Sudan University of Science and Technology

College of Graduate Studies

PRODUCTION AND CHARACTERIZATION OF HIGH STRENGTH CONCRETE FOR DAMS

إنتاج وتوصيف الخرسانة عالية المقاومة للسدود

A Thesis Submitted in Partial Fulfillment for the Degree of Master of Science in Construction Engineering at Sudan University of Science and Technology

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الآية

بسم الله الرحمن الرحيم

قال الله تعالى

اللَّهُ الَّذِي خَلَقَكُم مِّن ضَعْفٍ ثُمَّ جَعَلَ مِن بَعْدِ ضَعْفٍ قُوَّةً ثُمَّ جَعَلَ مِن بَعْدِ قُوَّةٍ ضَعْفًا وَشَيْبَةً يَخْلُقُ مَا يَشَاءُ وَهُوَ الْعَلِيمُ الْقَدِيرُ

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DEDICATION

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, my wife and my daughter whose words of encouragement and push for tenacity ring in my ears.

I also dedicate this research to my many friends who have supported me throughout the process. I will always appreciate all they have done.

Finally, all thanks to god, for giving me the ability and strength to do this project.

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Finally, I sincerely thank to my parents, family, and friends, who provide the advice and support. The product of this research paper would not be possible without all of them.

ABSTRACT

This research presents a part of an ongoing experimental laboratory investigation being carried out for production and characterization of High Strength Concrete (HSC) for the Dam Complex of Upper Atbara Project concrete dam which is located in the East of Sudan. The main objectives of this research are to produce concrete with compressive strength of 85 MPa using local available ingredients, to study the effects of different proportions of Silica Fume and various combinations of Silica Fume and Fly Ash on the mix and to find the optimum range of Silica Fume and Fly Ash contents.

Hundreds of specimens were performed and tested using local aggregates with addition of supplementary cementitious materials (Silica Fume, Fly Ash and Super Plasticizers). The Silica Fume and Fly Ash were added by weight of cement as a replacement. Various percentages of Silica Fume (SF) and Fly Ash (FA) were added at different Water/Cementitious materials Ratios (W/Cm). Twenty two mix design trials of grade 85 MPa had been successfully produced and their mechanical properties were measured and documented. The compressive strength tests were carried out on concrete specimens (cubes) at 7 days and 28 days, also the fresh concrete tests (Slump Test and Flow Test) have been done. A statistical approach was followed during the analysis of the test results according to ACI 211.4 and using Microsoft Office Excel program.

The analysis of the test results has shown the target compressive strength of 85 MPa was achieved with a range of Course Aggregate to Fine Aggregate ratio of (1.4 to 1.9), Optimum Water/Cementitious materials ratio of (0.25), the Super Plasticizer-binder ratio was set to be (1.6%), Silica Fume dosage was fixed to (8%) and finally the Fly Ash dosage was (12%). Test results were found to support the reviewed information on HSC production from local available aggregates in Sudan. Also the water/ Cementitious materials ratio and the suitable admixtures with their optimum dosages were found to be the most important parameters for producing HSC.

المستخلص

يستعرض هذا البحث جزءًا من الاختبارات التجريبية المستمرة لإنتاج الخرسانة عالية المقاومة، والتي تم تنفيذها في سدي أعالي عطبرة وستيت بشرق السودان. الهدف الرئيسي من هذا البحث هو إنتاج الخرسانة عالية المقاومة (85 ميغاباسكال) باستخدام المواد المحلية المتاحه، ومن ثم دراسة آثار نسب مختلفة من غبار السيليكا وغبار السيليكا بالتزامن مع الرماد المتطاير في الخلطة الخرسانية، وإيجاد النسبة المثلى لكل منها.

تم اختبار المئات من العينات الخرسانية باستخدام الركام المتوفر محليًّا مع استخدام المواد الاسمنتية التكميلية (غبارالسيليكا , الرماد المتطاير, الملدنات المتقدمة) تمت اضافة نسب مختلفة من الرماد المتطاير مع نسب مختلفة من الماء/المواد الاسمنتية. وقد تم بنجاح إجراء اثنتين وعشرين تجربة لإنتاج خرسانة ذات مقاومة (85 ميغاباسكال)، كما تم قياس خصائصها الميكانيكية وتوثيقها. وتم إجراء اختبار مقاومة الضغط للعينات الخرسانية في عمر 7 أيام و 28 يوما كل على حدى، كما تم أيضا إجراء اختبار الهبوط والانسياب للخرسانه الطازجة. وتم إجراء تحليل للنتائج عن طريق النموذج الإحصائي، كما ورد في المدونة الأمريكية (ACI 211.4) مع استخدام برنامج الاكسل.

وقد اتضح من تحليل النتائج التي تم تحقيقها أن المقاومة المستهدفة يمكن تحقيقها باستخدام نسبة الركام الخشن إلى الركام الناعم (من 1.4 إلى 1.9)، في حين بلغت نسبة الماء الى المواد الاسمنتية المثلى (0.25)، ونسبة الملدنات الفائقة (1.6%)، وجرعة غبار السيليكا (8%) وأخيرا جرعة الرماد المتطاير (12%). وتمت دراسة هذه النتائج لتدعيم المعلومات المتوفرة عن إنتاج الخرسانة عالية المقاومة من الركام المتوفر محليًّا في السودان. كما وجد أن نسبة الماء إلى المواد الاسمنتية والمضافات المناسبة مع الجرعات المثلى، هي أهم معايير إنتاج الخرسانة عالية المقاومة.

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CHAPTER ONE
INTRODUCTION

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INTRODUCTION

1.1 General

Reinforced concrete is the most commonly used construction material .Increasing construction with new innovations in materials and construction techniques have strengthened the position of concrete as a construction materials and lead to more rapid development in field of concrete technology. Production of concrete having higher strength (HSC) represents an important part of these developments.

The increased demand on land use in large cities, as a result of increasing rural-to-urban migration or high rate of inflation. Leads to more need for productive constructions. This need in turn leads to the conclusion that high strength construction materials will be increasingly used in the future for building dams, bridges , in order to keep column sizes at manageable dimensions and to make more effective use of floor areas, especially in the lower storeys of the high rise structures. Two other performance criteria lend weight to the argument for the use of HSC. Increased wind and traffic vibration susceptibility dictates that the modulus of elasticity of the materials should be as high as possible in order to limit small amplitude elastic displacements. Moreover, the need for rapid construction requires early age strength gain, a feature that may offered readily by high strength concrete. The combined effect of the three above mentioned requirements renders HSC economics rather appealing.

High strength concrete “HSC” can be defined as “concrete with compressive strength above what is considered “. This means that the definition varying geographically and with time depending mainly on the availability of raw materials and the demand from construction industry.

This study presents a part of an ongoing experimental laboratory investigation being carried out for production and characterization of high strength concrete for dam complex of upper Atbara project, which, located on Setit and Upper Atbara in Sudan, was constructed in 2017s for power generation and irrigation purposes.

The raising works of DCUAP concrete dam comprise the addition of mass concrete, reinforced concrete, and post-tensioning requirements, the concrete dam section is divided into 4 typical structures along its 12.5 km length, and each structure has its specific geometry and function different design methodologies are needed for each.

1.2 Significance of the Study

There are some parts of huge projects like dams, tall buildings and bridges were required high strength concrete (HSC) Many applications of HSC have already been reported. Further growth on a much wider scale is anticipated in the near future because it offers cost efficient solutions to many structural design problems.

This section will provide brief description on the various significances of the study given on two categories, technological and economic. The proposed study serves the mangers as their reference or guide to engineers, the proposed study will help engineers to have a deeper understanding to the high strength concrete. By this study they will come up with easier and powerful design of high strength concrete and production.

1.3 The Need for Research

Engineers are currently faced with increasing demands for improved efficiency and reduced concrete construction costs from developers and governmental agencies. As a result, engineers are beginning to design larger structures using higher strength concrete at higher stress levels.

There are distinct advantages in the use of concrete with compressive strengths in the range from 63 to 84 Mpa in both reinforced and pre-stressed concrete construction. For a given cross section pre-stressed concrete bridge girders can carry greater service loads across longer spans if made using high strength concrete. In high-rise buildings, where the main disadvantages of using concrete compared to steel are higher dead loads and large column cross-sections, using high strength concrete makes possible significant reductions in total structural dead weight and in column dimensions. Thus, concrete becomes technically and economically feasible as a structural alternative to steel in tall buildings when high strength concrete is used.

In addition, cost comparisons have shown that the savings obtained through the use of smaller and lighter high strength concrete members are significantly greater than the added cost of the higher quality concrete. Also, observed improvements in durability, shrinkage, and creep characteristics of high strength concrete will decrease serviceability and maintenance problems.

Numerous high strength concrete structures now standing in anywhere were constructed using concrete with a compressive strength of between 56 Mpa and 77 Mpa. Remarkably, the use of high strength concrete has preceded full information on its engineering properties, which are significantly different in some respects from those of ordinary strength materials. Current understanding of the behavior of concrete under load and the empirical equations now used to predict such basic properties as modulus of elasticity and tensile strength are based mainly on tests of concrete having a compressive strength of about 5,000 psi or less. Extrapolation to higher strength levels is unjustified and may be dangerous. There is an urgent need for studies focusing on the development of constitutive relationships applicable to design of structural members made using high strength concrete. For example, little is known about predicting the material's behavior in high shear zones or its confined strength in overstressed compression members.

Concrete compressive strengths of over 105 Mpa have been achieved in the laboratory for many years. It has been demonstrated that the production of high strength concrete having a compressive strength of 63 to 84 Mpa, using conventional materials and production methods, is technically and economically feasible. However, very little information has been developed concerning the identification of the most relevant parameters in the selection of material sand their proportions for producing high strength concrete. This is not surprising, given the variability in physical properties and availability of concrete-making materials in different regions of the mix design guidelines for high strength concrete need to be developed for each region of the country. Also, current quality control standards, as they relate to materials used in concrete, especially cement, are not narrow enough to ensure consistent production of good quality high strength concrete.

What is needed most is a systematic, reproducible procedure for attaining high strength concrete with readily available materials using conventional ready-mix batching procedures. If an engineer is to take advantage of this material, he must be given reason to be confident that high strength concrete can be produced and used safely, economically, and efficiently. This research program constitutes the much needed first step towards the development of the necessary information for using high strength concrete in DCUAP site.

1.4 Research Objectives

The research objectives are as follows:

- To identify the most relevant properties of cement, aggregate, and admixtures for producing high strength concrete.
- To evaluate the suitability of commercially available cements, aggregates, and admixtures in DCUAP for the production of high strength concrete.
- To establish, in a form useful for practicing engineers, guidelines for the selection of materials and their proportions for producing high strength concrete.
- To specify the most economical and practical combination of materials.
- To study strength characteristics of High Strength Concrete
- To acquiring high strength of concrete.

1.5 Research Question and Hypotheses

The research answers the following questions :

1. Is it expected target strength by using different types of admixtures material which is (fly Ash ,silica fume ,super-plastisizer) reach to 85 N/mm²?
2. What is the scope uses of high strength concrete?
3. Is it expected acquiring high early strength?

1.6 Research Methodology

In general, the following methodology was followed:

1. Collecting adequate information about the basic science of high strength concrete.
2. Collecting adequate information about High strength concrete special materials and their mechanism of work.

3. Selection of suitable materials required for producing high strength concrete.
4. Determine mix proportions.
5. Performing physical and mechanical laboratory tests on cement and aggregate (coarse and fine) and additives.
6. Analysis of Statistical data.
7. Drawing relevant conclusion and recommendations.

1.7 Research Out-line

This research is divided in to five chapters. An introduction in Chapter one and a brief literature review of the production of high strength concrete in Chapter two. The study problem of research is described in Chapter three. Test results discussed and analyzed in Chapter four. Conclusions and recommendations for producing high strength concrete are presented in Chapter five.

CHAPTER TWO
LITERATURE REVIEW

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Concrete is a compound material made from sand, gravel and cement. The cement is a mixture of various minerals which when mixed with water, hydrate and rapidly become hard binding the sand and gravel into a solid mass. The oldest known surviving concrete is to be found in the former Yugoslavia and was thought to have been laid in 5,600 BC using red lime as the cement.

The first major concrete users were the Egyptians in around 2,500 BC and the Romans from 300 BC The Romans found that by mixing a pink sand-like material which they obtained from Pozzuoli with their normal lime-based concretes they obtained a far stronger material. The pink sand turned out to be fine volcanic ash and they had inadvertently produced the first 'pozzolanic' cement. Pozzolana is any siliceous or siliceous and aluminous material which possesses little or no cementitious value in itself but will, if finely divided and mixed with water, chemically react with calcium hydroxide to form compounds with cementitious properties (A. M. Neville, 2011).

The Romans made many developments in concrete technology including the use of lightweight aggregates as in the roof of the Pantheon, and embedded reinforcement in the form of bronze bars, although the difference in thermal expansion between the two materials produced problems of spalling. It is from the Roman words 'caementum' meaning a rough stone or chipping and 'concretus' meaning grown together or compounded, that we have obtained the names for these two now common materials.

2.2 Definition of High Strength Concrete

High strength concrete refers to concrete which has a uniaxial compressive strength greater than that which is ordinarily obtained in a region. This definition has been widely accepted by practicing engineers because the maximum strength concrete which is currently being produced varies considerably from region to region.

Further complications in defining high strength concrete arise from specimen types used for compression testing and age at testing. For example, a 150 mm. dia. × 300 mm. cylinder, as is used in the U.S., and a 100 mm. × 100 mm. cube, as is used in Europe, molded from the same batch of concrete will yield two completely different compressive strengths. Whether specimens are tested at 28, 56 or 90 days, any of which may be more appropriate than the others for a particular job, can make a tremendous difference in the measured compressive strength.

2.2.1 Disadvantages of Using High Strength Concrete

Most of the disadvantages of using high strength concrete listed by engineers result from a lack of research and available information on the behavior of high strength concrete under actual field conditions. Some of the drawbacks reported in the past have been alleviated by recent developments and improvements in admixtures.

Possible drawbacks in using high strength concrete are listed below:

1. Increased quality control is needed.
2. High quality materials are less available and often cost more.
3. Allowable stresses in codes may discourage the use of high strength concrete.
4. Minimum thickness or cover may govern the design, preventing realization of full benefit of higher strength.
5. Total available pre-stress force may be insufficient to fully develop the strength.
6. Adequate curing can be difficult due to self-dessication of low water/cement ratio mixes. Even with no water loss by evaporation there is inadequate water for full hydration.
7. Curing can also be difficult because of the rapidly increasing impermeability of high strength concrete, which prevents applied curing water from compensating for any initial moisture loss.

A further disadvantage may be that, in structural members where excessive deflections control the design, full utilization of the material's load-carrying capacity when using high strength concrete would not be possible. For instance, the higher flexural strength of a high strength concrete flat slab or plate is of little consequence since deflection often controls design.

2.2.2 Advantages of Using High Strength Concrete

1. Greater compressive strength per unit cost, per unit weight, and per unit volume.
2. Increased modulus of elasticity which aids when deflection and stability control the design.
3. Increased tensile strength, which is a controlling parameter in the design of pre-stressed concrete members under service loads.

2.2.3 Methods of Producing High Strength Concrete

Several exotic methods for producing high strength concrete have been studied, such as:

1. Modification with polymers.
2. Fiber reinforcement.
3. Slurry mixing (pre-blending water and cement at high speed for efficient hydration).
4. Compaction by pressure.
5. Compaction by pressure combined with vibration.
6. Autoclave curing.
7. Mix proportioning using active or artificial aggregates.

One study advocated revibration 2-1/2 hours after initial vibration as a means for achieving higher strengths. Structural design which accounts for additional concrete strength resulting from triaxial compression or concrete confinement is also possible.

However, cost-effective production of high strength concrete in construction today is achieved by carefully selecting, controlling, and combining cement, fly ash, admixtures, aggregates, and water. Freedman stated that in order to achieve higher strength concretes, the concrete producer must optimize the cement characteristics, aggregate quality, paste proportioning, aggregate-paste interaction, mixing, consolidation, and curing procedures. The use of fly ash and very low water-cement ratios has been widely recommended for producing high strength concrete.

The National Crushed Stone Association further stated that cooperation and coordination among the engineer, architect, materials suppliers, ready-mix producers, contractor, and the testing and inspection agency are required for a successful high strength concrete project.

2.3 Previous Studies on High-Strength Concrete

2.3.1 First Study

According to (International Journal of Research in Engineering and Technology ISSN: 2319-1163), in 2010 K. Vedhasakthi (Assistant Professor, Department of Civil Engineering, Bannari Amman Institute of Technology, Sathyamangalam, TamilNadu, India) and M. Saravanan (Assistant Professor, Department of Civil Engineering, Bannari Amman Institute of Technology, Sathyamangalam, TamilNadu, India) studied the **Development of Normal Strength and High Strength Self Curing Concrete Using Super Absorbing Polymers (SAP) And Comparison of strength Characteristics**.

Results

Workability Tests: To find the workability properties slump cone test and compacting factor test were conducted. Slump value and compacting factor value were found out for Normal Strength and High Strength Self Curing Concrete and compared with conventionally cured concrete.

Strength Results: The average compressive strengths of conventionally cured concrete and self-cured concrete were found out using compression testing machine. The results are shown in Figure 2-1.

