameter,D**	**Cracking Strain**
19.4117	0.000000	0	0.000000	3.9000	0.000000	0	0
21.3189	0.000302	0	0.000302	2.9839	0.000088	0.2349	0.000088
23.2052	0.000332	0	0.000332	2.1140	0.000221	0.4579	0.000221
24.5093	0.000353	0	0.000353	1.6554	0.000338	0.5755	0.000338
25.0631	0.000362	0	0.000362	1.3694	0.000449	0.6489	0.000449
26.8832	0.000394	0	0.000394	1.1728	0.000556	0.6993	0.000556
28.6543	0.000428	0	0.000428	1.0288	0.000661	0.7362	0.000661
30.3633	0.000464	0	0.000464	0.9184	0.000766	0.7645	0.000766
31.9955	0.000503	0	0.000503	0.8309	0.000869	0.7869	0.000869
33.5344	0.000545	0	0.000545	0.7597	0.000972	0.8052	0.000972
34.9623	0.000592	0	0.000592	0.5382	0.001480	0.8620	0.001480
36.2608	0.000643	0	0.000643	0.4215	0.001984	0.8919	0.001984
37.4113	0.000700	0	0.000700				
38.3958	0.000763	0	0.000763				
39.1978	0.000833	0	0.000833				
39.8034	0.000910	0	0.000910				
40.2017	0.000995	0	0.000995				
40.3864	0.001089	0	0.001089				
40.4	0.001098	0	0.001098				
40.3554	0.001190	0.0011	0.001190				
40.1120	0.001299	0.0071	0.001299				
39.0253	0.001539	0.0340	0.001539				

38.2117	0.001670	0.0542	0.001670				
37.2436	0.001806	0.0781	0.001806				
36.1434	0.001947	0.1054	0.001947				
34.9348	0.002093	0.1353	0.002093				
33.6413	0.002241	0.1673	0.002241				
32.2862	0.002392	0.2008	0.002392				
30.8911	0.002544	0.2354	0.002544				
29.4757	0.002697	0.2704	0.002697				
28.0576	0.002850	0.3055	0.002850				
26.6517	0.003003	0.3403	0.003003				
25.2705	0.003154	0.3745	0.003154				
23.9242	0.003305	0.4078	0.003305				
22.6206	0.003453	0.4401	0.003453				
21.3657	0.003600	0.4711	0.003600				
20.1636	0.003745	0.5009	0.003745				
19.0169	0.003888	0.5293	0.003888				
17.9269	0.004029	0.5563	0.004029				
16.8940	0.004168	0.5818	0.004168				
15.9177	0.004304	0.6060	0.004304				
14.9967	0.004439	0.6288	0.004439				
14.1296	0.004571	0.6503	0.004571				
13.31431	0.004702	0.6704	0.004702				
12.54863	0.004830	0.6894	0.004830				
12.25573	0.004881	0.6966	0.004881				

42.9 MPa (2%)

SasplastSp60

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	27534.14	0.18

Dilatation Angle	*Eccentrically*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening	Concrete compression damage	Concrete tension stiffening	Concrete tension damage

Yield Stress (Mpa)	Inelastic Strain	Damage Parameter,D	Inelastic Strain	Yield Stress (Mpa)	Cracking Strain	Damage Parameter,D	Cracking Strain
20.4716	0.000000	0	0.000000	3.7000	0.000000	0	0
22.4816	0.000283	0	0.000283	2.3841	0.000113	0.3557	0.000113
24.4694	0.000311	0	0.000311	1.6890	0.000239	0.5435	0.000239
25.8435	0.000331	0	0.000331	1.3226	0.000352	0.6425	0.000352
26.4271	0.000340	0	0.000340	1.0941	0.000460	0.7043	0.000460
28.3449	0.000371	0	0.000371	0.9371	0.000566	0.7467	0.000566
30.2116	0.000403	0	0.000403	0.8220	0.000670	0.7778	0.000670
32.0139	0.000437	0	0.000437	0.7338	0.000773	0.8017	0.000773
33.7369	0.000475	0	0.000475	0.6639	0.000876	0.8206	0.000876
35.3641	0.000516	0	0.000516	0.6070	0.000978	0.8359	0.000978
36.8781	0.000561	0	0.000561	0.4300	0.001484	0.8838	0.001484
38.2604	0.000610	0	0.000610	0.3368	0.001988	0.9090	0.001988
39.4926	0.000666	0	0.000666				
40.5570	0.000727	0	0.000727				
41.4372	0.000795	0	0.000795				
42.1193	0.000870	0	0.000870				
42.5925	0.000953	0	0.000953				
42.8498	0.001044	0	0.001044				
42.9	0.001142	0	0.001142				
42.7117	0.001249	0.0044	0.001249				
41.7426	0.001484	0.0270	0.001484				
40.9777	0.001612	0.0448	0.001612				
40.0501	0.001745	0.0664	0.001745				
38.9811	0.001884	0.0914	0.001884				
37.7933	0.002027	0.1190	0.002027				
36.5099	0.002174	0.1490	0.002174				
35.1538	0.002323	0.1806	0.002323				
33.7468	0.002474	0.2134	0.002474				
32.3089	0.002627	0.2469	0.002627				
30.8583	0.002779	0.2807	0.002779				
29.4108	0.002932	0.3144	0.002932				
27.9800	0.003084	0.3478	0.003084				
26.5769	0.003235	0.3805	0.003235				
25.2106	0.003384	0.4123	0.003384				
23.8881	0.003532	0.4432	0.003532				
22.6146	0.003679	0.4729	0.003679				
21.3936	0.003823	0.5013	0.003823				
20.2274	0.003965	0.5285	0.003965				
19.1172	0.004106	0.5544	0.004106				
18.0631	0.004244	0.5789	0.004244				
17.0646	0.004380	0.6022	0.004380				

12.8550	0.005033	0.7004	0.005033				

48.2 MPa (2%)

Sikament NN

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	29185.45	0.18

Dilitation Angle	*Eccentricaly*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		Concrete compression damage		Concrete tension stiffening		Concrete tension damage	
Yield Stress (Mpa)	**Inelastic Strain**	**Damage Parameter,D**	**Inelastic Strain**	**Yield Stress (Mpa)**	**Cracking Strain**	**Damage Parameter,D**	**Cracking Strain**
22.7548	0.000000	0	0.000000	3.9000	0.000000	0	0
24.9835	0.000244	0	0.000244	2.6814	0.000108	0.3125	0.000108
27.1858	0.000269	0	0.000269	1.8997	0.000235	0.5129	0.000235
28.7070	0.000286	0	0.000286	1.4876	0.000349	0.6186	0.000349
29.3528	0.000294	0	0.000294	1.2306	0.000458	0.6845	0.000458
31.4745	0.000322	0	0.000322	1.0539	0.000564	0.7298	0.000564
33.5387	0.000351	0	0.000351	0.9245	0.000668	0.7630	0.000668
35.5319	0.000383	0	0.000383	0.8253	0.000772	0.7884	0.000772
37.4391	0.000417	0	0.000417	0.7467	0.000874	0.8085	0.000874
39.2440	0.000455	0	0.000455	0.6827	0.000977	0.8249	0.000977
40.9293	0.000498	0	0.000498	0.4837	0.001483	0.8760	0.001483
42.4774	0.000545	0	0.000545	0.3788	0.001987	0.9029	0.001987
43.8708	0.000597	0	0.000597				
45.0928	0.000655	0	0.000655				
46.1279	0.000719	0	0.000719				
46.9632	0.000791	0	0.000791				
47.5885	0.000869	0	0.000869				
47.9969	0.000955	0	0.000955				
48.1857	0.001049	0	0.001049				

48.2	0.001079	0	0.001079				
48.1561	0.001150	0.0009	0.001150				
47.4682	0.001374	0.0152	0.001374				
46.8325	0.001495	0.0284	0.001495				
46.0229	0.001623	0.0452	0.001623				
45.0582	0.001756	0.0652	0.001756				
43.9584	0.001894	0.0880	0.001894				
42.7448	0.002035	0.1132	0.002035				
41.4386	0.002180	0.1403	0.002180				
40.0605	0.002327	0.1689	0.002327				
38.6302	0.002476	0.1985	0.002476				
37.1660	0.002627	0.2289	0.002627				
35.6844	0.002777	0.2597	0.002777				
34.2001	0.002928	0.2905	0.002928				
32.7257	0.003079	0.3210	0.003079				
31.2719	0.003229	0.3512	0.003229				
29.8476	0.003377	0.3808	0.003377				
28.4599	0.003525	0.4095	0.003525				
27.1144	0.003671	0.4375	0.003671				
25.8152	0.003815	0.4644	0.003815				
24.5651	0.003958	0.4904	0.003958				
23.3661	0.004099	0.5152	0.004099				
22.2191	0.004239	0.5390	0.004239				
21.1244	0.004376	0.5617	0.004376				
20.0817	0.004512	0.5834	0.004512				
19.0899	0.004646	0.6039	0.004646				
18.1481	0.004778	0.6235	0.004778				
17.2547	0.004909	0.6420	0.004909				
16.4080	0.005038	0.6596	0.005038				
15.6062	0.005165	0.6762	0.005165				
14.8473	0.005291	0.6920	0.005291				
14.4834	0.005354	0.6995	0.005354				

43.0 MPa (2%)

MegaFlowSP1

Mass Density	Youngs Modulus	Poisson's Ratio

2.36E-09	27566.21	0.18

Dilitation Angle	***Eccentricaly***	***Initial biaxial/uniaxial ratio,***	***K***	***Viscosity***
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		**Concrete compression damage**		**Concrete tension stiffening**		**Concrete tension damage**	
Yield Stress (Mpa)	**Inelastic Strain**	**Damage Parameter,D**	**Inelastic Strain**	**Yield Stress (Mpa)**	**Cracking Strain**	**Damage Parameter,D**	**Cracking Strain**
20.5127	0.000000	0	0.000000	3.7000	0.000000	0	0
22.5267	0.000283	0	0.000283	2.6362	0.000104	0.2875	0.000104
24.5185	0.000311	0	0.000311	1.8677	0.000232	0.4952	0.000232
25.8953	0.000331	0	0.000331	1.4625	0.000347	0.6047	0.000347
26.4801	0.000339	0	0.000339	1.2098	0.000456	0.6730	0.000456
28.4018	0.000370	0	0.000370	1.0362	0.000562	0.7200	0.000562
30.2723	0.000402	0	0.000402	0.9089	0.000667	0.7543	0.000667
32.0783	0.000436	0	0.000436	0.8114	0.000771	0.7807	0.000771
33.8050	0.000474	0	0.000474	0.7341	0.000873	0.8016	0.000873
35.4359	0.000515	0	0.000515	0.6712	0.000976	0.8186	0.000976
36.9533	0.000559	0	0.000559	0.4755	0.001483	0.8715	0.001483
38.3391	0.000609	0	0.000609	0.3724	0.001986	0.8994	0.001986
39.5748	0.000664	0	0.000664				
40.6425	0.000726	0	0.000726				
41.5260	0.000794	0	0.000794				
42.2113	0.000869	0	0.000869				
42.6875	0.000951	0	0.000951				
42.9478	0.001042	0	0.001042				
43.0	0.001052	0	0.001052				
42.9896	0.001140	0.0002	0.001140				
42.8153	0.001247	0.0043	0.001247				
41.8507	0.001482	0.0267	0.001482				
41.0876	0.001609	0.0445	0.001609				
40.1615	0.001743	0.0660	0.001743				
39.0935	0.001882	0.0908	0.001882				
37.9064	0.002025	0.1185	0.002025				
36.6232	0.002171	0.1483	0.002171				