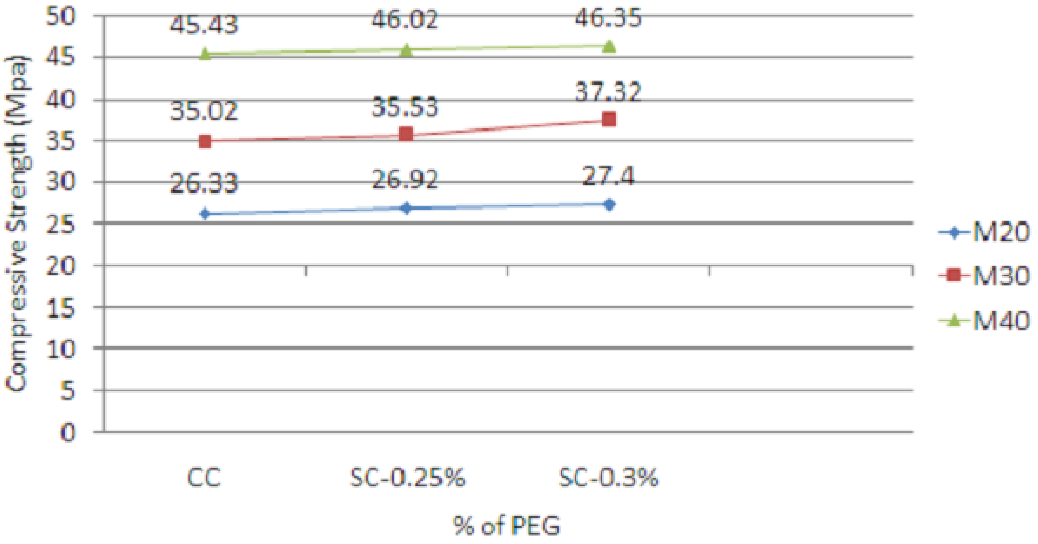

Figure 2-1: Variation of Compressive Strength in Normal Strength Concrete

Conclusions

The self-curing agent Polyethylene Glycol was found to be more effective than sorbitol. Desired strength test results were obtained by using Polyethylene Glycol as Self curing agent.

- From the workability test results, it was found that the self-curing agent improved workability.
- From the compressive strength results, it was found that self-curing concrete has given more strength than that of conventionally cured concrete.
- It was found that self-curing can be achieved in High Strength Concrete and there is significant increase in the strength of High Strength Self Curing Concrete than Conventionally Cured High Strength Concrete.
- For High Strength Concrete, the strength development of concrete is more if the replacement percentage of silica fume by weight of cement is 15%.
- The Strength of the concrete increases significantly with the increase of self-curing agent. i.e., concrete with 0.3% of PEG gives more strength than that with 0.25%.

Advantages of Self-Curing Concrete

- Each one cubic meter of concrete requires about $3m^3$ of water for construction most of which is for curing. As self-curing concrete will not require water for curing, there will be enormous saving of water.
- Helps to reduce the cost of labourers required for curing.
- SC is a good solution when there is a problem for occurrence of water
- SC is a good solution in the place of large buildings and in complicated areas where curing process is difficult.
- High Strength Concrete with Super absorbing polymers (SAP) as an internal curing agent significantly reduces the autogenous shrinkage and thus prevents the early-age cracking of bridge decks.
- In high rise structures, improper curing can be prevented by adopting Self Curing Concrete.
- Eliminates largely autogenous shrinkage.
- Provides water to keep the relative humidity (RH) high, keeping self-desiccation from occurring.

2.3.2 Second Study

According to (Cement and Concrete Research Journal, 1999), in 1999, C.S. Poon, L. Lam, Y.L. Wong (Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Hung Him, Hong Kong, People's Republic of China) had **A Study on High Strength Concrete Prepared With large Volumes of Low Calcium Fly Ash**.

Experimental Results

Compressive Strength of Concrete: The compression test of the concrete mixtures was performed on the 100 mm cubes at the ages of 3, 7, 28, and 90 days. The results are given in **Table 2-1**. At the w/b of 0.24, the mix with 25% fly ash showed slightly lower compressive strength at the ages of 3 and 7 days, but higher compressive strength at the ages of 28 and 90 days, when compared with the reference mix without fly ash. The mix with 45% fly ash showed a 28-day compressive strength of 89.4 MPa, which was 8% lower than that of the reference mix. The negative effect of using fly ash on concrete strength appeared to be insignificant. However, lowering the w/b ratio to 0.19 did not further improve the concrete strength.

Table 2-1: Compressive Strength of the Concrete Mixes

w/b Ratio	% Fly Ash	Compressive Strength (MPa)			
		3 days	7 days	28 days	90 days
0.24	0	70	79.5	97.4	110.2
0.24	25	62.3	74.6	105.9	124.5
0.24	45	42.5	56.3	89.4	107.2
0.19	0	78	83.5	96.8	114.5
0.19	25	66.8	74.2	102.3	123.6
0.19	45	41.7	56.4	88.5	109.2

Compressive strength of pastes: The compression test of the pastes was performed on the 70.7 mm cubes at the ages of 7, 28, and 90 days. The results are shown in **Table 2-2**. A comparison between the strength developments of the fly ash concrete and the corresponding pastes seems to indicate that the strength contribution of fly ash in concrete was better than in the pastes at the ages after 28 days.

Table 2-2: Compressive Strength of the Pastes

w/b Ratio	% Fly Ash	Compressive Strength (MPa)		
		7 days	28 days	90 days
0.24	0	74.7	103.7	119
0.24	25	69.5	99.5	120.2
0.24	45	56	95	104.5
0.19	0	85.7	116	133.9
0.19	25	74.9	113.3	136.9
0.19	45	54.7	99	116.1

Without fly ash (the reference mixes). At a w/b of 0.24, the fly ash concrete showed almost the same initial relative strength values as the pastes with the same fly ash replacements. At the age of 28 days, the concrete with 25% fly ash replacement showed higher relative strength value than the corresponding paste. At the age of 90 days, both the concrete with 25% and 45% fly ash replacements showed higher relative strength values than the corresponding pastes. Similar results were also observed for the pastes and concrete at the w/b of 0.19. It should be noted that lowering the w/b ratio from 0.24 to 0.19 resulted in an average 10% compressive strength increase for the fly ash/cement pastes **Table 2-2**, although it did not increase the strength of the corresponding concrete **Table 2-1**.

Discussion

Properties of High Strength Concrete with High Fly Ash Content: The results of the present study have shown that with a fly ash content of 45%, concrete with a 28-day compressive strength of 80 MPa could be obtained at the w/b of 0.24. As mentioned earlier in this paper, fly ash concrete at lower w/b ratios had better strength performance. When compared to our previous results, it can be seen that the fly ash concrete at lower w/b ratios yielded higher, the data show that the high strength concrete prepared with high fly ash content had lower chloride diffusivity than the equivalent plain cement concrete or the concrete with lower fly ash contents. The isothermal conduction calorimetry results also demonstrated that the high strength concrete with high fly ash content is effective in suppressing excessive heat evolution in fresh concrete.

However, it was noted that a higher dosage of super-plasticizer was required for the mix with 45% fly; this was due to the higher volume fraction of fine particles in the mix. When part of cement was replaced by the same mass of fly ash, the total volume of the cementitious materials increased because of the lower density of the fly ash. This made it difficult to prepare a workable concrete mixture. Adding excessive amount of superplasticizer may cause strong segregation of different materials and result in poorer concrete. Thus, the advantages of further lowering w/b ratio are limited. In this present investigation, large quantities of superplasticizer had been used for preparing the concrete mixtures at the w/b of 0.19. Although a lower w/b ratio at 0.19 resulted in lower porosity and higher compressive strength for the pastes, it did not reduce the concrete porosity, and did not further improve the concrete strength and durability properties.

Different Effects of Fly Ash in Concrete and in Cement Pastes: It is interesting to note that the beneficial effects of fly ash in cement pastes and in concrete are different. This can be noticed from both the results of MIP and the results of the strength test. Replacing cement by fly ash increased the porosities of the pastes, but the porosities of the concrete were reduced. These observations are consistent with our previous results comparing the effects of fly ash on plain cement and cement mortars. Also, the strength enhancement effect of fly ash in concrete was better than in the corresponding pastes. Both results indicate an improvement effect on the interfacial zone between the cement matrix and the aggregate when fly ash is added to the concrete.

Degree of Hydration in Fly Ash/Cement Systems at Low w/b Ratios: A number of papers have been published on the micro-structure development and hydration mechanism of high volume fly ash/cement system. In general, like other mineral admixtures, fly ash contributes to concrete properties by both the filler effect and the Pozzolanic effect. However, the relative importance of these effects has not been quantitatively identified. The results presented here on the degree of cement hydration and Pozzolanic reaction may lead to a better understanding of the strengthening mechanism of fly ash concrete.

The results show that at 7 days, a measurable amount of pozzolanic reaction in the fly ash/cement system has taken place. The reaction degree of about 5% of the fly ash may correspond to the initial attack on the fly ash particles by the alkali ions in the pore solution. According to Berryet, even at the ages as early as 7 days, fly ash particles are involved in chemical reactions forming ettringite (AFt). At this stage, the physical effect of space filling and the formation of AFt are important factors in strength development.

At 28 days of curing, the degree of fly ash reaction increased to more than 10%. At this age, according to Xu and Sarkar, hydration products are well established. CH on the fly ash particles undergoes re-dissolution and reacts with the fly ash and a considerable amount of the fly ash particles have been reacted. As can be seen from the results of strength test in this paper, the increased degree of fly ash reaction minimized the strength differences between the fly ash/cement pastes/concrete and the reference plain cement pastes/concrete. Some fly ash concrete had higher strength than the reference plain cement concrete, although at this age, there are still more than 80% fly ashes playing the role of space filler or micro-aggregates.

At the age of 90 days, the fly ash pastes had a degree of fly ash reaction between 14.8% and 22.6%. It is generally accepted that the pozzolanic reaction in the fly ash/cement systems becomes dominant at the ages after 28 days, the reaction between the fly ash and the CH forms gel-like calcium silicate hydrates (C-S-H) which have lower calcium-to-silicate ratios (C/S). The reacted fly ash resulted in an average 20% increase in compressive strength, and a 77% drop in total coulomb passed for fly ash concrete during the period from 28 to 90 days. In comparison, the plain cement concrete showed an increase of about 16% in compressive strength and a decrease of 40% in total coulomb passed.

The results also show that in the pastes with lower w/b ratios, the cement or the fly ash underwent a lower degree of hydration/reaction. This is because there is less water available for the reaction and less space for the reaction products to form. It is interesting to note that in the plain cement pastes at the w/b of 0.24 or 0.19, only 50 ± 60% of the cement were reacted at 90 days. This implies that about 40% to 50% of the cement plays the role as micro-aggregates like most of the fly ash particles in the fly ash/cement system. Thus, it is not difficult to understand that at lower w/b ratios, the difference in strength between the plain cement concrete and the fly ash concrete is small.

Conclusion

1. High strength concrete with a 28-day compressive strength of 80 MPa could be obtained with a w/b ratio of 0.24, and with a fly ash content of 45%. Such a concrete has a lower heat of hydration and chloride diffusivity when compared to the equivalent plain cement concrete.
2. In concrete mixes prepared at lower w/b ratios, the contribution to strength by fly ash was better than in the mixes prepared with higher w/b ratios. Also, the strength contribution of fly ash in concrete was better than in the equivalent fly ash/cement pastes.
3. In plain cement pastes at the w/c ratios of 0.19 and 0.24, about 50% of the cement hydrated at the age of 7 days. From 7 to 90 days, the increase in the degree of hydration was not significant.
4. In fly ash/cement pastes at the w/b ratios of 0.19 and 0.24, about 5% of the fly ash reacted at the age of 7 days. From 7 to

90 days, the degree of reaction of the fly ash ranged from about 15% to 23%, depending on the w/b ratios and the percentages of fly ash replacement. Fly ash in the pastes at lower w/b ratios and with higher fly ash replacement levels had lower degree of reaction.

5. In the plain cement pastes and the fly ash/cement pastes prepared at the w/b ratios of 0.19 and 0.24, about 40% of the cement and 80% of the fly ash remained unreacted at the age of 90 days. This unreacted cement and fly ash particles served as micro-aggregates, which also contributed to the strength of the cementitious material.

2.3.3 Third Study

In 2015, Mr. Ali Ahmed (Department of concrete in DIU) had A Study on **Production of High Strength Concrete in Sudan** and the result was:

It is clear that there are three different grades of high strength concrete (80, 90, 100MPa) successfully produced using local Sudanese aggregates and silica fume and silica fume with fly ash. w/c ratios ranges between 0.19~0.3. Silica fume and fly ash replacements in the range of 6.7 to 15% and zero to 15% of cementitious materials respectively. Cement content is range between 390 and 560 Kg/m^3 for the three grades. Trial batches were carried out, test specimens are fabricated and tested, and results are analyzed using standard statistical methods. Method one is the statistical approach which described in ACI211.4 and method two is the statistical approach by using statistical software program, called, JMP statistical software program. These methods include fitting empirical models to the data for each performance criterion. In these models, each response ,resultant concrete property, such as strength, slump, is expressed as an algebraic function of factors ,individual component proportions, such as w/cm, coarse aggregate, fine aggregate, chemical admixture dosage, and supplementary cementitious materials content has been fed in.

Experimental Program

Slump Test: After mixing, a portion of the fresh concrete was placed aside for plastic properties determination. Slump of fresh concrete was measured according to ASTM C143. Precautions were taken to keep the slump between 150-200 mm to obtain pumpable concrete for dam construction.

Compressive Strength Test: Lime saturated-water curing method was used in this study. Concrete casting was performed according to BS EN 12390-1:2000. Molds were covered to prevent loss of water from evaporation. Specimens were kept for 24 hours in molds at a temperature of about 23 C in casting room, and then cured for the specified time at approximately 23 C ± 2 C. The specimens were tested in dry state for compressive strengths tests, in accordance with **BS EN 12390-3:2002**.

Optimization of Mixes: Two approaches were used, the statistical approach which has been described in ACI 211.4 and another one is the JMP statistical program to make a modeling for predicting Compressive Strength and Slump for high strength concrete.

Conclusions

On the basis of test results the following major conclusions can be drawn:

1. Local aggregates with supplementary materials (silica fume and fly ash) and ordinary Portland cement with their optimum proportioning can be successfully used with other chemical admixtures (Super-plasticizer) to produce high strength concrete.
2. The present study shows that the maximum values of compressive strength for different grades were obtained at water-cementitious materials ratios between 0.19 and 0.3.
3. The relationship between compressive strength 28 days (MPa) and cost is direct relationship.
4. Predicted equations were given from JMP statistical program to predict 28 days compressive strength (MPa) and Slump (mm) for high strength concrete where local Sudanese aggregate granite and marble were used.
5. Second method gave suggestions for a new mixture proportions for high strength concrete in Sudan and it was predict 28 days compressive strength (MPa) and Slump (mm).

Recommendations

Recommendations from the Study

1. Regards to cost consideration, try to reduce Silica fume content and super-plasticizer or replace it by others local materials if available.
2. Recommended that to use marble and granite coarse aggregate in high strength concrete in Sudan

Recommendations for Further Research

1. Use statistical approach and JMP statistical software to predict equations for high strength concrete proprieties for another type of aggregate in Sudan.
2. Use statistical approach and JMP statistical software to predict equation for splitting tensile strength and flexural strength.
3. Study the ability of use local supplementary materials in high strength concrete.
4. Study the effect of long term more than 90 days of supplementary materials.
5. Consideration of harm full effect of use of supplementary materials in special case.

2.3.4 Forth Study

Whilst a number of studies have considered the development of a rational or standardized method of concrete mix design for HSC (de Larrard, 1999; Mehta and aitcin, 1990), no widely accepted method is currently available. The main requirements for successful and practical HSC are a low water/cement ratio combined with high workability and good workability retention characteristics. In the absence of a standard mix design method, the importance of trial mixes in achieving the desired concrete performance is increased the following factors should, however, be considered when designing a high strength concrete mix, see **Table 2-3**.

Table 2-3: Compressive Strength of Concrete Mixes

	1	2	3	4	5
Cement (kg/m^3)	564	475	487	564	475
Fly Ash (kg/m^3)	-	59	-	-	104
Micro-silica (kg/m^3)	-	24	47	89	74
Coarse Agg. (kg/m^3)	1068	1068	1068	1068	1068
Fine Agg. (kg/m^3)	647	659	676	593	593
Water (L/m^3)	158	160	155	144	151
Super-plasticizer (L/m^3)	11.61	11.61	11.22	20.12	16.45
Retarder (L/m^3)	1.12	1.04	0.97	1.47	1.51
w/c	0.281	0.287	0.291	0.22	0.231
90-day Cylinder Strength	86.5	100.4	96.0	131.8	119.3

- The appropriate free water/cement ratio should be selected either from experience or by reference to published data. This will typically be in the range 0.25–0.30.
- The cement composition should be selected to maximize strength and other performance requirements. At its simplest this will be Portland cement blended with 5–10 per cent silica fume.
- Proportion coarse and fine aggregates to give a smooth overall grading curve in order to keep the water demand low. The proportion of fine aggregate is generally around 5 per cent lower (as a proportion of total aggregate) than for normal strength concrete. Care must be taken, however, not to make the mix too deficient in fine aggregate, particularly where the concrete is to be pumped.
- Use the saturation dosage of admixture (or admixtures), determined with a flow cone, to produce workability. It should be noted that most HSC is also high workability concrete, of, say, 600 mm flow table spread.
- Trial mixes should be made and strength, workability and workability retention measured. Modifications can then be made to the mix to optimize the concrete’s performance.

2.4 Applications of High Strength Concrete

2.4.1 High-Rise Buildings

Most applications of high strength concrete to date have been in high-rise buildings. High strength concrete has already been used in columns, shear walls and foundations of high-rise buildings in cities such as Houston, Dallas, Chicago, New York, and abroad. Tall structures whose construction using normal strength concrete would not have been feasible have been successfully completed using high strength concrete. Column and beam dimensions can be reduced resulting in decreased dead weight of the structure, and an increase in the amount of rentable floor space in the lower stories. Reduced dead weight can substantially lessen the design requirements for the building’s foundation.