35.2669	0.002321	0.1798	0.002321				
33.8592	0.002472	0.2126	0.002472				
32.4202	0.002624	0.2460	0.002624				
30.9682	0.002777	0.2798	0.002777				
29.5188	0.002929	0.3135	0.002929				
28.0858	0.003081	0.3468	0.003081				
26.6804	0.003232	0.3795	0.003232				
25.3115	0.003382	0.4114	0.003382				
23.9862	0.003530	0.4422	0.003530				
22.7098	0.003676	0.4719	0.003676				
21.4858	0.003821	0.5003	0.003821				
20.3166	0.003963	0.5275	0.003963				
19.2033	0.004103	0.5534	0.004103				
18.1461	0.004242	0.5780	0.004242				
17.1446	0.004378	0.6013	0.004378				
16.1976	0.004512	0.6233	0.004512				
15.3036	0.004645	0.6441	0.004645				
14.4608	0.004775	0.6637	0.004775				
13.6671	0.004904	0.6822	0.004904				
12.9203	0.005031	0.6995	0.005031				

39.7 MPa (2.5%)

SasplastSP60

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	26487.33	0.18

Dilitation Angle	*Eccentricaly*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		Concrete compression damage		Concrete tension stiffening		Concrete tension damage	
Yield Stress (Mpa)	Inelastic Strain	Damage Parameter,D	Inelastic Strain	Yield Stress (Mpa)	Cracking Strain	Damage Parameter,D	Cracking Strain
19.1156	0.000000	0	0.000000	3.5000	0.000000	0	0
20.9939	0.000307	0	0.000307	2.4608	0.000107	0.2969	0.000107

22.8518	0.000337	0	0.000337	1.7434	0.000234	0.5019	0.000234
24.1361	0.000359	0	0.000359	1.3652	0.000348	0.6099	0.000348
24.6816	0.000368	0	0.000368	1.1293	0.000457	0.6773	0.000457
26.4740	0.000401	0	0.000401	0.9672	0.000563	0.7237	0.000563
28.2181	0.000435	0	0.000435	0.8484	0.000668	0.7576	0.000668
29.9006	0.000471	0	0.000471	0.7574	0.000771	0.7836	0.000771
31.5069	0.000510	0	0.000510	0.6852	0.000874	0.8042	0.000874
33.0206	0.000553	0	0.000553	0.6265	0.000976	0.8210	0.000976
34.4240	0.000600	0	0.000600	0.4439	0.001483	0.8732	0.001483
35.6985	0.000652	0	0.000652	0.3476	0.001987	0.9007	0.001987
36.8256	0.000710	0	0.000710				
37.7872	0.000773	0	0.000773				
38.5669	0.000844	0	0.000844				
39.1507	0.000922	0	0.000922				
39.5280	0.001008	0	0.001008				
39.7	0.001101	0	0.001101				
39.6423	0.001203	0.0015	0.001203				
39.3810	0.001313	0.0080	0.001313				
38.2637	0.001555	0.0362	0.001555				
37.4381	0.001687	0.0570	0.001687				
36.4608	0.001823	0.0816	0.001823				
35.3542	0.001965	0.1095	0.001965				
34.1423	0.002111	0.1400	0.002111				
32.8488	0.002260	0.1726	0.002260				
31.4968	0.002411	0.2066	0.002411				
30.1079	0.002563	0.2416	0.002563				
28.7016	0.002716	0.2770	0.002716				
27.2953	0.002869	0.3125	0.002869				
25.9037	0.003022	0.3475	0.003022				
24.5389	0.003174	0.3819	0.003174				
23.2107	0.003324	0.4153	0.003324				
21.9267	0.003472	0.4477	0.003472				
20.6925	0.003619	0.4788	0.003619				
19.5119	0.003763	0.5085	0.003763				
18.3873	0.003906	0.5368	0.003906				
17.3196	0.004046	0.5637	0.004046				
16.3092	0.004184	0.5892	0.004184				
15.3551	0.004320	0.6132	0.004320				
14.4563	0.004454	0.6359	0.004454				
12.8168	0.004716	0.6772	0.004716				
11.9285	0.004870	0.6995	0.004870				

41.0 MPa (2.5%)

Sikament NN

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	26917.5	0.18

Dilitation Angle	***Eccentricaly***	***Initial biaxial/uniaxial ratio,***	***K***	***Viscosity***
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		**Concrete compression damage**		**Concrete tension stiffening**		**Concrete tension damage**	
Yield Stress (Mpa)	**Inelastic Strain**	**Damage Parameter,D**	**Inelastic Strain**	**Yield Stress (Mpa)**	**Cracking Strain**	**Damage Parameter,D**	**Cracking Strain**
19.6640	0.000000	0	0.000000	3.6000	0.000000	0	0
21.5958	0.000298	0	0.000298	2.5571	0.000105	0.2897	0.000105
23.5065	0.000327	0	0.000327	1.8117	0.000233	0.4968	0.000233
24.8273	0.000348	0	0.000348	1.4187	0.000347	0.6059	0.000347
25.3883	0.000357	0	0.000357	1.1736	0.000456	0.6740	0.000456
27.2320	0.000388	0	0.000388	1.0051	0.000563	0.7208	0.000563
29.0261	0.000422	0	0.000422	0.8817	0.000667	0.7551	0.000667
30.7578	0.000457	0	0.000457	0.7871	0.000771	0.7814	0.000771
32.4121	0.000496	0	0.000496	0.7121	0.000874	0.8022	0.000874
33.9726	0.000538	0	0.000538	0.6511	0.000976	0.8191	0.000976
35.4216	0.000584	0	0.000584	0.4613	0.001483	0.8719	0.001483
36.7408	0.000635	0	0.000635	0.3612	0.001987	0.8997	0.001987
37.9114	0.000692	0	0.000692				
38.9155	0.000754	0	0.000754				
39.7368	0.000824	0	0.000824				
40.3610	0.000901	0	0.000901				
40.7776	0.000985	0	0.000985				
41.0	0.001097	0.0000	0.001097				
40.9654	0.001178	0.0008	0.001178				
40.7375	0.001287	0.0064	0.001287				
39.6773	0.001526	0.0323	0.001526				
38.8741	0.001656	0.0519	0.001656				
37.9143	0.001791	0.0753	0.001791				
36.8199	0.001932	0.1020	0.001932				
35.6144	0.002077	0.1314	0.002077				
34.3213	0.002225	0.1629	0.002225				

32.9639	0.002375	0.1960	0.002375				
31.5638	0.002527	0.2302	0.002527				
30.1410	0.002680	0.2649	0.002680				
28.7130	0.002833	0.2997	0.002833				
27.2952	0.002986	0.3343	0.002986				
25.9003	0.003138	0.3683	0.003138				
24.5388	0.003288	0.4015	0.003288				
23.2188	0.003437	0.4337	0.003437				
21.9464	0.003585	0.4647	0.003585				
20.7261	0.003730	0.4945	0.003730				
19.5607	0.003873	0.5229	0.003873				
18.4517	0.004015	0.5500	0.004015				
17.3997	0.004154	0.5756	0.004154				
16.4044	0.004291	0.5999	0.004291				
15.4646	0.004425	0.6228	0.004425				
14.5789	0.004558	0.6444	0.004558				
13.7454	0.004689	0.6647	0.004689				
12.9621	0.004818	0.6839	0.004818				
12.2979	0.004933	0.7001	0.004933				

40.1 MPa (2.5%)

MegaFlowSP1

Mass Density	Youngs Modulus	Poisson's Ratio
2.36E-09	27566.21	0.18

Dilitation Angle	*Eccentricaly*	*Initial biaxial/uniaxial ratio,*	*K*	*Viscosity*
27	**0.1**	**1.16**	**0.67**	**0**

Concrete compression hardening		Concrete compression damage		Concrete tension stiffening		Concrete tension damage	
Yield Stress (Mpa)	**Inelastic Strain**	**Damage Parameter,D**	**Inelastic Strain**	**Yield Stress (Mpa)**	**Cracking Strain**	**Damage Parameter,D**	**Cracking Strain**
19.2955	0.000000	0	0.000000	3.6000	0.000000	0	0
21.1910	0.000307	0	0.000307	2.6362	0.000101	0.2677	0.000101

23.0657	0.000337	0	0.000337	1.8677	0.000230	0.4812	0.000230
24.3616	0.000358	0	0.000358	1.4625	0.000345	0.5937	0.000345
24.9120	0.000368	0	0.000368	1.2098	0.000455	0.6639	0.000455
26.7203	0.000400	0	0.000400	1.0362	0.000561	0.7122	0.000561
28.4796	0.000434	0	0.000434	0.9089	0.000666	0.7475	0.000666
30.1769	0.000471	0	0.000471	0.8114	0.000770	0.7746	0.000770
31.7973	0.000510	0	0.000510	0.7341	0.000873	0.7961	0.000873
33.3244	0.000553	0	0.000553	0.6712	0.000975	0.8136	0.000975
34.7406	0.000600	0	0.000600	0.4755	0.001482	0.8679	0.001482
36.0274	0.000652	0	0.000652	0.3724	0.001986	0.8966	0.001986
37.1663	0.000709	0	0.000709				
38.1394	0.000773	0	0.000773				
38.9304	0.000843	0	0.000843				
39.5253	0.000921	0	0.000921				
39.9137	0.001006	0	0.001006				
40.0892	0.001100	0	0.001100				
40.1	0.001129	0	0.001129				
40.0501	0.001201	0.0012	0.001201				
39.7998	0.001310	0.0075	0.001310				
38.7034	0.001552	0.0348	0.001552				
37.8872	0.001682	0.0552	0.001682				
36.9184	0.001818	0.0793	0.001818				
35.8191	0.001959	0.1068	0.001959				
34.6129	0.002105	0.1368	0.002105				
33.3236	0.002253	0.1690	0.002253				
31.9739	0.002403	0.2026	0.002403				
30.5856	0.002555	0.2373	0.002555				
29.1781	0.002708	0.2724	0.002708				
27.7687	0.002861	0.3075	0.002861				
26.3723	0.003013	0.3423	0.003013				
25.0011	0.003164	0.3765	0.003164				
23.6652	0.003314	0.4098	0.003314				
22.3723	0.003463	0.4421	0.003463				
21.1282	0.003609	0.4731	0.003609				
19.9368	0.003754	0.5028	0.003754				
18.8007	0.003896	0.5312	0.003896				
17.7211	0.004037	0.5581	0.004037				
16.6983	0.004175	0.5836	0.004175				
15.7317	0.004311	0.6077	0.004311				
14.8202	0.004445	0.6304	0.004445				

13.9622	0.004577	0.6518	0.004577				
13.1556	0.004708	0.6719	0.004708				
12.3982	0.004836	0.6908	0.004836				
12.0372	0.004900	0.6998	0.004900				

APPINDIX B: Photo Gallery

	
Compressive strength Test	Unit weight test
	
Sand equivalent test	Sand Specific gravity test

SasplastSp60 Sikament NN

Sand Quartering Partial crushed Cubes

APPINDIX C: Concrete Mix Design

Mix Design for Cement Concrete ---- (C-25)

Cement Type: Dangote PPC

1) Summary of Requirements

Cement Content : Maximum =550 kg/m3

Maximum Water/Cement Ratio :- 0.5 [Project & ERA's Technical Specification]
Required Slump :- 25-75 mm [From Table A 1.5.3.1, ACI 211.1 - 91

2) Determination of Target Mean Strength

Specified/Characterstic Cylinderical Compressive Strength (f'c) :- 20 Mpa
Specified/Characterstic Cubical Compressive Strength (f'c) :- 25 Mpa
Required/Characterstic Cylinderical Compressive Strength (f'c) :- 26.9 Mpa
Required/Characterstic Cubical Compressive Strength (f'c) :- 33.6 Mpa
~Target Average Compressive Strength (f'cr)[From Table 4.2, ACI 214R-02]