Wacker Drive (see Figure 2.1) where high strength columns (Design strength 83 MPa (cylinder)) were used at the base of the building, with lower strength concrete (69 and 62 MPa) being used in the more lightly loaded upper floors (Russell, 1994). The HSC was used in conventionally reinforced columns and nearby all the concrete was placed using pumps.

In Seattle, a different form of construction with HSC has been employed. Large-diameter (3 m) steel tubes form the core of the building with smaller steel tubes around the perimeter. These tubes contain shear studs on the internal face but not reinforcement.

High strength concrete (Design strength 97 MPa (cylinder)) is pumped into the tubes from the bottom of each storey and without any vibration. This forms a very economic and stiff structure. During the construction of 2 Union Square in Seattle, a 58-storey structure (Russell, 1994), the designer also wished to achieve an elastic modulus of at least 50 GPa. Consequently the actual strength of the concrete was much higher than the design strength in order to produce the desired modulus. Long-term compressive cylinder strengths in excess of 130 MPa (approximately equivalent to a cube strength of 145 MPa) were measured during construction.

In addition to well documented examples in North America, HSC has been used in all tall buildings in Australia, Germany and South-east Asia (CEB, 1994).

Figure 2-2: South Wacker Drive, Chicago – high strength concrete used in columns.

2.4.2 Highway Bridges

Pre-stressed, precast concrete bridge girders do not exceed 41.15m to 45.72m. in length. Steel members are currently used for spans greater than 41.15m to 45.72m. High strength concrete would permit using greater spans for a given number of girders, or fewer girders for ordinary spans, than when using normal strength concrete. As a result, the slab thickness had to be increased. In order to support the traffic load on the wider girder spacing. However, the overall dead load of the bridge was reduced. This comparison was based on allowable tensile stresses in the concrete of 3(fc') 1/2, an allowable compressive stress of 0.4 fc' and alive load deflection criteria of L/800, where fc' refers to concrete compressive strength (psi) and L refers to the girder span. The limiting factor controlling the design in this case was spacing of the pre-stressing tendons within the girders. The use of fewer tendons of a larger diameter and of new girder sections and shapes may have to be considered for efficient use of high strength concrete in bridge girders.

A reduction in number and size of bridge columns and piers can result from a reduction in dead load and use of longer spans due to the use of a higher concrete compressive strength. This will allow for significant savings in cost, labor, and construction time.

Other applications of high strength concrete include both heavily loaded transfer girders and offshore structures.

No special or "exotic" techniques were employed in constructing any of the high strength concrete structures mentioned in this section. All utilized high-quality materials and good quality control programs.

2.5 Concrete Consistence of Properties

This section summarizes the properties of all the components used in the various concrete mixes. Concrete is a structural material that contains some simple elements but when mixed with water would form a rock like material. Concrete mix is comprised of coarse aggregates usually gravel, fine aggregates usually sand, cement, water, and any necessary additives. Concrete possesses many favorable properties as a structural material, among which are its high compressive strength and its property as a fire-resistant element to a considerable extent discussed.

2.5.1 Cement

Cement is a fine mineral powder manufactured with very precise processes. Mixed with water, this powder transforms into a paste that binds and hardens when submerged in water. Because the composition and fineness of the powder may vary, cement has different properties depending upon its makeup. Cement is a fine powder which sets after a few hours when mixed with water, and then hardens in a few days into a solid, strong material.

Manufacturing of Cement

The production of cement takes place with several steps:

- Quarrying of limestone and shale
- Dredging the ocean floor for shells
- Digging for clay and marl
- Grinding
- Blending of components
- Fine grinding
- Burning
- Finish grinding
- Packaging and/or shipping

Cement Components

Four compounds are regarded as the major constituents of cement: they are listed in **Table 2-1** together with their abbreviated symbols.

Table 2-4: Main Compounds in Portland Cement

Name of the Compound	Oxide Composition	Abbreviation
Tricalcium Silicate	$3CaO.SiO_2$	C3S
Dicalcium Silicate	$2CaO.SiO_2$	C2S
Tricalcium Aluminate	$3CaO.Al_2O_3$	C3A
Tetracalcium Aluminoferrite	$4CaO.Al_2O_3.Fe_2O_3$	C4AF

The silicates, C_3S and C_2S are the most important compounds, which are responsible for the strength of hydrated cement paste.

The presence of C_3A is undesirable, it contributes little or nothing to the strength of cement except at early ages, and when hardened cement paste is attacked by sulfates, the formation of calcium sulfo-aluminate may cause disruption. However, C_3A is beneficial in manufacture of cement in that it facilitate the combination of lime and silica.

C_4AF is also present in cement in small quantities, and, compared with the other three compounds, it does not affect the behavior significantly

Proper selection of the cement is one of the most important steps in the production of high strength concrete. For high strength concrete containing no chemical admixtures or fly ash, a high cement content of 450 -500 kg/m3.must be used. For a given set of materials, the optimum cement content beyond which no additional increase in strength is achieved from increasing the cement content must be determined. A1binger and Moreno stated that for any particular combination of materials, an optimum cement content exists above which strength declines and the mix becomes too sticky to handle. Additional cement above the optimum cement content will not compensate for the loss in strength due to the increase in mixing water demand needed in order to make the mix manageable in the field.

2.5.2 Tests of Cement

1. Fineness of cement

Object

To determine fineness of cement

Apparatus

- Standard balance with 100 g weighing capacity.
- IS: 900 micron sieve confirming to IS: 460-1962 and a Brush.

Procedure

- Break down any air –set lumps in the cement sample with fingers.
- Weigh accurately 100 gms of the cement and place it on a standard 90 micron IS. Sieve.
- Continuously sieve the sample for 15 minutes.
- Weigh the residue left after 15 minutes of sieving. This completes the test.

Result:

The percentage weight of residue over the total sample is reported.

% Weight of Residue = Wt of Sample Retained on the sieve Total Weight of the Sample

Limits:

The percentage residue should not exceed 10%.

2. Initial and Final Setting Times

Objective

To determine the initial and final setting times of cement.

Apparatus

- Vicat apparatus conforming to IS: 5513-1976.
- Balance of capacity 1kg and sensitivity 1 gram.
- Gauging trowel conforming to IS: 10086-1982.

Procedure is as follows

- Unless otherwise specified this test shall be conducted at a temperature of 27 + 20C and 65 + 5% of relative humidity of the Laboratory.
- Prepare a paste of 300 grams of cement with 0.85 times the water required to give a paste of standard consistency IS: 4031 (Part 4) 1988.
- The time of gauging in any case shall not be less than 3 minutes not more than 5 minutes and the gauging shall be completed before any sign of setting occurs.
- Count the time of gauging from the time of adding water to the dry cement until commencing to fill the mould.
- Fill the vicat mould with this paste making it level with the top of the mould.
- Slightly shake the mould to expel the air.
- In filling the mould the operator hands and the blade the gauging trowel shall only be used.

Initial Setting Time:

- Immediately place the test block with the non-porous resting plate, under the rod bearing the initial setting needle.
- Lower the needle and quickly release allowing it to penetrate in to the mould.
- -n the beginning the needle will completely pierce the mould
- Repeat this procedure until the needle fails to pierce the mould for 5 + 0.5mm.
- Record the period elapsed between the time of adding water to the cement to the time when needle fails to pierce the mould by 5 + 0.5mm as the initial setting time.

Final Setting Time:

- Replace the needle of the vicat apparatus by the needle with an annular ring
- Lower the needle and quickly release.
- Repeat the process until the annular ring makes an impression on the mould.
- Record the period elapsed between the time of adding water to the cement to the time when the annular ring fails to make the impression on the mould as the final setting time.

2.5.3 Water and the Water/Cement Ratio

Almost any natural water that is drinkable and has no pronounced taste or odor can be used as mixing water for making concrete. However, some waters that are not fit for drinking may be suitable for use in concrete.

Six typical analyses of city water supplies and sea water. These waters approximate the composition of domestic water supplies for most of the cities over 20,000 population in the United States and Canada. Water from any of these sources is suitable for making concrete. A water source comparable in analysis to any of the waters in the table is probably satisfactory for use in concrete.

Water of questionable suitability can be used for making concrete if mortar cubes (ASTM C 109 or AASHTO T 106) made with it have 7-day strengths equal to at least 90% of companion specimens made with drinkable or distilled water. In addition, ASTM C 191 (AASHTO T 131) tests should be made to ensure that impurities in the mixing water do not adversely shorten or extend the setting time of the cement. Acceptable criteria for water to be used in concrete are given in ASTM C 94 (AASHTO M 157) and AASHTO T 26A U.S. Air Force investigation concluded that the single most important variable in achieving high strength concrete is the water/cement ratio. Others reported that the highest concrete strengths were achieved with the lowest water/cement ratios, although considerable effort was required to compact the concrete in some cases. For example, Perenchio acknowledged that the very dry concretes he studied which produced the highest strengths would probably be unacceptable for use in the field in cast-in-place structures.

Most sources agree that high strength concrete cannot be obtained with a water/cement ratio in excess of 0.40. It has been reported that a water/cement ratio in the field of about 0.27 is adequate for hydration of cement. However, others have stated that complete hydration cannot occur with a water/cement ratio of less than 0.38 to 0.40. Concretes having a compressive strength of 63Mpa to 70Mpa or more have been produced with water/cement ratios of less than 0.35 in most cases.

2.5.4 Aggregate

The importance of using the right type and quality of aggregates cannot be overemphasized. The fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete’s freshly mixed and hardened properties, mixture proportions, and economy. Fine aggregates (Figure 2-3) generally consist of natural sand or crushed stone with most particles smaller than 5 mm (0.2 in.).

Figure 2-3: Close-up of fine aggregate (sand)

Coarse aggregates (Figure 2-4) consist of one or a combination of gravels or crushed stone with particles predominantly larger than 5 mm (0.2 in.) and generally between 9.5 mm and 37.5 mm (3⁄8 in. and 11⁄2 in.). Some natural aggregate deposits, called pit-run gravel, consist of gravel and sand that can be readily used in concrete after minimal processing. Natural gravel and sand are usually dug or dredged from a pit, river, lake, or seabed.

Figure 2-4: Coarse aggregate; Rounded gravel (left) and crushed stone (right)

Crushed stone is produced by crushing quarry rock, boulders, cobbles, or large-size gravel. Crushed air-cooled blast-furnace slag is also used as fine or coarse aggregate. The aggregates are usually washed and graded at the pit or plant. Some variation in the type, quality, cleanliness, grading, moisture content, and other properties is expected. Close to half of the coarse aggregates used in Portland cement concrete in North America are gravels; most of the remainder are crushed stones. Naturally occurring concrete aggregates are a mixture of rocks and minerals. A mineral is a naturally occurring solid substance with an orderly internal structure and a chemical composition that ranges within narrow limits. Rocks, which are classified as igneous, sedimentary, or metamorphic, depending on origin, are generally composed of several minerals. For example, granite contains quartz, feldspar, mica, and a few other minerals; most lime stones consist of calcite, dolomite, and minor amounts of quartz, feldspar, and clay. Weathering and erosion of rocks produce particles of stone, gravel, sand, silt, and clay. Recycled concrete, or crushed waste concrete, is a feasible source of aggregates and an economic reality, especially where good aggregates are scarce. Conventional stone crushing equipment can be used, and new equipment has been developed to reduce noise and dust. Aggregates must conform to certain standards for optimum engineering use: they must be clean, hard, strong, durable particles free of absorbed chemicals, coatings of clay, and other fine materials in amounts that could affect hydration and bond of the cement paste. Aggregate particles that are friable or capable of being split are undesirable.

Aggregates containing any appreciable amounts of shale or other shaly rocks, soft and porous materials, should be avoided; certain types of chert should be especially avoided since they have low resistance to weathering and can cause surface defects such as popouts. Identification of the constituents of an aggregate cannot alone provide a basis for predicting the behavior of aggregates in service. Visual inspection will often disclose weaknesses in coarse aggregates. Service records are invaluable in evaluating aggregates. In the absence of a performance record, the aggregates should be tested before they are used in concrete. The most commonly used aggregates—sand, gravel, crushed stone, and air-cooled blast-furnace slag—produce freshly mixed normal-weight concrete with a density (unit weight) of 2200 to 2400 kg/m^3 (140 to 150 lb/ft^3). Aggregates of expanded shale, clay, slate, and slag are used to produce structural light weight concrete with a freshly mixed density ranging from about 1350 to 1850 kg/m^3 (90 to 120 lb/ft^3).

Other lightweight materials such as pumice, scoria, perlite, vermiculite, and diatomite are used to produce insulating lightweight concretes ranging in density from about 250 to 1450 kg/m^3 (15 to 90 lb/ft^3). Heavyweight materials such as barite, limonite, magnetite, ilmenite, hematite, iron, and steel punching or shot are used to produce heavyweight concrete and radiation-shielding concrete (ASTM C 637 and C 638). For special types of aggregates and concretes. Normal-weight aggregates should meet the requirements of ASTM C 33 or AASHTO M 6/M 80. These specifications limit the permissible amounts of deleterious substances and provide requirements for aggregate characteristics.

Compliance is determined by using one or more of the several standard tests cited in the following sections and tables. However, the fact that aggregates satisfy ASTM C 33 or AASHTO M 6/M 80 requirements does not necessarily assure defect-free concrete.

Gradation of the coarse aggregate within ASTM limits makes very little difference in strength of high strength concrete.

Optimum strength and workability of high strength concrete are attained with a ratio of coarse to fine aggregate above that usually recommended for normal strength concrete. This means using a higher coarse aggregate factor.

Table 2-5: Particle Shape Classification of BS 812-1: 1975 with Examples

Classification	Description	Examples
Round	Fully water-worn or completely shaped by attrition	River or seashore gravel, desert, seashore and wind-blown sand
Irregular	Naturally irregular, or partly shaped by attrition and having round edges	Other gravels, land or dug flint
Flaky	Material of which the thickness is small relative to the other two dimensions	Laminated rock
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types, talus, crushed slag
Elongated	Material, usually angular, in which the length is considerably larger than the other two dimensions	
Flaky and elongated	Material having the length considerably larger than the width, and the width considerably larger than the thickness	

2.5.5 Mineral and Chemical Admixtures

Admixtures are those ingredients in concrete other than Portland cement, water, and aggregates that are added to the mixture immediately before or during mixing (Figure 2-5). Admixtures can be classified by function as follows:

1. Air-entraining admixtures.
2. Water-reducing admixtures.
3. Plasticizers.
4. Accelerating admixtures.
5. Retarding admixtures.
6. Hydration-control admixtures.
7. Corrosion inhibitors.
8. Shrinkage reducers.
9. Alkali-silica reactivity inhibitors.
10. Coloring admixtures.
11. Miscellaneous admixtures such as workability, bonding, damp roofing, permeability reducing, grouting, gas-forming, anti-washout, foaming, and pumping admixtures.

Figure 2-5: Liquid admixtures, from left to right: anti-washout admixture, shrinkage reducer, water reducer, foaming agent, corrosion inhibitor, and air-entraining admixture

Table 2-6: Concrete Admixtures by Classification

Type of Admixture	Desired Effect	Material
Superplasticizer and retarder (ASTM C 1017, Type 2)	Increase flowability with retarded set Reduce water/cement ratio	See superplasticizers and also water reducers
Water reducer (ASTM C 494 and AASHTO M 194, Type E)	Reduce water content at least 5%	Lignosulfonates Hydroxylated carboxylic acids Carbohydrates
Water reducer and accelerator (ASTM C 494 and AASHTO M 194, Type E)	Reduce water content (minimum 5%)	See water reducer, Type A (accelerator is added)
Water reducer and retarder (ASTM C 494 and AASHTO M 194, Type D)	Reduce water content (minimum 5%) and retard set	See water reducer, Type A (retarder is added)
Water reducer—high range (ASTM C 494 and	Reduce water content (minimum 12%)	See superplacticizers

Type of Admixture	Desired Effect	Material
AASHTO M 194, Type F)		
Water reducer—high range—and retarder (ASTM C 494 and AASHTO M 194, Type G)	Reduce water content (minimum 12%) and retard set	See superplasticizers and also water reducers
Water reducer—mid range	Reduce water content (between 6 and 12%) without retarding	Lignosulfonates Polycarboxylates

The use of mineral and chemical admixtures in producing high strength concrete results in significant increases in concrete strength while reducing the cement requirement and the water/cement ratio. However, the compatabl1ity between these admixtures and the cement used must be checked prior to their use in high strength concrete. The fact that a cement, a fly ash and a chemical admixture individually meet ASTM requirements do not ensure that they are compatible in combination for use in producing high strength concrete.

1- Fly Ash

A good quality fly ash has been said to be mandatory for producing high strength concrete. The concrete strength gain from the use of 10 to 15 percent Class F fly ash, by weight of cement, cannot be attained through the use of additional cement. For Class C fly ash, even higher fly ash contents can be used. However, when using fly ash as cement replacement, by volume or weight, lower compressive and flexural strengths may result at ages less than 90 days. Greater compressive strengths will be achieved at later ages. For comparable early strengths, mixes made with fly ash must contain more fly ash than the amount of Portland cement replaced.

The effect of pozzolans, such as fly ash, on the properties of concrete have been widely investigated, but much controversy still exists about their use in producing concrete.