Table 4.2—Minimum required average strength without sufficient historical data

$f'_{cr} = f'_c + 6.9$ MPa (1000 psi)	when $f'_c < 20.7$ MPa (3000 psi)
$f'_{cr} = f'_c + 8.3$ MPa (1200 psi)	when $f'_c \geq 20.7$ MPa (3000 psi) and $f'_c \leq 34.5$ MPa (5000 psi)
$f'_{cr} = 1.10 f'_c + 4.8$ MPa (700 psi)	when $f'_c > 34.5$ MPa (5000 psi)

3) Constituent Material Sources

2.1 Cement : Portland Pozzolan Cement (PPC) Produced and Produced by Dangote Cement Factory in Ethiopia.

2.2 Coarse Aggregate : Crushed Aggregate Produced at Addis Abeba (Worku sefer Stone quarry site Tulu demtu) a Nominal Size of 25mm
2.3 Fine Aggregate : Natural Sand From near Meki town Awash River sand (139 km Addis Abeba to Hawasa Road, offset 5 km, LHS)
2.4 Water : From a Source Addis Abeba Tap Water

4) Input Data's

Parameters	Water	Cement	Sand/FA	CA
Sp. Gravity	1	3.15	2.32	2.63
Absorbition (%)	…	…	4.17	2.3
Natural Moisture Content (%)	…	…	1.5	1.1
Fineness Modulus	…	…	2.8	…
Dry Rodded Unit Weight (Kg/m^3)	…	…	…	1540
Loose Unit Weight (Kg/m^3)	…	…		1480

5)Water-Cement Ratio

Nom.max size of aggregate= 25 mm
Target Avg Compr. Strength= 33.6 Mpa
~w/c= 0.5 For a nom. Max size of aggr. of 25mm … [Table A1.5.3.4 (a) and (b) of ACI 211.1 - 91]

6) Amount of Mixing Water and Cement Content Estimation

~Cement content (to be economical we consider fixing the quantity 360 Kg per cu.m of concrete
Water-Cement Ratio= 0.5
Amount of mixing water= 180 Kg per cu.m of concrete
Therefore, take the amount of cement to be= 360 Kg
Therefore, take the amount of mixing water to be= 180 Kg

7) Estimation of Coarse Aggregate Content

Nom.max size of aggregate=	25 mm		
Fineness Modulus of Sand=	2.8		
~Volume of CA, on a dry rodded basis,=	0.67 cu.m…[Table A1.5.3.6 of ACI 211.1 - 91]		
Therefore, the volume of CA per unit volume of Concrete is=	0.392 cu.m		1030.96 Kg (dry)

8) Estimation of Fine Aggregate Content

\>>>Absolute Volume Method

Vc=	0.114 cu.m		
Vw=	0.18 cu.m		
Vca=	0.392 cu.m		
Vair=	0.015 cu.m…air from [Table A1.5.3.3 of ACI 211.1 - 91]		
~Vs=	0.299 cu.m		
Therefore, the sand/fine aggregate content per unit volume of concrete is=	0.299	cu.m…………	693.68 Kg (Dry)

9) Adjustment of Constituent Materials for Natural Moisture

Constituent Materials	Estimated Quantity (Kg per cu.m of concrete)	Absorption (%)	NMC (%)	Free Water (%)	Free Water (kg)	Adjusted Qty. (Kg per cu.m of concrete)
Cement (PPC)	360					360
Water	180					211
Coarse Aggregate (dry)	1030.96	2.3	1.1	-1.2	-12.37	1042.3
Fine Aggregate (dry)	693.68	4.17	1.5	-2.67	-18.52	704.09

Therefore the mass of each component to get 1cu.m of concrete is :

Cement=	360.00 Kg
Water=	210.89 Kg
Coarse Aggregate(wet)=	1042.30 Kg
Sand (wet)=	704.09 Kg
Total=	2317.28 kg/m^3

10) Composition of Laboratory Trial Batch, scale the masses down to produce 0.0405m3 of concrete

Therefore the mass of each component to get 0.0405 m3 of concrete is :

Cement=	14580.00 gm	
Water=	8541.00 gm	
Coarse Aggregate(wet)=	42213.00 gm	
Sand (wet)=	28516.00 gm	
Total=	93850.00 gm	2317.28 kg/m^3

The batch as mixed shows the follwing properties :

Measured Slump=	50.00 mm
Workability =	O.K.
Additional Water=	420.00 gm
Water (Net Mixing)=	7693.07 gm
Unight Weight of Fresh Concrete=	2378.00 kg/m^3
Yield of Trial Batch=	0.039 m^3
New (w/c) Ratio=	0.53

11) Corrected Proportions of Constituent Materials for 1m^3 of Concrete

Therefore the mass of each component to get 1cu.m of concrete is :

Cement=	360.00	Kg
Water=	211.00	Kg
Coarse Aggregate(wet)=	1042.30	Kg
Sand (wet)=	704.09	Kg
Total=	2317.39	kg/m^3

APPINDIX D: Statistical results

0.5 % HRWRAs (Superplasticizer) dosage

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Sikament NN (0.5%)	3	98.3	32.76667	0.103333
SasplastSP60 (0.5%)	3	86.6	28.86667	0.023333
MegaFlowSP1 (0.5%)	3	96.7	32.23333	0.253333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1827.417	3	609.1389	1765.62	1.27E-11	4.066181
Within Groups	2.76	8	0.345			
Total	1830.177	11				

1 % HRWRAs (Superplasticizer) dosage

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Sikament NN (1%)	3	104.1	34.7	0.43
SasplastSP60 (1%)	3	94.6	31.53333	0.043333
MegaFlowSP1 (1%)	3	103.9	34.63333	0.523333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2129.513	3	709.8378	1422.046	3.02E-11	4.066181
Within Groups	3.993333	8	0.499167			
Total	2133.507	11				

1.5 % HRWRAs (Superplasticizer) dosage

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Sikament NN (1.5%)	3	139.3	46.43333	0.463333
SasplastSP60 (1.5%)	3	113	37.66667	0.763333
MegaFlowSP1 (1.5%)	3	121.1	40.36667	1.203333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3454.087	3	1151.362	1342.696	3.8E-11	4.066181
Within Groups	6.86	8	0.8575			
Total	3460.947	11				