One study demonstrated that 90-day compressive strengths improved when 10 percent of the cement was replaced with fly ash, but concrete strengths dropped when 30 percent of the cement was replaced with fly ash, Yamamoto and Kobayashi stated that if any mineral fine, fly ash, blast furnace slag, or even inert standard sand, replaced cement by 15 percent, the strength was essentially unaffected at any age after 7 days, but that replacement by up to 30 percent may cause considerable strength reduction. Another study concluded that replacing 18 to 25 percent of the cement with fly ash, by weight, increases the 28- and 56-day compressive strength and the modulus of elasticity of concrete. Cement replacements with fly ash in the range from 35 to 50 percent resulted in no increase in compressive strength at any age. Two investigations reported that fly ash mixes resulted in somewhat lower compressive strengths and elastic modeling at 28 days; but the addition of fly ash inevitably resulted in stronger, stiffer concrete at one year of age.

2-High Range Water Reducers (Superplasticizers)

Three types of superplasticizers are currently available in the U.S.: a sulfonated melamine formaldehyde condensate which, when added to concrete, forms a lubricating film on the cement particle surfaces; a sulfonated naphthalene formaldehyde condensate, which causes a reduction in the surface tension of the water; and a modified lignosulfate which electrically charges the particles of cement so that they repel each other. The net effect of using any type of superplasticizer is enhanced dispersion of cement particles. The initial cement hydration rate is increased since overall water-cement contact is increased. However, the later hydration rate is slower than usual because the reaction product which forms at first around the cement particles tends to be thicker and more impermeable than in non superplasticized mixes. The film of admixture on hydrating cement particles also tends to restrict further water movement into the cement particles. Some of the admixture apparently even associates with the water on a molecular level, completely preventing a small fraction of the water from ever hydrating the cement

Super plasticizers increase concrete strength by reducing the mixing water requirement for a constant slump, and by dispersing cement particles, with or without a change in mixing water content, permitting more efficient hydration. The addition of superplasticizers to a mix can save cement and increase the slump without changing the consistency of the fresh concrete. High-slump flowing concrete with high compressive strengths have been produced and used which thoroughly fill in the volume surrounding tightly spaced reinforcement, harden quickly to facilitate rapid slip forming, and as a result save 20 to 30 percent in labor cost.

An additional advantage of using superplasticizers results from their use in hot-weather concreting. Slump loss can be successfully readjusted by redosage with superplasticizers instead of with water. A second dosage generally restores the slump and results in greater 28-daystrengths. Third and subsequent redoses may not improve strength, but it is important to experiment with higher dosages than those recommended by the admixture manufacturers. Dosage rates as high as 50percent above manufacturers' recommended amounts have resulted in '0 percent increases in compressive strength without detrimental effects

The main consideration when using superplasticizers in concrete are the high fines requirements for cohesiveness of the mix and rapid slump loss. Neither is harmful for the production of high strength concrete. High strength concrete mixes generally have more than sufficient fines due to high cement contents. The use of retarders, together with high doses and redoses of superplasticizers at the plant or at the job site can improve strength while restoring slump to its initial amount. Even a superplasticized mix that appears stiff and difficult to consolidate is very responsive to applied vibration.

3-Air Entrainment

Air entraining agents are not required, nor have they been recommended for high strength concrete in buildings, since the primary applications of high strength concrete, such as caissons, interior columns, and shear walls, will normally not require airentrained concrete. One investigation recommended that if high strength concrete is to be used under saturated freezing conditions, air entrained concrete should be considered despite the loss of strength due to air entrainment. High strength concrete is much more durable than lower strength concrete; but an air-entrained concrete with only half the strength of high strength concrete is more durable than the high strength concrete containing no entrained air. Ryan stated that effective levels of air content cause an increase in void space which quickly reduces the strength and limits the use of the water/cement ratio as a factor for field control of the mix. It has been shown, however, that adding an air entrained additive to a mix with 2 percent air to get a 5 percent air content reduced the 90-day strength of a 9,400 psi mix by only 2 to 5 percent. In that study, the air entrained mix had a water/cement ratio of 0.03 less than the control mix. This shows that the resulting reduction in the water/cement ratio cannot fully compensate for strength loss due to increased air content. It has been reported that as compressive strengths increase and water/cement ratios decrease, air void parameters improve and entrained air percentages can be set at the lower limits of the acceptable range.

2.6 Fresh Concrete

It is the concrete phase from time of mixing to end of time concrete surface finished in its final location in the structure.

2.6.1 Concrete Operations

They comprise batching, mixing, transporting, placing, compacting, surface finishing. Then curing of in-placed concrete starts 6-10 hours after casting (placing) and during first few days of hardening is important.

It is known that fresh state properties enormously affect hardened state properties due to the following reasons:

- The potential strength and durability of concrete of a given mix proportion is very dependent on the degree of its compaction.
- The first 48 hours are very important for the performance of the concrete structure.
- It controls the long-term behavior, influence f'_c (ultimate strength), E_c’ (elastic modulus), creep, and durability.

Main properties of fresh concrete during mixing, transporting, placing and compacting are:

- Fluidity or consistency: capability of being handled and of flowing into formwork and around any reinforcement, with assistance of compacting equipment.

- Compactability: air entrapped during mixing and handling should be easily removed by compaction equipment, such as vibrators.
- Stability or cohesiveness: fresh concrete should remain homogenous and uniform. No segregation of cement paste from aggregates (especially coarse ones).

2.6.2 Workability Definition

The amount of useful internal work necessary to produce full compaction without occurrence of the known concrete problems. The useful internal work is the work or energy required to overcome the internal friction between the individual particles in the concrete.

In practice, however, additional energy is required to overcome the surface friction between concrete and the framework or the reinforcement.

Thus, in practice, it is difficult to measure the workability as defined above, and what we measure is workability which is applicable to particular method adopted.

Factors Affecting Workability are as follows**:**

- **Water content of the mix:** Adding water increases workability and decreases strength.
- **Maximum size of aggregate:** Less surface area to be wetted and more water in medium.
- **Grading of aggregate:** Poor grading reduces the consistency.
- **Shape and texture of aggregates:** Smooth surfaces give better workability.

Workability Measurement Methods are as follows:

- Slump test
- Compacting factor test
- Vebe test
- Flow table test
- Kelly Ball Test

2.6.3 Properties of Fresh Concrete

1-Segregation

Segregation is separation of the constituents of a heterogeneous mixture so that their distribution is no longer uniform.

There are two forms of segregation:

- **First form**: Course particles tend to separate out since they tend to settle more than fine particles.
- **Second form:** Occurs in wet mixes; it is manifested by the separation of (cement + water) from the mix.

Figure 2-6: Flow test for segregated concrete

2-Bleeding

Bleeding (water gain) is a form of segregation, in which some of the water in the mix tends to rise to the surface of freshly placed concrete.

Reason: Caused by the inability of the solid constituents of the mix to hold all of the mixing water when they settle downwards.

Result: Top of every lift may become too wet and if the water is trapped by concrete, porous, weak, and non-durable concrete will result.

If the bleeding water is remixed during finishing of the top surface a weak wearing surface will be formed.

This can be avoided by delaying the finishing operations until the bleeding water has evaporated.

Some of the rising water becomes trapped on the underside of coarse aggregate particles or of reinforcement, thus creating zones of poor bond.

2.6.4 Flow Table Test

Concrete flow table test is to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work. Concrete flow table test is carried out from batch to batch to check the uniform quality of concrete during construction.

The flow table test is very simple workability test for concrete, involves low cost and provides immediate results. Due to this fact, it has been widely used for workability tests. The flow table is carried out as per procedures mentioned in BS EN 12350-5 generally concrete flow value is used to find the workability, which indicates water-cement ratio, but there are various factors including properties of materials, mixing methods, dosage, admixtures etc. also affect the concrete flow value.

Factors which influence the concrete flow table test are as follows:

1. Material properties like chemistry, fineness, particle size distribution, moisture content and temperature of cementitious materials. Size, texture, combined grading, cleanliness and moisture content of the aggregates,
2. Chemical admixtures dosage, type, combination, interaction, sequence of addition and its effectiveness,

3. Air content of concrete,
4. Concrete batching, mixing and transporting methods and equipment,
5. Temperature of the concrete,
6. Sampling of concrete, flow -testing technique and the condition of test equipment,
7. The amount of free water in the concrete, and
8. Time since mixing of concrete at the time of testing.

Equipment Required for Concrete flow Test consist of:

mould for flow test, nonporous base plate, measuring scale, temping rod. The mould for the test is in the form of the frustum of a cone having height 30 cm, bottom diameter 20 cm and top diameter 10 cm. The tamping rod is of steel 16 mm diameter and 60cm long and rounded at one end.

Figure 2-7: Equipment Required for concrete flow test

Procedure for concrete flow test is summarized as follows:

1. Clean the internal surface of the mold and apply oil.
2. Place the mold on a smooth horizontal non- porous base plate.
3. Fill the mold with the prepared concrete mix in 2approximately equal layers.
4. Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mold. For the subsequent layers, the tamping should penetrate into the underlying layer.

5. Remove the excess concrete and level the surface with a trowel.
6. Clean away the mortar or water leaked out between the mold and the base plate.
7. Raise the mold from the concrete immediately and slowly in vertical direction.
8. Measure the flow as the average diameter of tow sides of the mold.

2.6.5 Slump Test

The slump test is the most well-known and widely used test method to characterize the workability of fresh concrete. The inexpensive test, which measures consistency, is used on job sites to determine rapidly whether a concrete batch should be accepted or rejected. The test method is widely standardized throughout the world, including in ASTM C143 in the United States and EN 12350-2 in Europe.

The apparatus consists of a mold in the shape of a frustum of a cone with a base diameter of 200mm, a top diameter of 100mm, and a height of 300mm. The mold is filled with concrete in three layers of equal volume. Each layer is compacted with 25 strokes of a tamping rod. The slump cone mold is lifted vertically upward and the change in height of the concrete is measured.

Four types of slumps are commonly encountered, as shown in Figure 3. The only type of slump permissible under ASTM C143 is frequently referred to as the “true” slump, where the concrete remains intact and retains a symmetric shape. A zero slump and a collapsed slump are both outside the range of workability that can be measured with the slump test. Specifically, ASTM C143 advises caution in interpreting test results less than 12.5mm and greater than 9 inches. If part of the concrete shears from the mass, the test must be repeated with a different sample of concrete. A concrete that exhibits a shear slump in a second test is not sufficiently cohesive and should be rejected.

The slump test is not considered applicable for concretes with a maximum coarse aggregate size greater than 37.5mm. For concrete with aggregate greater than 37.5mm in size, such larger particles can be removed by wet sieving.

2.7 Hardened Concrete

Hardened concrete must be strong enough to withstand the structural and service loads which will be applied to it and must be durable enough to withstand the environmental exposure for which it is designed. If concrete is made with high-quality materials and is properly proportioned, mixed, handled, placed and finished, it will be the strongest and durable building material.

2.7.1 Properties of Hardened Concrete

A-Strength

When refered to concrete strength, we generally talk about compressive strength of concrete. Because, concrete is strong in compression but relatively weak in tension and bending. Concrete compressive strength is measured in pounds per square inch (psi). Compressive strength mostly depends upon amount and type of cement used in concrete mix. It is also affected by the water-cement ratio, mixing method, placing and curing.

Concrete tensile strength ranges from 7% to 12% of compressive strength. Both tensile strength and bending strength can be increased by adding reinforcement.

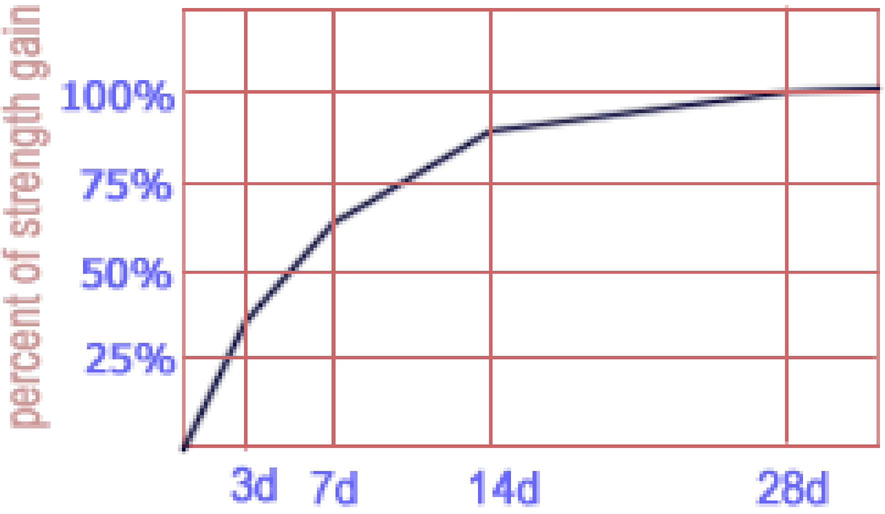

Figure 2-8: Strength gaining of concrete with age (day)

B-Creep

Deformation of concrete structure under sustained load is defined as concrete creep. Long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is applied.

C-Durability

Durability might be defined as the ability to maintain satisfactory performance over and extended service life. The design service life of most buildings is often 30 years, although buildings often last 50 to 100 years. Most concrete buildings are demolished due to obsolescence rather than deterioration.

Different concretes require different degrees of durability depending on the exposure environment and properties desired. Appropriate concrete ingredients, mix proportions, finishes and curing practices can be adjusted on the basis of required durability of concrete.

D-Shrinkage

Shrinkage is the volume decrease of concrete caused by drying and chemical changes. In another word, the reduction of volume for the setting and hardening of concrete is defined as shrinkage.

E-Modulus of Elasticity

The modulus of Elasticity of concrete depends on the Modulus of Elasticity 0f the concrete ingredients and their mix proportions. As per ACI code, the modulus of Elasticity to be calculated using following equation:

$$Ec = 33\omega_c.1.5\sqrt{f_c'} \quad \text{(Psi)} \tag{2-1}$$

Where; ω_c *≡ unit weight of concrete, lb/ft*^{2}*.*
f_c*' ≡ 28 days compressive strength of concrete.*

For normal weight concrete (90 lb/ft3 to 160 lb/ft3), we assume that formula

$$Ec = 57000\sqrt{f_c'} \tag{2-2}$$

F-Water Tightness

Another property of concrete is water tightness. Sometime, it's called impermeability of concrete. Water tightness of concrete is directly related to the durability of concrete. The lesser the permeability, the more the durability of concrete.

In simple word, the capability of penetrating outer media into concrete is the permeability of concrete. Outer media means water, chemicals, sulphates, etc.

2.8 Concrete Mix Design

Design of concrete may be defined as process of selecting suitable ingredients of concrete and determining their relative quantities with the object of producing as economically as possible concrete of certain minimum properties, notable consistency, strength and durability. This definition stresses two points:

1. The concrete is to have certain specified minimum properties.
2. It is to be produced as economically as possible- a most common requirement in engineering.

2.8.1 Factors Influencing the Choice of Mix Properties

The fundamental requirement of a concrete mix is that it should be satisfactory both in the fresh as well as in the hardened state, possessing certain minimum desirable properties like workability, strength and durability. Besides, these requirements it is essential that the concrete mix is prepared as economically as possible by using the least possible amount of cement content per unit volume of concrete, with due regard to the strength and durability requirement.

The following parameters control the proportions of ingredients in the mix:

1. Compressive Strength: The usual primary requirement of good concrete is a satisfactory compressive strength in its hardened state. Many of the desirable properties like durability, impermeability, abrasion resistance are high influenced by the strength of concrete. The strength of concrete depends upon the type of cement used and the method of curing employed, since the rate of hardening of cements of different types vary considerably.
2. Workability: The workability of concrete mix is mainly determined to suite the type of construction, placing conditions and the means of compaction available at site. The properties of fresh concrete, amount and condition of reinforcement and the shape and size of the mould are important factors which control workability. The main factor affecting workability is the water content in the mix. Other parameters influencing workability are the maximum size of aggregate, its grading, texture and shape and the mix proportions.
3. Type, Size and Grading of Aggregate: Good concrete can be made by using different types of aggregates like rounded and irregular gravel and crushed rock which is mostly angular in shape. The maximum nominal size of the aggregate to be selected for a particular job depends upon the width of the section and the spacing of the reinforcement. The grading of aggregate is a major factor influencing the workability of a concrete mix. The grading of the aggregate should be such as to ensure that the voids between the larger aggregates are filled

with the smaller fractions and mortar so as to achieve maximum density and strength.

4. Aggregate/ Cement Ratio: The various factors involved in selecting the aggregate/ cement ration of a mix are, the desired workability, size, shape, texture and overall grading of the aggregates. The aggregate/ cement ration affects the strength of concrete in the high strength range to a significant degree and this is one of the reasons for considering the design of high strength concrete separately.
5. Durability: Generally, concrete made from suitable ingredients, with proper compaction is durable under ordinary conditions of exposure. In such cases, the mix is designed by selecting the water/cement on the basis of strength and workability rather than durability criterion. If the conditions of exposure are such that high durability is essential, the mix has to be designed by limiting the values of the water/cement ratio depending upon the type of exposure.

2.8.2 Early Mix Design Methods

When concrete was first adopted as a structural material during the nineteenth century, compressive strength was perhaps the only criterion in the proportioning of a concrete mix. The concept of workability, durability and other factors influencing the mix proportions, as they are understood are of comparatively recent origin. Some of the earlier mix design methods are based on the principles of minimum voids and maximum density.

1. Minimum Voids Method.
2. Fuller’s Maximum Density Method.
3. Talbot- Richart Method.
4. Fineness Modulus Method.

With the recent development of concrete science and technology, new methods of concrete mix design have been developed. American Method of selection of Mix Proportions and British Method of Mix Selection are the most widely used mix design methods.

2.8.3 American Method of Selection of Mix Proportions

The American Concrete Institute (ACI) recommends a method of mix design, considering the most economical use of available materials to produce concrete of a desirable workability, durability and strength. The following design criteria are assumed in formulating the design tables:

1. Type I, non-air entraining cement with a specific gravity of 3.15 is used.
2. The coarse and fine aggregates are of satisfactory quality and are graded within limits generally accepted specifications.
3. The coarse aggregate has a bulk dry specific gravity of .68 and absorption of 0.5 percent.
4. The fine aggregate has a bulk dry specific gravity of 2.64, absorption of 0.7 percent and fineness modulus of 2.8.
5. The method consists of a sequence of logical, straightforward steps which take into account the characteristics of the materials to be used.

These steps will now be described:

Step 1: Depending upon the type of constructions, the required slump and maximum size of aggregate are selected from the Tables. Recommended Slumps for and maximum size of aggregate are selected from **Table 2-7**and **Table 2-8**.

Table 2-7: Recommended Slumps for Various Types of Construction

Type of Construction	Slump (mm)	
	Max.	Min.
Reinforced foundation walls and footings	175	50
Plain footings, caissons and sub-structure walls	100	25
Slabs, beams and reinforced walls	150	75
Building Columns	150	75
Pavements	75	50
Heavy mass construction	75	25

Table 2-8: Maximum Size of Aggregate Recommended for Various Types of Construction

Min. Dimension of Section (mm)	Max. Size of Aggregate (mm)			
	Reinforced Walls, Beams and Columns	Un-reinforced Walls	Heavily Reinforced Slab	Lightly Reinforced or Un-reinforced slab
62.5 – 125	12.5 – 20	20	20 – 25	20 – 40
150 – 275	0 – 0	40	40	40 – 80
300 –750	40 – 80	80	40 – 80	80
750 or more	40 – 80	160	40 – 80	80 – 160

Step 2: The type of exposure will help in deciding air entrained or non-air entrained concrete is to be used and the recommendations contained in Table 3 are useful in this regard.

Step 3: The water/cement ratio is selected based on the dual criterion of durability and strength using

Table 2-9 and

Table 2-10. The minimum of the two values is adopted for the trial mix.

Table 2-9: Relationship between Water/cement Ratio and Compressive Strength of Concrete

Cylinder Compressive at 28 days (kg/cm^2)	Water/Cement Ratio by Weight	
	Non-Air Entrained Concrete	Air Entrained Concrete
450	0.38	-
400	0.43	-
350	0.48	0.40
300	0.55	0.46
250	0.62	0.53
200	0.70	0.61
150	0.80	0.71

Table 2-10: Approximate Mixing Water (kg/m^3 of concrete) Requirements for Different Slumps and Maximum Sizes of Aggregates

Slump (mm)	Maximum Size of Aggregate (mm)							
	10	12.5	20	25	40	50	70	150
Non-Air Entrained Concrete								
2 – 5	205	200	185	180	160	155	145	125
8 – 10	225	215	200	195	175	170	160	140
15 – 10	240	20	210	205	185	180	170	-
Approximate amount of entrapped air in non-air entrained air in non-air entrained concrete (percent)	3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2
Air Entrained Concrete								
3 – 5	180	175	165	160	145	140		120
8 – 10	200	190	180	175	160	155		135
15 – 18	215	205	190	185	170	165		-
Recommended average total air content (percent)	8.0	7.0	6.0	5.0	4.5	4.0		3.0

Step 5: The cement content is calculated from the water content and water/cement ratio required for durability or strength. It is the water content divided by the water/ cement ratio.

Step 6: The coarse aggregate content is estimated from table 6 for maximum size of aggregate and the fineness modulus of sand.

Table 2-11: Volume of Dry Rodded Coarse Aggregate per Unit Volume of Concrete

Max. Size of aggregate (mm)	Fineness Modulus of Sand			
	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.56
40	0.76	0.74	0.72	0.70
50	0.78	0.76	0.74	0.72
70	0.81	0.79	0.77	0.75
150	0.87	0.85	0.83	0.81

Step 7: The fine aggregate content is determined by subtracting the sum of the volumes of coarse aggregate, cement, water and air content from the unit volume of concrete. For each ingredient, the absolute volume is equal to the mass divided by the absolute density of the material (in kg/m^3); the absolute density is the specific gravity of the material divided by the density of water (1000 kg/m^3).

In general terms, it is important to remember that, if workability is to be changed, but the strength is to remain unaffected, the water/cement ratio must remain unaltered. Change can be made in the aggregate/cement ratio or, if suitable aggregates are available, in the grading of the aggregate. Conversely, changes in strength but not in workability are made by valuing the water/cement ratio with the water content of the mix remaining unaltered. This means that a change in the water/cement ratio must be accompanied by a change in the aggregate/cement ratio so that the mass ratio water is $\frac{water}{water+cement+aggregate}$ approximately constant.

2.8.4 British Method of Mix Selection (Mix Design)

The current British method is that of Department of the Environment revised in 1988. Similarly to the AC approach, the British method explicitly recognizes the durability requirements in the mix selection. The method is applicable to normal weight concrete made with Portland cement only or also incorporating ground granulated blast furnace slag or fly ash, but it does not cover flowing concrete or pumped concrete; nor does it deal with lightweight aggregate concrete. Three maximum size of aggregate are recognized: 40, 20 and 10 mm.

Step 1: The Target Mean Strength is calculated based on the Characteristic Strength and Standard Deviation.

$$f_m = f_c + k.s \tag{2-3}$$

Where; f_m ≡ *The target mean strength.*
f_c ≡ *Characteristic strength.*
s ≡ *Standard deviation.*
k ≡ *A constant.*

The constant k is derived from the mathematics normal distribution and increases as the proportion of defectives is decreased.

k for 10% defectives is 1.28

k for 5% defectives is 1.64

k for 2.5% defectives is 1.96

k for 1% defectives is 2.33

The value of Standard Deviation s of concrete cylinder tests can be obtained from the figure.

Step 2: From **Table 2-12**, a value is obtained for the compressive strength of a mix made with a free water/cement ratio of 0.5, according to the specified age, the type of cement and the type of aggregate used.

Table 2-12: Approximate compressive strengths of concrete mixes made with water/cement ratio of 0.5

Type of Cement	Type of Coarse Aggregate	Compressive Strength (MPa) at the Age of (days)			
		3	7	28	91
Ordinary Portland or Sulfate Resisting Portland	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
Rapid Hardening Portland	Uncrushed	29	37	48	54
	Crushed	24	43	55	61

Step 3: This strength value is plotted on **Table 2-12**, and a curve is drawn from the point and parallel to the printed curves until it intercepts a horizontal line passing through the ordinate representing the Target Mean Strength. The corresponding of the free water/cement ratio can then be read from the abscissa.

Step 4: the free water content required depending upon the type and maximum size of aggregate to give a concrete of the specified slump is obtained from **Table 2-13**.

Table 2-13: Approximate water contents (kg/m^3) required to give various levels of workability.

Slump (mm)		0 – 10	10 – 30	30 – 60	60 – 180
Vee bee (sec)		12	6 – 12	3 – 6	0 – 3
Max. Size of Aggregate (mm)	Type of Aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Note: When coarse aggregate and fine aggregate of different types are used, the water content are estimated by the expression given by:

$$\frac{2}{3}w_f + \frac{1}{3}w_c \qquad (2\text{-}4)$$

Where; w_f *≡ water content appropriate to the type of fine aggregate.*

w_c *≡ water content appropriate to the type of coarse aggregate.*

Step 5: Knowing the water/ cement ratio and water content, the cement content is obtained as:

$$cement\ content = \frac{Free\ water/cement\ ratio}{Free\ water\ content} \qquad (2\text{-}5)$$

Step 6: An estimate of the wet density of the fully compacted concrete is obtained from the chart. Depending upon the free water content and 11w specific gravity of the combined aggregate. From this estimated density of the concrete, the total aggregate content is determined from the following relation:

$$Total\ Aggregate\ Content = D - W_c - W_{fw} \qquad (2\text{-}6)$$

Where; D *≡ The wet density of the concrete* (kg/m^3)*.*

W_c *≡ The cement content* (kg/m^3)*.*

W_{fw} *≡ The free water content* (kg/m^3)

Step 7: The proportion of fine aggregate in the total aggregate is determined from the figure. The governing factors are: the maximum size of aggregate, the level of wrkabi1ity, the water/cement ratio and the percentage of fine aggregate passing the 600 pm sieve.

Fine aggregate content (Total aggregate content) x (Proportion of fines) Coarse aggregate content = (Total aggregate content) - (Fine aggregate content) It should be remembered that the British method is based on the experience of British materials so that the various values given in the tables and figures may not be applicable in other parts.

CHAPTER THREE
CASE STUDY

CHAPTER THREE
CASE STUDY

3.1 Introduction

This chapter presents the experimental program and the constituent materials used to produce HSC in DCUAP site.

The laboratory investigation consisted of tests for both fresh and hardened concrete.

Fresh concrete was tested for flow and temperature in order to ensure reasonable workability in the plastic state. The tests for hardened concrete included compression tests for strength.

The properties of different constituent materials used to produce HSC are discussed such as moisture content, unit weight, specific gravity and the grain size distribution. The test procedures, details and equipment used to assess concrete properties are illustrated in chapter tow.

HSC constituent materials used in this project include of Portland ordinary cement from many manufactures, silica fume, fly ash, sand and aggregate, in addition to superplasticizer are used to ensure suitable workability. Proportions of these constituent materials have been chosen carefully in order to optimize the packing density of the mixture.

The results of 93 compressive strength samples were tested and analyzed.

3.2 Preparation of Material and Testing

After selection of all needed constituent materials and amounts to be used (mix designs); all materials were weighted properly. Then mixing with a power-driven tilting revolving drum mixer started to ensure that all particles are surrounded with cement paste and silica fume and all the materials should be distributed homogeneously in the concrete mass.

3.2.1 General Rules

There is no “scientific” method for proportioning. This means that there is no chart that can be used to derive the mixture ingredients to meet a specified level of performance. There are simply too many variables for such a chart to be developed. Here are some general rules for proportioning.

Test at both the laboratory and production scale during mixture development. The process is too complex to predict what the outcome will be without appropriate testing. Allow plenty of time for the necessary testing.

Finally, follow the procedure described in the following section.

This procedure has evolved over many years and is the best recommendation currently available.

3.2.2 Step-By-Step Procedure

This section presents the main steps procedure. Examples are given for each step.

Step 1: Determine project requirements

Read the specifications carefully. Look for requirements not only for concrete performance but also for concrete proportioning. Items to look for include:

- Compressive strength.
- Chloride exposure.
- Freezing and thawing exposure, including specified air content.
- Aggregate requirements, including nominal maximum size.
- Chemical exposure.
- Abrasion resistance.
- Temperature restrictions.
- Maximum water content.
- Cementitious materials contents.
- Percentages of fly ash, slag, and silica fume.
- Flow.

Step 2: Coordinate with contractor who will be placing the concrete

Save time and expense by getting input from the contractor early in the process. Items to consider here include:

- Special constructability requirements.
- Placing and finishing methods.
- Nominal maximum allowable aggregate size.
- Flow requirements - don’t forget to increase the flow for silica fume concrete.
- Responsibility for adding admixtures on the site, if necessary.

Step 3: Select starting mixture

Contains a number of silica-fume concrete mixtures that have been developed for a variety of applications, from experience or previous projects.

Step 4: Determine volume of entrained air required

It is essential that silica-fume concrete that will be exposed to freezing and thawing while saturated contain entrained air. Use an industry standard table such as found in ASTM or ACI to determine the volume of air required.

Step 5: Incorporate local aggregates into the starting mixture

There are two considerations here:

- Calculate a total aggregate volume that will yield one cubic meter of concrete. (Note: some concrete producers proportion their concrete mixtures to yield slightly more than one cubic meter. It is best to first proportion the concrete to develop the necessary fresh and hardened properties and then adjust the proportions for yield as appropriate.)
- Use a ratio of fine to coarse aggregate that works well for project materials. This ratio can always be adjusted while making trial mixtures.

Although the ratio of fine to coarse aggregate will have an influence on the workability, small changes will not seriously affect hardened concrete properties. Because of the very fine nature of silica fume, it may be appropriate to start with a concrete mixture that is slightly “under sanded” compared to similar mixtures without silica fume. If an appropriate starting ratio of fine to coarse aggregate is not known, guidance on selecting starting aggregate proportions may be found in ACI 211.1, Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete.

Step 6: Prepare laboratory trial mixtures

This step is not all that different from what is normally done on a daily basis. However, the Silica Fume Association is aware of instances in which silica-fume concrete prepared in a laboratory has failed to produce the expected hardened concrete properties, whether the property is compressive strength or low permeability. This problem is particularly common in laboratories having small, and often less efficient, concrete mixers.

Following are points to keep in mind when producing silica-fume concrete in a laboratory.

Silica fume is a very fine powder - the particles are approximately 1/100 the diameter of Portland cement grains. When used to produce high-performance concrete, silica fume is typically 4-15% of the cement weight. The exact addition rate depends upon the specific performance characteristic to be improved. Compared to the other ingredients in concrete, the amount of silica fume used is small. For the silica fume to be effective, there are two issues that must be addressed:

- First, the agglomerations that make up the densified silica fume must be broken down.
- Second, the silica fume must be distributed uniformly throughout the concrete.

When making concrete in the laboratory, the key to both of these issues is batching the silica fume at the appropriate time and then mixing the concrete adequately. ASTM C192, Standard Practice for Making and Curing Concrete Test specimens in the Laboratory.

- Silica fume must always be added with the coarse aggregate and some of the water. Batching silica fume alone or first can result in head packing or balling in the mixer. Mix silica fume, coarse aggregates, and water for1 1⁄2 minutes.

- Add the Portland cement and any other cementitious material such as fly ash or slag cement. Mix for an additional 11⁄2minutes.
- Add the fine aggregate and use the remaining water to wash in any chemical admixtures added at the end of the batching sequence. The mixer rotated for 2 minutes (dry mixing). Super-plasticizer was dispersed in about 2/3 of water before added to the mixer and started rotated the mixer again for 2 minutes Mix for 5 minutes. Actual mixing time may vary, depending upon the characteristics of a specific mixer. If there are any doubts that full dispersion and efficient mixing has been accomplished, mix longer. Silica-fume concrete cannot be over mixed.

Following these recommendations will help ensure that the results in the laboratory will closely resemble the results to be expected in actual silica-fume concrete production.

1. The Silica Fume Association’s experience is that truck mixers or central plant mixers are much more efficient in breaking down the agglomerations and dispersing silica fume. However, remember to limit batch sizes to the rated mixing capacity of the equipment.
2. Batch the concrete at the maximum allowed water content. Remember that even with the maximum allowed water there may not be any measurable flow. Use chemical admixtures to achieve the necessary workability.
3. Review the properties of the fresh concrete and make adjustments as necessary to get the desired workability, air content, and other properties. Once the fresh properties are established, make specimens for hardened concrete testing.
4. Based upon the results of testing the hardened concrete, adjust the mixture proportions as necessary. At this point it may be necessary to make additional laboratory mixtures or it may be time to go to production-scale testing.

Step 7: Conduct production-scale testing

There can always be minor differences between proportions developed in the laboratory and those used for concrete production, particularly in chemical admixture dosages. Making production batches of the concrete is the best way to work out the bugs. Keep in mind:

This is not a time to economize by making very small batches.

Make enough concrete to be representative of what will be made during the project.

Test to determine whether the concrete meets the fresh and hardened requirements for the project. Because the mixture has already been fine tuned in the laboratory, major adjustments at this point should not be required. If it appears that the performance is not the same seen in the lab, examine the process carefully — there is no reason to expect major differences.

Make more than one batch. It is always good to confirm the performance of a particular concrete mixture.

3.2.3 Mixing procedure

Mixing procedure was according following steps:

1. Placing all dry materials (Cement, Sand and Coarse Aggregate) in the mixer pan, and mixing for 2 minutes.
2. Adding super plasticizer to the mixing water by different dosages.
3. Adding water (with super plasticizer) to the dry materials.
4. Continuation of mixing changes from a dry powder to a thick paste.

After final mixing, the mixer is stopped, turned up with its end right down, and the fresh homogeneous concrete is poured into a clean earth the casting.

The laboratory testing consists of tests for both fresh and hardened concrete. Fresh concrete tested for flow. Hardened concrete tested for compressive strength.

3.2.4 Procedure for Concrete Flow Test

1. Clean the internal surface of the mold and apply oil.
2. Place the mold on a smooth horizontal non- porous base plate.

3. Fill the mold with the prepared concrete mix in 2approximately equal layers.
4. Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mold. For the subsequent layers, the tamping should penetrate into the underlying layer.
5. Remove the excess concrete and level the surface with a trowel.
6. Clean away the mortar or water leaked out between the mold and the base plate.
7. Raise the mold from the concrete immediately and slowly in vertical direction.
8. Measure the flow as the average diameter of tow sides of the mold.