2 % HRWRAs (Superplasticizer) dosage

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Sikament NN (2%)	3	144.65	48.21667	0.763333
SasplastSP60 (2%)	3	128.9	42.96667	0.103333
MegaFlowSP1 (2%)	3	128.95	42.98333	0.123333

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3971.624	3	1323.875	2661.055	2.47E-12	4.066181
Within Groups	3.98	8	0.4975			
Total	3975.604	11				

2.5 % HRWRAs (Superplasticizer) dosage

Anova: Single Factor

SUMMARY

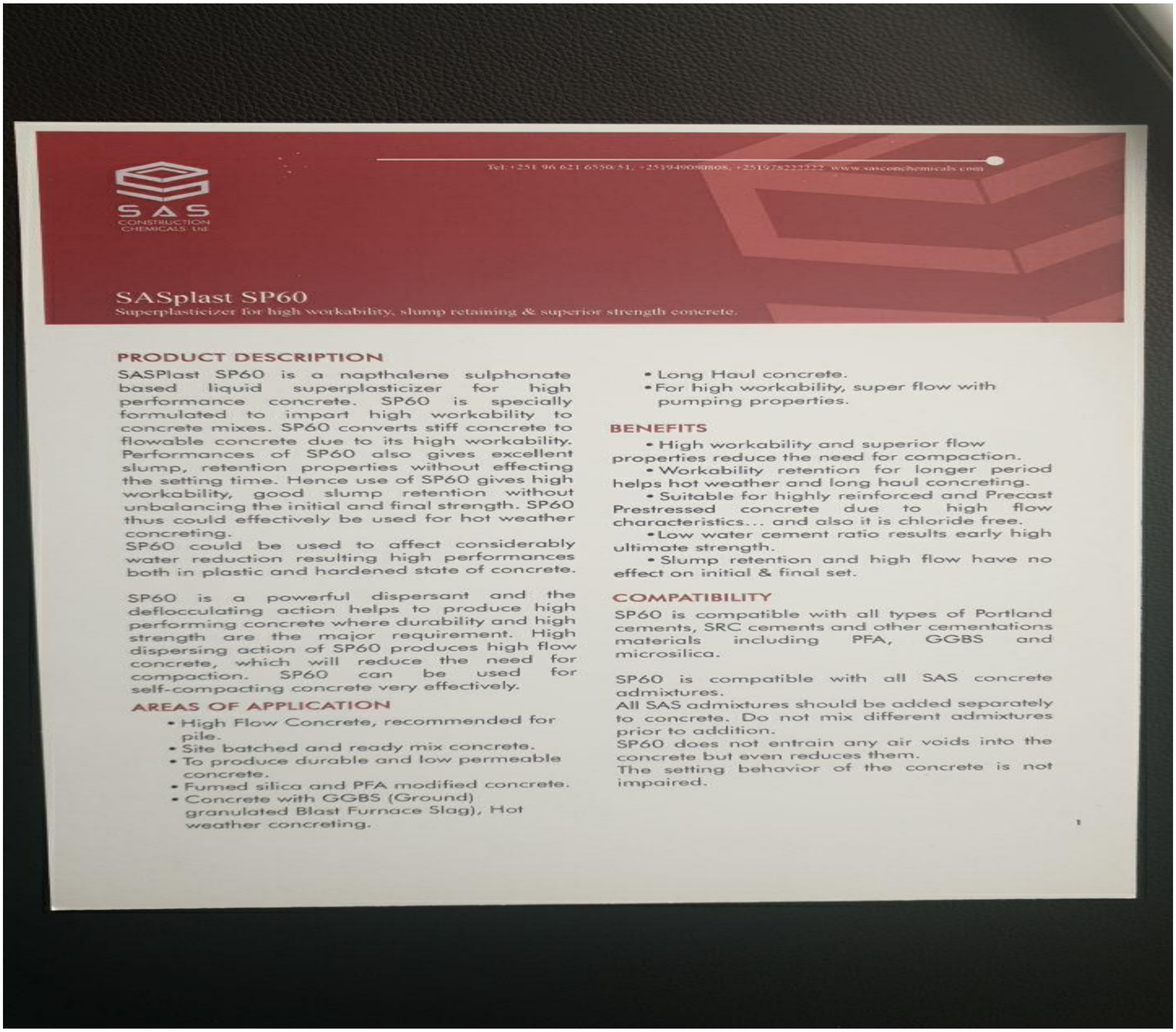
Groups	*Count*	*Sum*	*Average*	*Variance*
Sikament NN (2.5%)	3	123	41	0.07
SasplastSP60 (2.5%)	3	119.2	39.73333	0.123333
MegaFlowSP1 (2.5%)	3	121.07	40.35667	0.073633

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3143.449	3	1047.816	3308.11	1.04E-12	4.066181
Within Groups	2.533933	8	0.316742			
Total	3145.983	11				

APPINDIX E : Superplastisizer/High range Water-reducers

SASplast SP60



SASplast SP60

Superplasticizer for high workability, slump retaining & superior strength concrete.

PRODUCT DESCRIPTION

SASPlast SP60 is a napthalene sulphonate based liquid superplasticizer for high performance concrete. SP60 is specially formulated to impart high workability to concrete mixes. SP60 converts stiff concrete to flowable concrete due to its high workability. Performances of SP60 also gives excellent slump, retention properties without effecting the setting time. Hence use of SP60 gives high workability, good slump retention without unbalancing the initial and final strength. SP60 thus could effectively be used for hot weather concreting.

SP60 could be used to affect considerably water reduction resulting high performances both in plastic and hardened state of concrete.

SP60 is a powerful dispersant and the deflocculating action helps to produce high performing concrete where durability and high strength are the major requirement. High dispersing action of SP60 produces high flow concrete, which will reduce the need for compaction. SP60 can be used for self-compacting concrete very effectively.