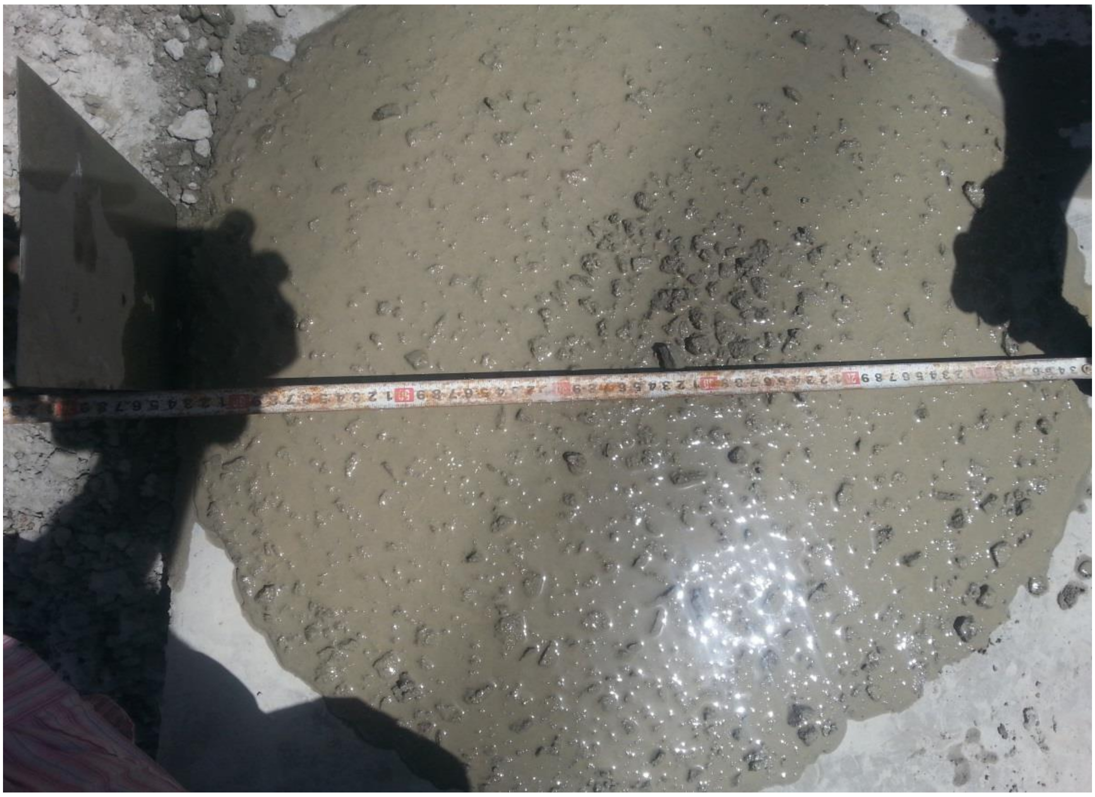

Figure 3-1: Concrete flow test

3.3 Adjusting the Mixture

There are two areas that frequently require adjustments during either the laboratory or the production-scale testing. These are compressive strength and the stickiness of the fresh concrete.

Compressive strength: Failure to achieve a required compressive strength is most frequently the result of having too much water in the concrete. For very high strength concrete, don’t be afraid to drop the w/cm well below customary levels. Look again at the starting mixtures in. To get into the very high strength range, there must be a very low water content.

Concrete stickiness: The most common complaint regarding silica-fume concrete is that it tends to be sticky. This stickiness is a result of the high fines content and the high super-plasticizer content. If stickiness a problem, here are some suggestions:

- Silica fume from a particular source can behave differently when used with a different super-plasticizers. Simply try a different super-plasticizer from your admixture supplier and see if that switch makes a difference in stickiness.
- Use of one of the mid-range water-reducing admixtures may also help reduce stickiness. Many of these products are usually based upon a lignin ingredient, which seems to help reduce stickiness. Try replacing about one-third of the superplasticizer with the mid-range product. Since these midrange products are priced about the same as superplasticizers, there should be little impact on the cost of the concrete.
- Look at reducing the volume of fine aggregate by a small amount. As stated earlier, silica-fume concrete performs well when slightly under sanded. This success of this approach will depend upon the fineness of the aggregate.
- Look at the grading of the fine aggregate. If there are a lot of fines in the aggregate, replacing some or all of the fine aggregate with a coarser material may help reduce stickiness.

3.4 Placing and Consolidating

Silica-fume concrete has been successfully placed by all means of placing concrete. These include direct discharge from mixer trucks, crane and bucket, tremie under water, and pumping. Given the nature of the applications where silica-fume concrete tends to be used, the vast majority has been placed by pump. Overall, do not expect to see any significant differences when placing and consolidating silica-fume concrete.

It is always easier to work with as high a flow as practical for a given placement. Use a flow for silica-fume concrete based upon actual job conditions and not based upon arbitrary recommendations that were probably developed for concrete without silica fume and superplasticizer. Because a lot of silica-fume concrete is placed by pump, there are the usual concerns over air loss. Silica-fume concrete is no more or no less susceptible to air loss than any concrete without silica fume placed under the same circumstances. Following good pumping practices, air loss of 1 to 2% going through the pump can be expected. If greater air loss is being seen, look at the procedures and configuration of the pump boom before blaming the concrete mixture. If higher air losses are being experienced, be very careful attempting to fix the problem by increasing the air content of the concrete going into the pump. What may work on one day may not work well the next day if the configuration of the boom is changed. See ACI 304.2R, Placing Concrete by Pumping Methods, for additional information on pumping and air loss.

Silica-fume concrete is a very fluid material, particularly if the recommendations regarding increasing flow are followed. However, don’t be fooled by the apparent workability — this concrete still needs to be adequately vibrated during placement. Do not assume that a vibratory screed will vibrate concrete in deeper sections such as beams cast integrally with slabs. An internal vibrator must be used in accordance with recommendations from ACI. For more information, see ACI 309R, Guide for Consolidation of Concrete.

3.5 Curing of Samples

Note that there is a difference between curing silica-fume concrete flatwork and structural elements. Because of its large surface to volume ratio, all concrete flatwork, with or without silica fume, is more susceptible to drying and shrinkage cracking. Structural elements such as columns or beams are less susceptible to this type of cracking. The Silica Fume Association is not aware of instances where cracking of structural members has been an issue on a project.

These precautions are necessary in order to protect the concrete from negative impact on methods of curing. In this trials, Method of curing was used as Normal Water Curing (Immerse in water) until day of testing or until the age of 14 days at side in case of chemical curing is not allowable.

3.6 Test of Hardened Concrete

3.6.1 Compressive Strength Test

The cubes (150×150×150) mm were filled with fresh concrete without compacting, after preparing the specimens; It was placed for 24 hours until harden. The cubes were stored in water until the time of the test, as shown in Figure 3-2 the cubes are placed in the testing machine so that the load is applied to opposite sides as cast and not to the top and bottom as cast. Therefore, the bearing faces of the specimen are sufficiently plane as to require no capping. If there is appreciable curvature, the face is grinded to plane surface because, much lower results than the true strength are obtained by loading faces of the cube specimens that are not truly plane surfaces. The compressive strength machine used for determining the maximum compressive loads carried by concrete specimen cubes, as shown in figure 3-2The compressive strength of the specimen(in Map), is calculated by dividing the maximum load carried by the cube specimen during the test by the cross sectional area of the specimen.

The compressive strength was determined at ages of 7, and 28 days.

Figure 3-2: The cubes after fresh concrete process

3.7 case study

The purpose of this research was to produce high strength concrete for special purposes by using local Sudanese aggregate with supplementary cementitious materials and investigate the use of statistical approach in concrete mixture proportioning.

This study presents a part of an ongoing experimental laboratory investigation being carried out for production and characterization of high strength concrete (HSC) for DCUAP project in Sudan. Brief description of the main features of the dam and concrete works is presented. Hundreds of trial mixes were performed and tested using local Sudanese aggregates with addition of Supplementary Cementitious Materials (Silica Fume and Fly Ash) and Super plasticizers. The HSC (85MPa) had been successfully produced and the mechanical properties was measured and documented.

Statistical analysis of tests results was performed. The results have offered an important insight for optimizing the rheological characteristics of HSC and permitted to develop guidelines for optimum mix design methods for HSC from locally available aggregates in Sudan. The effect of constituent materials on strength of HSC was also highlighted. It is concluded that local concrete materials, in combination with Supplementary Cementitious Materials can be utilized in producing High Strength Concrete for special purposes.

Series of tests were carried out on the concrete cubes to evaluate the mechanical properties of High Strength Concrete (HSC). This chapter discusses the results obtained from the testing program in chapter three. The results are the chemical and physical tests of each single element, compression test of 93 cubic samples and the results were analysis by using excel program.

Dams will provide flood protection measures along the river banks through the regulation of the river flow in the project area.

Figure 3-3: Upper Atbara Spillway

CHAPTER FOUR
RESULTS AND DISCUSSION

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4.1 Cement

Currently the Contractor are uses there types of cement which are yufeng (OPC), 42.5 and 52.4N Slag Cement CEM III/B28 days compressive strength 42.5& 52.5MPa and it contains30% OPC (ordinary portland cement) ,70% GGBS (ground granulated blast furnace slag).The properties of cement are shown in **Table 4-1**.

Table 4-1: The properties of cement

SI. No.	Property	Results
1	Normal Consistency	27.4%
2	Final Setting Time	3.6 hrs
3	Initial Setting Time	2.2 hrs
4	Specific Gravity	3.15
5	Fineness of Cement	1%

4.1.1 Advantages of Slag Cement (GGBS) Compared with OPC

- No further filler (fly ash) needed.
- Low heat of hydration.
- Dense concrete (less pores).

4.1.2 Disadvantages

- Needs good curing.
- Lower early strength (no problem at DCUAP).
- High fresh concrete temperatures increase thermal cracks.

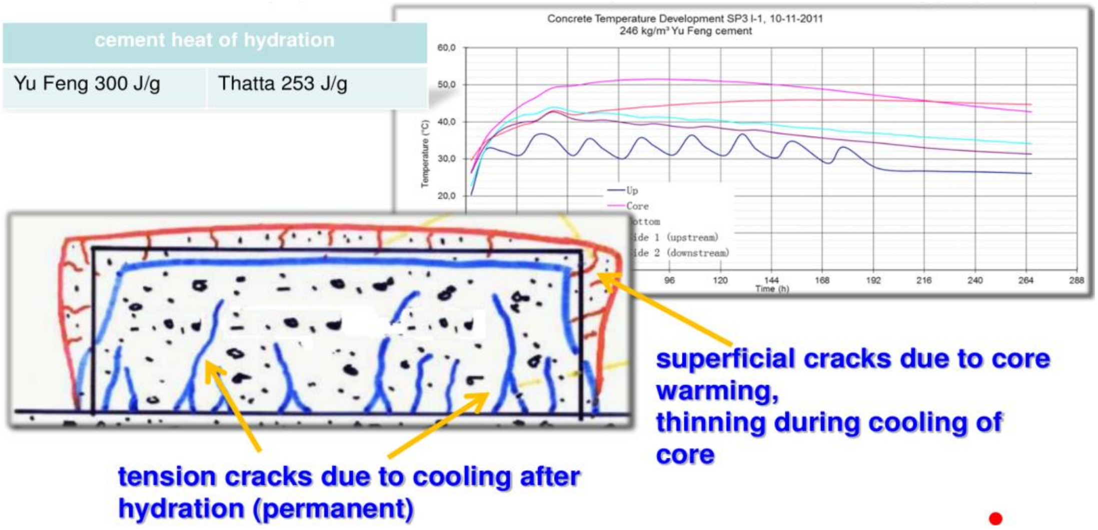

Figure 4-1: Relationship between temperature of fresh concrete and thermal cracks

Table 4-2: Summary results of cement physical and chemical properties test during March 2017

Type	Molding Date	Density (g/cm³)	Consistency %	Setting Time (min)		Soundness (mm)	Fineness (%)	Compressive Strength (MPa)		
				Initial	Final			2 days	7 days	28 days
Slag 42.5N	2017/3/30	2.98	32.8	180	242	0.00	1.8	14.9	35.7	54.3
Slag 42.5N	2017/3/30	2.97	33.0	185	250	0.25	1.4	15.7	30.7	53.4
Slag 42.5N	2017/3/30	2.33	33.2	188	260	0.50	0.9	14.4	32.1	52.9

In table (4.2) was shown that the result of the compressive strength after 28 days is more than 42.5N.

4.2 Aggregates

Mainly basalt gained at Jebel Aklaiyit, hauled 20 km was used in concrete work and crushed into fractions.

Table 4-3: Different types of aggregate

Size (mm)	Type
0 – 5	Sand
5 – 16	Grade 1
16 – 32	Grade 2

Average compressive strength of course aggregate around 100 MPa.

4.2.1 Properties of DCUAP Aggregate

The specific gravity and absorption of the coarse aggregates, determined in according with ASTM C127 [10] were 2.84 and 0.25respectively, where as those of fine aggregates, determined in accordance with ASTM C128 [11] were 2.839 and 0.45 respectively. All the sand samples were tested for their absorption percentage in saturated surface dry (SSD) condition. Organic impurities in sand were tested in accordance with ASTM C-40. The water-cement ration of all trial mixes were based on saturated surface dry condition (SSD) of the aggregates.

Note: all these results had been observing during March 2017.

Table 4-4: Grading test on fine aggregate (0 - 5 mm)

Sample No.	Finest Content (%)	Fineness Modulus	Gradation (%)						
			9.5 mm	4.75 mm	2.36 mm	1.18 mm	0.6 mm	0.3 mm	0.15 mm
1	1.29	2.61	100.0	98.9	91.4	67.5	44.8	25.1	11.7
2	1.41	2.79	100.0	98.2	88.0	62.8	39.3	22.2	10.5
3	1.66	2.61	100.0	99.2	91.5	68.5	44.8	24.7	10.8
4	1.54	2.77	100.0	98.8	88.0	63.5	39.8	22.2	10.8
5	1.90	2.80	100.0	99.1	88.8	62.7	37.7	21.3	10.8
6	1.66	2.73	100.0	97.2	89.8	65.6	42.1	23.8	7.5
7	1.83	2.69	100.0	98.6	89.8	65.9	42.9	25.0	9.2
8	2.35	2.78	100.0	98.4	89.5	63.0	38.7	21.2	10.8
9	1.65	2.68	100.0	98.8	89.2	65.1	42.4	24.7	12.0
10	1.58	2.77	100.0	99.0	89.7	63.8	38.8	21.9	9.8
11	1.55	2.59	100.0	98.7	91.3	71.4	43.9	24.4	10.7
12	2.9	2.75	100.0	97.8	88.5	64.3	40.9	23.1	10.5

Sample No.	Finest Content (%)	Fineness Modulus	Gradation (%)						
			9.5 mm	4.75 mm	2.36 mm	1.18 mm	0.6 mm	0.3 mm	0.15 mm
13	1.02	2.65	100.0	98.3	90.9	67.5	44.1	24.4	10.1
14	1.99	2.55	100.0	98.9	92.1	70.0	46.3	26.0	11.4
15	1.36	2.64	100.0	97.9	90.0	67.2	44.6	24.7	11.7
16	1.51	2.79	100.0	98.2	87.9	62.0	39.9	22.1	11.1
17	1.52	2.67	100.0	98.9	91.7	68.3	43.3	22.5	8.2
18	1.50	2.70	100.0	98.7	90.1	65.6	42.5	23.2	10.4
19	1.51	2.68	100.0	98.2	90.4	66.2	43.0	23.8	10.9
20	2.82	2.73	100.0	99.0	89.0	63.7	40.8	23.9	11.1
21	1.91	2.80	100.0	98.7	89.0	63.0	38.1	21.4	9.9
22	1.39	2.74	100.0	98.8	89.7	65.1	40.9	21.8	10.1
23	1.12	2.82	100.0	98.7	88.9	62.5	37.8	20.8	9.7
24	1.76	2.75	100.0	99.0	89.0	63.5	39.9	22.8	10.8
25	1.46	2.65	100.0	99.1	90.6	67.1	43.8	24.0	10.0
26	1.62	2.74	100.0	97.4	90.0	67.5	44.7	18.4	8.4
27	1.47	2.68	100.0	99.1	90.2	66.1	42.6	22.8	11.0
28	1.92	2.64	100.0	98.3	90.9	66.9	44.0	24.3	11.8
29	1.59	2.64	100.0	98.8	91.3	67.2	44.3	24.8	10.0
30	1.54	2.71	100.0	98.9	90.5	64.8	41.5	22.7	10.8
31	1.64	2.60	100.0	98.9	91.3	68.2	45.2	25.4	11.5

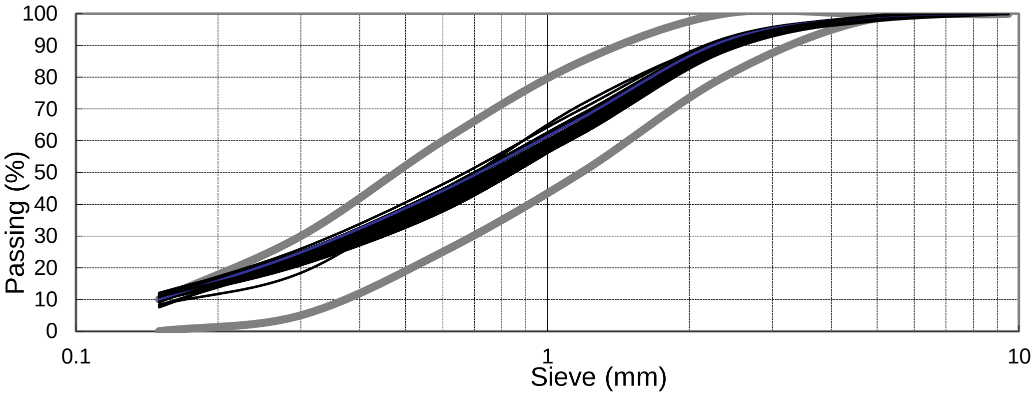

Chart 4-1: Grading test on fine aggregate (0 - 5 mm)

In table (4.4) was shown that all results were acceptable according to standards.

Table 4-5: Grading test on coarse aggregate (5 - 16 mm)

Sample No.	Sampling Date	Testing Date	Grading (%)				
			32 mm	22 mm	16 mm	5.0 mm	2.5 mm
1	2017/3/25	2017/3/26	100.0	100.0	91.5	2.0	1.0
2	2017/3/29	2017/3/30	100.0	100.0	90.0	8.0	4.0
3	2017/4/4	2017/4/5	100.0	100.0	94.0	4.0	1.0
4	2017/4/9	2017/4/10	100.0	100.0	91.5	4.0	1.0
5	2017/4/14	2017/4/15	100.0	100.0	92.5	9.5	1.0
6	2017/4/19	2017/4/20	100.0	100.0	94.5	2.0	0.5
7	2017/4/24	2014/4/25	100.0	100.0	89.5	3.5	0.5

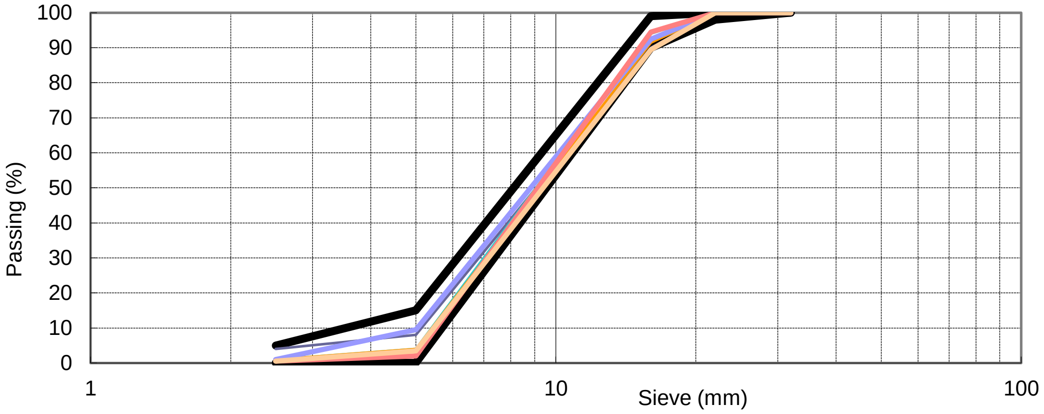

Chart 4-2: Grading test on coarse aggregate (5 - 16 mm)

In table (4.5) was shown that all results were acceptable according to standards.

Table 4-6: Grading test on coarse aggregate (16 - 32 mm)

Sample No.	Sampling Date	Testing Date	Grading (%)				
			32 mm	22 mm	16 mm	5.0 mm	2.5 mm
1	2017/3/25	2017/3/26	100.0	100.0	94.0	4.0	0.7
2	2017/3/29	2017/3/30	100.0	100.0	93.7	3.7	1.0
3	2017/4/4	2017/4/5	100.0	100.0	94.0	8.0	2.0
4	2017/4/9	2017/4/10	100.0	100.0	94.0	16.3	0.7
5	2017/4/14	2017/4/15	100.0	100.0	93.7	18.3	0.3

6	2017/4/19	2017/4/20	100.0	100.0	94.0	6.3	0.7
7	2017/4/24	2014/4/25	100.0	100.0	90.3	2.7	0.3

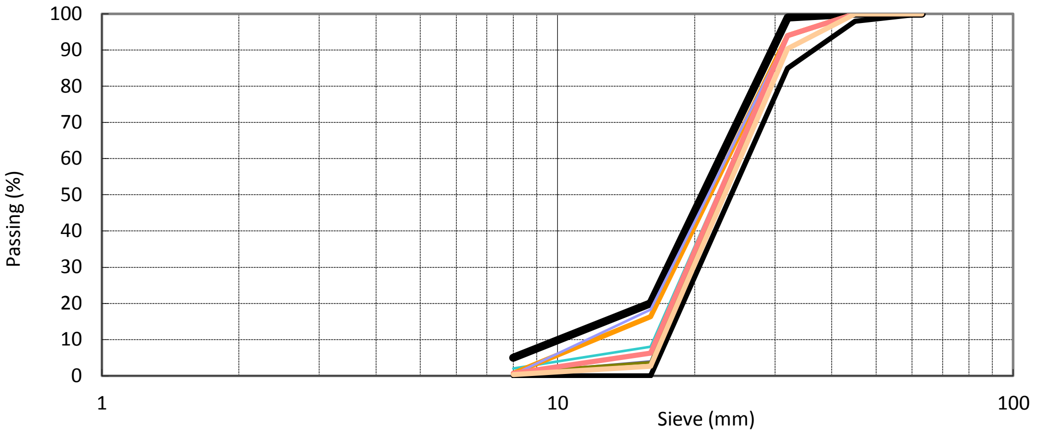

Chart 4-3: Grading test on coarse aggregate (16 - 32 mm)

In table (4.6) was shown that all results were acceptable according to standards.

Table 4-7: M.C of fine aggregate (0 – 5 mm) from HL240 Batch Plant

Date	Time	M.C	Date	Time	M.C	Date	Time	M.C
2017/3/27	08:05	4.2	2017/4/2	08:09	4.1	2017/4/15	07:50	3.6
2017/3/27	08:00	3.8	2017/4/4	08:00	3.8	2017/4/19	07:58	3.8
2017/3/28	08:40	4.0	2017/4/5	07:50	4.7	2017/4/20	07:40	4.2
2017/3/29	08:20	3.8	2017/4/6	08:15	4.2	2017/4/21	08:00	4.1
2017/3/31	08:00	4.4	2017/4/9	07:00	4.0	2017/4/24	08:00	3.9
2017/4/1	08:00	4.2	2017/4/10	07:55	3.9	2017/4/25	08:00	3.6

Table 4-8 to be considered before adding mixing water to mix.

Table 4-9: M.C of aggregate (5 – 16 mm) from HL240 Batch Plant

Date	Time	M.C	Date	Time	M.C	Date	Time	M.C
2017/3/27	08:20	1.1	2017/4/1	08:20	1.7	2017/4/17	07:50	1.0
2017/3/28	08:10	1.8	2017/4/4	08:00	1.9	2017/4/19	07:40	1.0
2017/3/29	08:20	1.8	2017/4/5	08:20	1.3	2017/4/24	07:50	1.0
2017/3/31	08:00	2.1	2017/4/9	07:52	1.4	2017/4/25	07:58	1.0

Table 4-8 to be considered before adding mixing water to mix.

Table 4-10: M.C of aggregate (16 – 32 mm) from HL240 Batch Plant

Date	Time	M.C
2017/4/19	08:00	0.3
2017/4/24	07:50	0.4

Table 4-11 to be considered before adding mixing water to mix.

4.3 Superplasticizer (Water Reducer)

The superplasticizer used in this study has the trade name of “PCA- (I)” from Jiangsu Bote New Materials Company-China. PCA-(I) is a polycarboxylate polymer-based composite admixture. It is a liquid which has the performance of high range water reduction, excellent flow retention and strengthening. The specific gravity of the super-plasticizer was shown in **Table 4-12**. It is specially adapted for the production of high durability concrete, self-compacting concrete, high compressive strength concrete, and high workability concrete. PCA-(I) super-plasticizer is formulated to comply with the ASTM specifications for concrete admixture: ASTM494, Type G [11].

Figure 4-2: The super-plasticizer PCA-(I)

Table 4-12: Specific gravity of the super-plasticizer

Times	Density		
	Max.	Min.	Average
14	1.091	1.089	1.090

In table (4.10) was shown that all results were acceptable according to the standards.

4.4 Silica Fume

Silica fume (SF) is ideally suited to the most demanding applications, such as concrete spillways, dam spillways and hard standings, where chloride, chemical or abrasion resistance are required. SF concretes have performed well under these circumstances, as they are chemically stable and have very low permeability. The SF used in this study (manufacturer by Kaidi) was in accordance with the most international standards such the European BS EN 13263 Silica fume for concrete, Part 1:2005 Definitions, requirements and conformity criteria Part 2:2005 Conformity evaluation, and the American ASTM C1240-97b Standard specification for silica fume for use as a mineral admixture in hydraulic- cement concrete, mortar and grout. The specific gravity of the silica fume silica fume used in this study was 2.373. SF the pozzolanic high activity, which can be filled the gap between cement, increase the density of the system, so as enhance strength, impermeability, wear proof, anti-corrosion, anti-scour, antifreeze, and strong early performance.

Table 4-13: Physical Properties of KD-12 Silica Fume

Test Items	Specified Limits According to ASTM C12405, BS EN13263	Test Results
Absolute Density (kg/m^3)	≥ 2200	2249
Loss on Ignition (%)	≤ 3.5	1.88
Coarse Particle	≤ 1.5	1.1
SiO2 (%)	≥ 86	92
Carbon Content (%)	≤ 2.5	2.3
Moisture (%)	≤ 1.0	0.85
Specific Area (m2/g)	≥ 15	20

In table (4.11) was shown that all results were acceptable according to the standards.

4.5 Fly Ash

Fly ash used in this study was manufacture by Zouxian power plant-China. The specific gravity of the fly ash is 2.4, loss on ignition 0.48, the other properties of fly ash are presented in **Table 4-14**. ASTM C618; the requirement for Class F and Class C fly ashes, and the raw or calcined natural pozzolans, Class N, for use in concrete. Fly ash properties may vary considerably in different areas and from different sources within the same area. The preferred fly ashes for use in high strength concrete have a loss on ignition not greater than 3 percent, have a high fineness, and come from a source with a uniformity meeting ASTM C 618 requirements.

Table 4-14: Physical and chemical properties of Fly Ash

Sample No.	M.C (%)	L.O.I (%)	Density (g/cm^3)	Difference of Initial Setting Time (min)	Fineness (%)	Soundness (%)	Water Requirement (%)	Strength Activity Index (%)	
								28 days	90 days
1	0.24	1.2	2.23	203	13.9	1.0	92.0	91.0	98.0
2	0.30	2.1	2.24	204	14.5	1.5	92.0	87.0	98.0
3	0.16	1.6	22.6	205	12.7	1.5	92.4	70.1	84.1
4	0.32	2.5	2.26	200	13.8	1.0	92.0	84.3	99.5
5	0.26	2.1	2.27	188	13.1	1.0	92.0	92.0	97.0
6	0.30	2.3	2.26	199	12.5	0.5	92.0	86.7	75.0
7	0.36	2.6	2.31	201	12.9	1.0	92.0	86.0	99.0
8	0.20	1.9	2.26	184	10.0	1.0	92.0	74.0	95.0
9	0.24	2.2	2.27	185	9.9	1.1	92.0	79.0	93.0
10	0.22	2.2	2.24	183	9.9	1.5	93.0	86.0	97.0
11	0.22	1.3	2.23	190	11.0	1.0	92.0	86.0	94.0
12	0.22	1.1	2.26	196	9.8	1.5	92.0	91.0	99.0
13	0.28	2.7	2.27	194	9.9	1.0	92.0	85.0	93.0
14	0.06	2.9	2.13	194	9.9	1.0	93.0	99.0	89.0
15	0.06	1.9	2.12	187	13.8	1.5	92.0	90.0	88.0
16	0.06	2.3	2.11	185	13.5	1.0	92.0	105.0	105.0
17	0.10	2.4	2.21	192	10.0	1.0	92.0	88.0	88.0
18	0.22	2.9	2.19	193	10.9	1.0	92.0	96.0	85.0
19	0.10	4.1	2.17	44	10.9	1.0	92.0	78.0	87.0

Sample No.	M.C (%)	L.O.I (%)	Density (g/cm^3)	Difference of Initial Setting Time (min)	Fineness (%)	Soundness (%)	Water Requirement (%)	Strength Activity Index (%)	
								28 days	90 days
20	0.12	4.7	2.17	35	9.8	1.0	92.0	83.0	86.0
21	0.08	2.5	2.17	25	9.5	1.0	92.0	83.0	86.0
22	0.10	3.7	2.18	33	9.3	1.0	92.0	78.0	86.0
23	0.14	2.9	2.14	32	8.0	0.5	92.0	89.0	91.0
24	0.08	3.1	2.24	45	14.4	1.0	92.0	81.0	93.0
25	0.10	3.6	2.26	31	13.2	1.0	92.0	90.0	87.0
26	0.12	3.5	2.26	31	13.6	1.0	92.0	90.0	87.0
27	0.14	3.1	2.26	35	8.1	1.0	92.0	84.0	102.0
28	0.10	2.7	2.23	32	10.4	1.5	92.0	83.0	92.0
29	0.12	2.6	2.28	34	11.5	1.5	92.0	89.0	90.0
30	0.16	2.1	2.26	34	10.7	1.0	92.0	75.0	96.0
31	0.08	2.1	2.29	31	11.3	1.5	92.0	91.0	85.0
32	0.12	2.5	2.27	33	1.3	1.5	92.0	88.0	104.0
33	1.40	3.1	2.29	33	9.4	1.0	92.0	88.0	95.0
34	0.10	3.1	2.25	31	11.1	1.5	92.0	82.0	93.0
35	0.14	2.5	2.27	23	11.0	1.5	92.0	79.0	93.0
36	0.14	2.0	2.26	35	10.4	1.5	92.0	100.0	111.0
37	0.10	2.6	2.27	32	11.2	1.5	92.0	85.0	91.0
38	0.08	1.9	2.28	35	11.1	1.5	92.0	83.0	97.0
39	0.02	2.3	2.28	27	10.3	1.0	92.0	94.0	97.0
40	0.04	1.7	2.29	29	8.8	0.5	92.0	86.0	103.0
41	0.06	1.7	2.21	31	10.1	1.5	92.0	96.0	94.0
42	0.16	1.2	2.17	26	10.5	1.0	92.0	90.0	105.0
43	0.06	2.8	2.26	30	10.2	1.0	92.0	91.0	86.0
44	0.14	1.8	2.30	27	10.5	1.5	92.0	95.0	100.0
45	0.06	1.9	2.31	22	10.7	1.0	92.0	89.0	99.0
46	0.10	1.5	2.29	27	10.6	1.0	92.0	108.0	103.0
47	0.16	1.7	2.32	30	10.1	1.5	92.0	106.0	109.0
48	0.14	1.5	2.26	28	10.5	1.0	92.0	97.0	106.0
49	0.12	1.5	2.33	27	10.3	0.5	92.0	83.0	91.0
50	0.10	1.3	2.30	33	12.1	1.0	92.0	94.0	97.0
51	0.14	1.9	2.26	21	10.5	0.5	92.0	94.0	97.0
52	0.18	1.1	2.15	28	10.7	1.0	92.0	90.0	89.0
53	0.10	1.0	2.16	27	10.3	0.5	92.0	100.0	101.0

Sample No.	M.C (%)	L.O.I (%)	Density (g/cm^3)	Difference of Initial Setting Time (min)	Fineness (%)	Soundness (%)	Water Requirement (%)	Strength Activity Index (%)	
								28 days	90 days
54	0.14	2.2	2.26	33	9.8	0.5	92.0	86.0	101.0
55	0.10	1.7	2.25	29	7.6	1.0	92.0	89.0	104.0
56	0.12	1.1	2.26	24	5.4	0.5	92.0	89.0	104.0
57	0.12	1.6	2.26	37	10.2	0.5	92.0	90.0	97.0
58	0.14	1.9	2.31	35	10.2	0.5	92.0	101.0	92.0
59	0.08	1.6	0.29	28	9.4	1.0	92.0	89.0	106.0

In table (4.12) was shown that all results were acceptable according to the standards.

4.6 Retarder

Increases workability time by delaying the hydration (setting). Dosage: undiluted 0.2 - 0.6 % of cement content.

4.7 Proportioning, Mixing and Casting of Specimens

There is no empirical method available for proportioning high strength concrete. The procedure to get the proportions in this study is the approach that recommended in ACI 211.4R-08[1], by starting with mixture proportion that has been used successfully on other projects with similar requirements. Given this starting point, trial mixtures were made in the laboratory and under field conditions to verify performance with actual project materials this are presented in **Table 4-15**. Hundreds of trial batches were performed in the laboratory and several adjustments were carried out in order to identify the optimum proportions. The final

Optimum and best trials used in the construction will finalize a according to statistical approach was described in ACI 211.4R-08 and the concrete components cost shown presented in **Table 4-14: Physical and chemical properties of Fly Ash**. A concrete fixed mixer with capacity of 60 dm^3 was used, the mixes from **Table 4-15** were scaled down depending on number of molds for different tests, and the mixer was buttered by mixing amount of cement, sand with water because it is difficult to recover all the mortar from the mixer. The mortar adhering to the mixer after discharging is intended to compensate for loss of mortar from the test batch. The following steps were to mix each batch; all the mixing ingredients, including the mixtures, were scaled down and weight out. The coarse and fine aggregates, cement and other cementitous materials were added to the mixer. The mixer rotated for 2 minutes (dry mixing). Superplasticizer was dispersed in about 2/3 of water before added to the mixer and started rotated the mixer again for 2 minutes. The mixer was shut off about 1 minute to let the aggregate absorb some of the paste, the aggregates were approximately in saturated surface dry condition (SSD) at the time the batch was prepared. The aggregates were sprayed with water and covered by burlaps for at least 24 hours.

4.8 Curing and Testing of Specimens

Lime saturated-water curing method was used in this study. After mixing, a portion of the fresh concrete was placed for fresh concrete properties determination. Flow was measured according to specifications. Precautions were taken to keep the flow between 48 and 53 cm to obtain pumpable concrete for dam construction. Concrete casting was performed according to BS EN 12390-1:2000. Molds were covered to prevent loss of water from evaporation. Specimens were kept for 24 hours in molds at a temperature of about 22 C in casting room, and then cured for the specified time at approximately 22 C ± 2 C. The specimens were tested in dry state for compressive strengths, determination of length change of hardened concrete-drying shrinkage tests in accordance with BS EN 12390-2:2000[12], ASTM C-157 M respectively.

4.9 Step-by-Step Procedure For Proportioning a High Strength Concrete Mixture for Concrete Dam in SI Units

Here by, we present a step-by-step procedure to produce a high strength concrete in a simple case, but in the complex mixes statistical approach is essential.

1- A review of the specifications develops the following requirements:

- Design compressive strength of 85 MPa at 28 days.
- No exposure to freezing and thawing.