AREAS OF APPLICATION

- High Flow Concrete, recommended for pile.
- Site batched and ready mix concrete.
- To produce durable and low permeable concrete.
- Fumed silica and PFA modified concrete.
- Concrete with GGBS (Ground) granulated Blast Furnace Slag), Hot weather concreting.
- Long Haul concrete.
- For high workability, super flow with pumping properties.

BENEFITS

- High workability and superior flow properties reduce the need for compaction.
- Workability retention for longer period helps hot weather and long haul concreting.
- Suitable for highly reinforced and Precast Prestressed concrete due to high flow characteristics... and also it is chloride free.
- Low water cement ratio results early high ultimate strength.
- Slump retention and high flow have no effect on initial & final set.

COMPATIBILITY

SP60 is compatible with all types of Portland cements, SRC cements and other cementations materials including PFA, GGBS and microsilica.

SP60 is compatible with all SAS concrete admixtures.

All SAS admixtures should be added separately to concrete. Do not mix different admixtures prior to addition.

SP60 does not entrain any air voids into the concrete but even reduces them.

The setting behavior of the concrete is not impaired.

SAS
CONSTRUCTION CHEMICALS Ltd.

SASplast SP60

Superplasticizer for high workability, slump retaining & supervisor strength concrete.

TECHNICAL PROPERTIES

Specific Gravity	:	1.22 ± 0.03@ 25°C
Appearance	:	Dark Brown Liquid
Air Entrainment	:	1 – 2% Depending on dosage
Chloride Content	:	Nil – Tested to B.S. 5075
Freezing	:	0°C, Mix before use

CONFORMITY

SP60 confirms to following standard.

ASTM C-494- Type F & G, B.S 5075 – Part 1 ASTM C 1017

DOSAGE

Recommended dosage range 0.5 – 2.5 % of cement weight. The actual dosage rate applied can exceed the recommended dosage range on common mix design and should be determinated in preliminary tests.
Further regulations on maximum dosage rates should be observed.

METHOD OF ADDITION

SP60 is supplied as a ready to use brown liquid. SP60 can be added to concrete in the mixing cycle after the addition of 90% water – or can be added along with the gauging water. Care must be taken not to add SP60 to dry mix. SP60 can also be added a few minutes before the actual pouring concrete.

EFFECTS OF OVER DOSAGE

- Results in increased workability.
- Slightly higher entrainment.
- Delayed setting.

Reason for over dosage must be ascertained to avoid recurrence. Anyway, over dosing will not adversely affect the overall performance of the concrete mix, provided proper curing to be done. Also form work removal should be delayed to allow the setting. In most cases the compressive strength is more than compared to the normal concrete.
SP60 preferably dispensed by using automatic dispensing equipment.

HEALTH & SAFETY

SP60 is non-hazardous. It is always advisable to avoid contact with skin or eyes. If contact with skin wash with water. Wear protective goggles and hand gloves while handling. If swallowed seek immediate medical attention.

PACKING & STORAGE

SP60 is available in 210 Litre and in bulk to site installed storage tanks. SP60 should be stored in cool, shaded warehouses. Shelf life is 12 months.
Before using, homogenize sample by shaking or mixing with a mixer.
After thawing, the product must be used after mixing.

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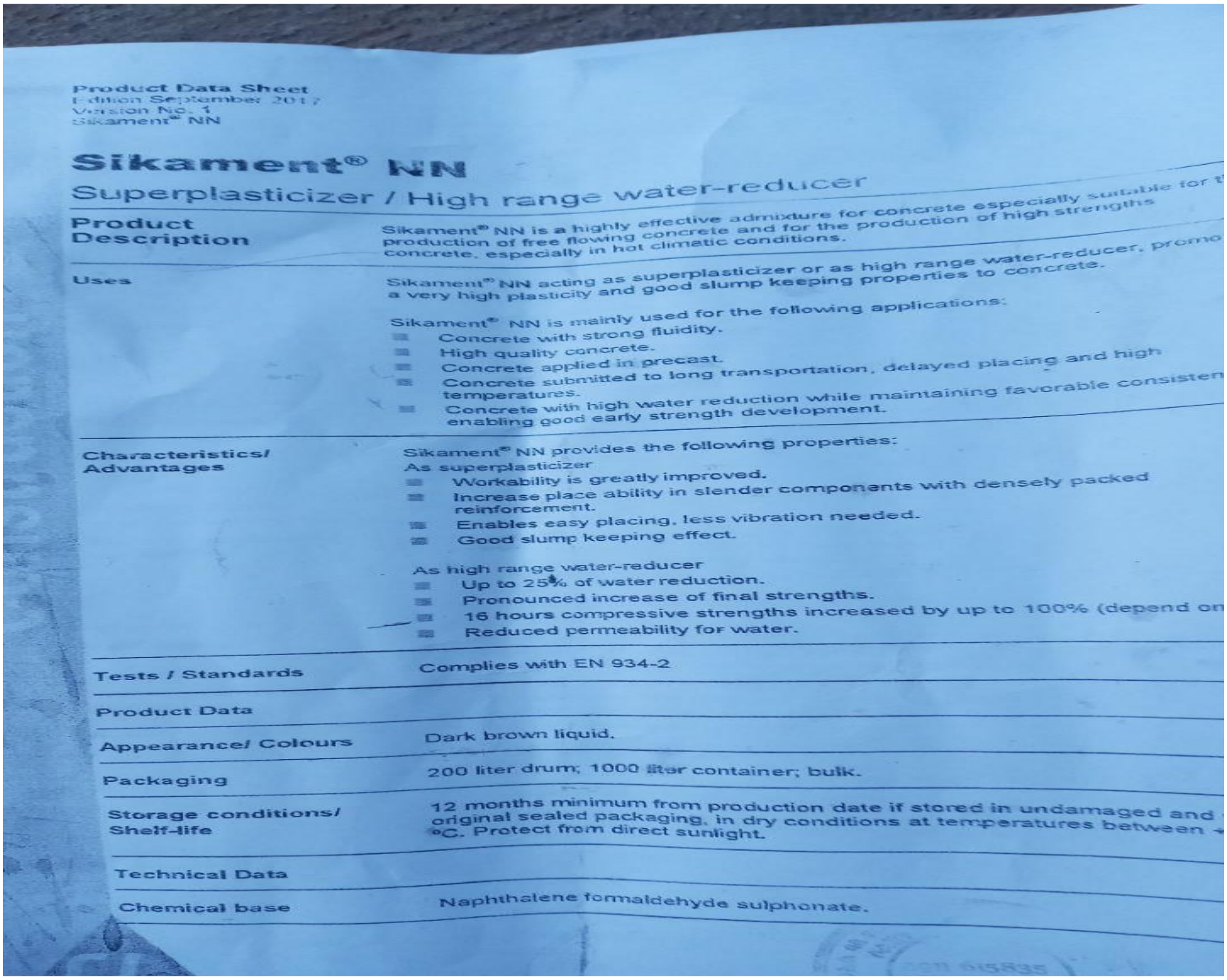
Information in this brochure is given as a result of our experiences and many experiments conducted on this subject. However, this doest not encumber any responsibility or guarantee, due to situation that may arise as a result of misuses. Test to be carried out before every use will demonstrate satisfaction of usage method and condition of materials. Our experts are ready to help users and provide solution in case of any problems.

Sikament NN



Product Data Sheet
Edition September 2017
Version No. 1
Sikament® NN

Sikament® NN

Superplasticizer / High range water-reducer

Product Description	Sikament® NN is a highly effective admixture for concrete especially suitable for t[he] production of free flowing concrete and for the production of high strengths concrete, especially in hot climatic conditions.
Uses	Sikament® NN acting as superplasticizer or as high range water-reducer, promo[tes] a very high plasticity and good slump keeping properties to concrete. Sikament® NN 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 consisten[cy] enabling good early strength development.
Characteristics/ Advantages	Sikament® NN 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 ▪ 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 original sealed packaging, in dry conditions at temperatures between + °C. Protect from direct sunlight.
Technical Data	
Chemical base	Naphthalene formaldehyde sulphonate.

Density	1.2 ± 0.02 kg/liter.
pH (23 ± 2°C)	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 rec
Mixing / Dispensing	Sikament® NN can be added to the mixing water prior to its addition to the aggregates or directly to the freshly mixed concrete (the plasticizing effect pronounced). Never add Sikament® NN directly to dry cement or aggregat (efficiency reduction). Sikament® NN can also be added to the concrete immediately prior to disc after further mixing has taken place for at least three more minutes.
Aplication method/ Tools	Sikament® NN allows the production of high performance concrete, as lor composition is well design and standard rules of good concreting practice followed (production as well as placing). Fresh concrete must be cured properly and as early as possible especiall climatic conditions in order to prevent plastic and drying shrinkage.
Cleaning of tools	Clean all tools and application equipment with water immediately after us
Notes on application/ Limitations	We recommend previous tests to determine the correct dosage of th admixture and whenever concrete composition is changed. When accidental overdosing occurs, the set retarding effect increas this period the concrete must be kept moist in order to prevent prem drying out. For further details contact our Technical Department.
Value base	All technical data stated in this Product Data Sheet are based on laborat Actual measured data may vary due to circumstances beyond our contr
Health and Safety Information	For information and advice on the safe handling, storage and disposal o products, users shall refer to the most recent Material Safety Data Shee physical, ecological, toxicological and other safety related data.

The information, and, in particular, the recommendations relating to the application and end- products, are given in good faith based on Sika's current knowledge and experience of the p properly stored, handled and applied under normal conditions. In practice, the differences in substrates and actual site conditions are such that no warranty in respect of merchantability a particular purpose, nor any liability arising out of any legal relationship whatsoever, must b from this information, or from any written recommendations, or from any other advice offered proprietary rights of third parties must be observed. All orders are accepted subject to our cu sale and delivery. Users must always refer to the most recent issue of the Product Data She product concerned, copies of which will be supplied on request or accessed on the Internet u www.nga.sika.com

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MegaFlow SP1 (Muraplast SP1)

MC FOR
CONCRETE INDUSTRY

BE SURE. BUILD SURE.

Muraplast SP1 (Formerly Known As MegaFlow SP1)
High Range Water Reducing Superplasticiser

Description

Muraplast SP1 is a highly effective water reducing superplasticiser and an extremely powerful de-flocculating agent based on soluble salt of polymericnapthalene sulphonate.

Standards

ASTM C494, Type F, BSEN 934-2

Advantages

- Good workability with fast strength gain.
- Economical and cost effective solution for Pre Cast Concrete.
- Increases Durability by reducing permeability.
- Normal setting witout retardation effect.
- Increased production in Precast Yards.
- Chloride free and safe for use in pre-stressed and reinforced concrete.

>> Concrete Admixture

Application

Areas of application

It is used to produce flowing concrete for the congested areas, slabs, foundations, large pours, beams, columns and precast elements. It provides excellent strength gain at early ages and major increase at all ages of concrete.

Compatability

Muraplast SP1 can be used with all types of cements and cementitious materials like fly ash, GGBS, micro silica, etc. **Muraplast SP1** should not be premixed with other admixtures.

Dosage

Recommended dosage is 0.5 - 3.0% by weight of cementitious material. Higher dosage can be used after verification of performance by conducting lab and site trials. Optimum dosage of **MegaFlow SP1** and effect on concrete properties such as workability, strength, setting time, etc. are best assessed after preliminary tests on site using the actual materials of mixes under consideration.

Effects of Overdosing

Overdosing may result in higher workability and delay in setting.If intentionally or accidentally increased above the recommended limit,ensure that the stripping time of formwork is extended accordingly. In such cases,provided theconcrete is properly cured,the ultimate strength will generally be higher than the regular concrete.

Dispensing

Muraplast SP1 should be dispensed into the concrete mixer together with the mixing water.

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