2-Discussions with the contractor develop the following additional requirements:

- Maximum size of coarse aggregate is 16 mm.
- Desired flow is 48 to 53 cm.
- Concrete will primarily be placed by pump.

3-From historical experience select the high-strength mixture as being a good starting mixture. This mixture has characteristics shown in **Table 4-15**.

Table 4-15: Trial mixes which had been testing in DCUAP for HSC

Test No.	Cement (kg/m^3)	Silica-Fume Type KD-12 (kg/m^3)	Fly Ash (kg/m^3)	Superplasticizer Type PCA(I) (kg/m^3)	Sand (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
1	480	48.0	72.0	9.600	647	893	180
2	440	44.0	66.0	8.800	674	931	165
3	432	43.0	65.0	10.800	680	938	162
4	457	45.5	68.5	11.420	667	922	160
5	512	51.0	77.0	12.800	623	897	160
6	429	42.0	65.0	8.567	670	964	150
7	471	47.0	71.0	9.424	642	924	165
8	560	56.0	84.0	11.200	578	867	175
9	486	49.0	72.0	9.712	633	910	170
10	560	56.0	84.0	11.200	578	867	175
11	486	49.0	72.0	9.712	633	910	170
12	471	47.0	71.0	9.430	638	957	165
13	471	59.0	59.0	9.430	638	957	165
14	471	53.0	79.0	10.560	580	946	165
15	496	50.0	74.0	9.920	599	977	155
16	500	50.0	75.0	11.250	599	977	150
17	480	48.0	72.0	12.000	564	1047	150
18	500	50.0	75.0	12.500	555	1030	150
19	500	50.0	75.0	12.500	555	1030	150
20	500	50.0	75.0	12.500	576	1069	150

Test No.	Cement (kg/m^3)	Silica-Fume Type KD-12 (kg/m^3)	Fly Ash (kg/m^3)	Superplasticizer Type PCA(I) (kg/m^3)	Sand (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
21	500	50.0	75.0	12.500	576	1069	150
22	528	52.0	0.0	11.600	539	1102	145

Note: See the appendix for more information.

From table 4-16 It was very difficult to get compressive strength after 28 days more than 85 MPa with optimum cost from the first trial so that you need to prepare many mixes and select the better.

4-Assume that 1.5% will be entrapped in this mixture.

5-Don’t forget the following:

- Control silica fume dispersion.
- Carefully control and account for moisture on the aggregates
- Mix thoroughly
- Conduct necessary testing on fresh and hardened concrete
- Adjust mixture as necessary to obtain the properties that are required.

6-Once satisfied with the results of the laboratory testing program, conduct production-scale testing.

Consider these points:

- Use large enough batches to be representative
- Test more than once
- Work with the contractor to conduct placing and finishing trials as required.

4.6 Statistical Approach for Complex Mixtures

4.10.1 Statistical Approach for Complex -ACI 211.4R-08

For projects with complex requirements and where Portland cement and silica fume may be used in conjunction with either fly ash or slag, development of mixture proportions in the laboratory may entail making a very large number of trial mixtures. Even with a large number of batches, the optimum mixture, in terms of best performance at the least cost, may not be found.

In such a case, it may be better to use a statistical approach to mixture development. In essence, this approach consists of six steps:

1. Determine the range of variables to be tested. For example, a set of variables could include a range of w/cm, a range of Portland cement contents, a range of Portland cement substitution by fly ash, and a range of silica fume contents.

Table 4-17: Range of variables mixtures component

Component	ID	Minimum	Maximum
Water/Cement Ratio	x1	0.19	0.30
Silica Fume Type KD-12	x2	50	126
Fly Ash Type F	x3	0	83
Superplasticizer Type PCA(I)	x4	7.77	13.44
Fine Aggregate	x5	268	704
Coarse Aggregate	x6	991	1235

2. Develop a suitable set of mixtures to be prepared to evaluate the various ranges define above.

Table 4-18: The approved mixes of HSC that had been used in DCUAP

Mix No.	Cement	Aggregate		Silica Fume	Fly Ash	Superplasticizer	W/C	Compressive Strength for 28 days
		Fine	Coarse					

	(kg/m^3)	(kg/m^3)	(kg/m^3)	kg)		(litre)		(MPa)
PAC-1-31	496	567	1008	0	74	9.92	0.25	86.7
PAC-1-8	453	644	1006	4	55	5.52	0.25	91.1

Note: The range of flow test is (48-53) cm.

3. Make the concrete mixtures in the laboratory and determine the fresh and hardened concrete properties of interest. See **Table 4-15** and more details in Appendix A.
4. Review the test data to determine the concrete mixture that will best meet the requirements of the project at the least cost. This can be considered the optimum concrete mixture.
5. Confirm the performance of the optimum mixture in the laboratory. In all likelihood, this exact mixture will not have been prepared during the testing phase.
6. Move on to production-scale testing.

Table 4-19: The result of hardened concrete properties Ave Compressive Strength (MPa) for 7 days, Ave Compressive Strength (MPa) for 28 days that had been testing in DCUAP

No.	Ave Compressive Strength (MPa)	
	for 7 days	for 28 days
1	60.1	87.7
2	68.8	86
3	64.2	86.6
4	69.6	90
5	77.4	95.2
6	63.8	62.8
7	66.7	83.8
8	70.2	84.8
9	64.3	78.99
10	69.7	75.8
11	62.6	78.9
12	48.1	90.4
13	51.2	79.1
14	59.0	82.8
15	68.8	87
16	64	80
17	55.9	69.2
18	59.3	72

No.	Ave Compressive Strength (MPa)	
	for 7 days	for 28 days
19	60.9	74.8
20	59.3	75.8
21	60.6	77.1
22	54.4	91.3

Note:

- The range of slump test (150-200) cm.
- The highlighted trials were failed according to results of compressive strength after 28 days.

Table 4-20: The results of fresh concrete with properties of trails mixes that had been testing in DCUAP

Mix No.	Cement (kg/m^3)	Aggregate		Silica Fume (kg)	Fly Ash	Superplasticizer (litre)	W/C	Slump (mm)
		Fine (kg/m^3)	Coarse (kg/m^3)					
1	480	647	893	9.6	72	48	0.3	228
2	440	647	931	8.8	66	44	0.3	175
3	432	680	938	10.8	65	43	0.3	212
4	457	667	922	11.42	68	45.5	0.28	210
5	512	632	897	12.8	77	51	0.25	215
6	429	670	964	8.576	65	43	0.35	104
7	471	642	924	9.424	71	47	0.25	155
8	560	578	867	11.2	84	56	0.25	215
9	486	633	910	9.712	72	48	0.25	210
10	560	578	867	11.2	84	65	0.25	195
11	486	633	910	9.712	72	49	0.25	190
12	471	638	957	9.43	71	47	0.28	205
13	471	638	957	9.43	59	59	0.28	203
14	471	580	946	10.56	79	53	0.25	195
15	496	599	977	9.92	74	50	0.25	155
16	500	599	977	11.25	75	50	0.24	142
17	480	564	1047	12.0	72	48	0.25	204
18	500	555	1030	12.5	75	50	0.24	184
19	500	555	1030	12.5	75	50	0.24	150
20	500	579	1069	12.5	75	50	0.24	220
21	500	576	1069	12.5	75	50	0.24	210

22	528	593	1102	11.6	0.0	52	0.25	212

Note:

- The range of slump test (150-200) cm.
- The highlighted trials were failed according to the range of slump test.

Table 4-17 was shown that:

1. We have 22 trials mixes designs by using basalt aggregate Which available at DCUAP site, the minimum compressive strength for 28 days is 62.8(MPa), the maximum once up to 95.2 (MPa), this means that we achieved the desired aim to produce high strength concrete.
2. The design slump range is (150~200mm) the results which were obtained above the minimum limit, minimum slump =104mm, but we had 12 test exceed the maximum limit slightly.
3. From two points above we are satisfy hardened properties and fresh properties for high strength concrete.
4. The relationship between compressive strength 28 days (MPa) and w/cm ratio is strong inverse relationship in an inverse relationship, when one quantity increases the other decreases. For example, when w/cm ratio is increased, the compressive strength decreases.
5. The relationship between compressive strength 28 days (MPa) and Silica fume is direct relationship both physical quantities may increase or decrease simultaneously.
6. The relationship between compressive strength 28 days (MPa) and fly ash type (F) is inverse relationship, because fly ash type (F) is effect in direct relationship when the age of concrete reach 90 days and above but in 28 days there are no positive effect.
7. The relationship between compressive strength 28 days (MPa) and Superplasticizer type PCA (I) is inverse relationship.
8. The relationship between compressive strength 28 days (MPa) and fine aggregate is inverse relationship.

9. The relationship between compressive strength 28 days (MPa) and coarse aggregate is strong direct relationship. That means the local aggregate is main factor in produce high strength concrete.
10. The relationship between compressive strength 28 days (MPa) and compressive strength for 7 days is strong direct relationship.

Table 4-21: The result of hardened concrete properties Ave Compressive Strength (MPa) for 7days, Ave Compressive Strength (MPa) for 28days that had been casting by mix no PAC-1-31

Sample No.	Class	Mix No.	Sample Date	Compressive Strength (MPa)		Quantity (m^3)
				7 days	28 days	
C-SW-A-579	C70/85	PAC-1-31	26-Oct-12	58.2	80.8	20.5
C-SW-A-580			26-Oct-12	64.2	72.6	
C-SW-A-587	C70/85	PAC-1-31	29-Oct-12	59.2	80.4	36
C-SW-A-588			30-Oct-12	52.8	80.1	
C-SW-A-613	C70/85	PAC-1-31	9-Nov-12		76.3	140
C-SW-A-614			9-Nov-12		73.0	
C-SW-A-615			9-Nov-12	48.8	76.5	
C-SW-A-616			9-Nov-12	51.7	72.3	
C-SW-A-617			9-Nov-12	54.8	72.5	
C-SW-A-618			9-Nov-12	58.0	74.7	
C-SW-A-619			9-Nov-12	59.5	78.3	
C-SW-A-630	C70/85	PAC-1-31	14-Nov-12	55.2	75.3	19
C-SW-A-637	C70/85	PAC-1-31	16-Nov-12	59.5	86.4	137
C-SW-A-638			16-Nov-12	67.1	84.5	
C-SW-A-639			16-Nov-12	60.7	94.3	
C-SW-A-646	C70/85	PAC-1-31	22/11/2012	70.4	84.5	8
C-SW-A-647			22/11/2012	68.1	85.3	
C-SW-A-648	C70/85	PAC-1-31	23/11/2012	66.4	89.9	76
C-SW-A-654	C70/85	PAC-1-31	25/11/2012	64.3	87.9	40
C-SW-A-690	C70/85	PAC-1-31	06/12/2012	69.3	80.9	194.5
C-SW-A-691	C70/85	PAC-1-31	06/12/2012	57.3	82.1	6
C-SW-A-693	C70/85	PAC-1-31	06/12/2012	64.4	83.3	194.5
C-SW-A-695	C70/85	PAC-1-31	08/12/2012	60.1	79.1	17.5

Sample No.	Class	Mix No.	Sample Date	Compressive Strength (MPa)		Quantity (m^3)
				7 days	28 days	
C-SW-A-724	C70/85	PAC-1-31	14/12/2013	60.4	91.2	41.5
C-SW-A-728	C70/85	PAC-1-31	16/12/2013	84.1	96.8	41.5
C-SW-A-739	C70/85	PAC-1-31	17/12/2013	70.9	94.6	390
C-SW-A-740			17/12/2013	68.5	86.0	
C-SW-A-741	C70/85	PAC-1-31	18/12/2013	77.2	98.7	23
C-SW-A-768	C70/85	PAC-1-31	23/12/2013	67.5	84.2	48
C-SW-A-771	C70/85	PAC-1-31	24/12/2013	84.4	95.8	84.5
C-SW-A-786	C70/85	PAC-1-31	30/12/2013	64.0	86.2	21
C-SW-A-806	C70/85	PAC-1-31	05/01/2013	72.0	89.2	231.5
C-SW-A-807	C70/85	PAC-1-31	05/01/2013	62.0	101.4	24
C-SW-A-816-2	C70/85	PAC-1-31	10/01/2013	73.3	88.4	69
C-SW-A-817-1	C70/85	PAC-1-31	10/01/2013	77.3	96.7	30
C-SW-A-819-2	C70/85	PAC-1-31	12/01/2013	67.2	87.1	22
C-SW-A-820-1	C70/85	PAC-1-31	13/01/2013	64.9	82.8	50.5
C-SW-A-825-2	C70/85	PAC-1-31	15/01/2013	26.8	80.3	19.5
C-SW-A-826-1	C70/85	PAC-1-31	16/01/2013	70.5	72.7	56
C-SW-A-829	C70/85	PAC-1-31	18/01/2013	63.9	86.6	27
C-SW-A-830	C70/85	PAC-1-31	18/01/2013	69.1	88.6	145.5
C-SW-A-834	C70/85	PAC-1-31	19/01/2013	66.3	83.6	24
C-SW-A-835	C70/85	PAC-1-31	19/01/2013	70.0	86.0	190
C-SW-A-842	C70/85	PAC-1-31	23/01/2013	73.0	88.6	89.5
C-SW-A-845	C70/85	PAC-1-31	26/01/2013	70.4	88.3	83
C-SW-A-850	C70/85	PAC-1-31	27-Jan-13	66.3	87.8	27
C-SW-A-851	C70/85	PAC-1-31	27-Jan-13	64.1	82.1	20
C-SW-A-853	C70/85	PAC-1-31	27-Jan-13	70.0	88.0	74
C-SW-A-856	C70/85	PAC-1-31	28-Jan-13	71.6	91.3	20
C-SW-A-866	C70/85	PAC-1-31	1-Feb-13	63.0	93.6	74
C-SW-A-868	C70/85	PAC-1-31	1-Feb-13	64.8	88.1	54
C-SW-A-874	C70/85	PAC-1-31	3-Feb-13	67.9	85.0	93
C-SW-A-879	C70/85	PAC-1-31	4-Feb-13	68.2	86.7	105
C-SW-A-881	C70/85	PAC-1-31	4-Feb-13	63.6	87.3	90
C-SW-A-882	C70/85	PAC-1-31	5-Feb-13	56.7	86.8	224.5
C-SW-A-884-1	C70/85	PAC-1-31	6-Feb-13	59.5	84.3	433.5
C-SW-A-884-2			6-Feb-13	47.5	96.0	
C-SW-A-893-1	C70/85	PAC-1-31	17-Feb-13	70.8	85.7	65
C-SW-A-901	C70/85	PAC-1-31	22-Feb-13	73.5	84.7	314
C-SW-A-909	C70/85	PAC-1-31	5-Mar-13	73.9	86.3	30.5

Sample No.	Class	Mix No.	Sample Date	Compressive Strength (MPa) 7 days	Compressive Strength (MPa) 28 days	Quantity (m^3)
C-SW-A-916	C70/85	PAC-1-31	7-Mar-13	66.6	85.9	12
C-SW-A-919	C70/85	PAC-1-31	9-Mar-13	67.2	93.3	29.5
C-SW-A-921	C70/85	PAC-1-31	10-Mar-13	76.4	95.6	161
C-SW-A-924	C70/85	PAC-1-31	11-Mar-13	62.1	86.0	12
C-SW-A-925	C70/85	PAC-1-31	14-Mar-13	64.8	90.0	237.5
C-SW-A-928	C70/85	PAC-1-31	18-Mar-13	67.8	89.3	50
C-SW-A-930	C70/85	PAC-1-31	18-Mar-13	74.1	91.6	192
C-SW-A-932	C70/85	PAC-1-31	18-Mar-13	68.2	91.8	121
C-SW-A-941	C70/85	PAC-1-31	22-Mar-13		95.6	8.5
C-SW-A-954	C70/85	PAC-1-31	26-Mar-13	64.6	86.9	184
C-SW-A-965	C70/85	PAC-1-31	4-Apr-13	72.5	89.0	139
C-SW-A-976	C70/85	PAC-1-31	14-Apr-13	67.6	87.5	89
C-SW-A-989	C70/85	PAC-1-31	27-Apr-13	62.9	89.1	276
C-SW-A-991	C70/85	PAC-1-31	28-Apr-13	74.9	89.0	154.5
C-SW-A-993	C70/85	PAC-1-31	28-Apr-13	61.8	88.6	316
C-SW-A-999	C70/85	PAC-1-31	2-May-13	66.4	89.8	132.5
C-SW-A-1002-1	C70/85	PAC-1-31	2-May-13	61.3	88.4	393
C-SW-A-1002-2			2-May-13	64.3	87.4	
C-SW-A-1015	C70/85	PAC-1-31	8-May-13	74.0	88.6	192
C-SW-A-1017	C70/85	PAC-1-31	9-May-13	65.4	89.5	122
C-SW-A-1018	C70/85	PAC-1-31	10-May-13	61.5	88.9	123
C-SW-A-1021	C70/85	PAC-1-31	12-May-13	61.8	86.3	42
C-SW-A-1027	C70/85	PAC-1-31	13-May-13	65.2	87.0	2
C-SW-A-1267	C70/85	PAC-1-31	8-Feb-14	69.9	90.6	89.5
C-SW-A-1275	C70/85	PAC-1-31	24-Feb-14	76.0	97.4	31
C-SW-A-1329	C70/85	PAC-1-31	16-Jun-14	65.5	93.8	83
C-SW-A-1341	C70/85	PAC-1-31	17-Oct-14	33.0	91.8	227.1
C-SW-A-1344	C70/85	PAC-1-31	2-Nov-14	73.2	89.8	70.5
C-SW-A-1364	C70/85	PAC-1-31	3-Jan-15	70.7	88.3	29

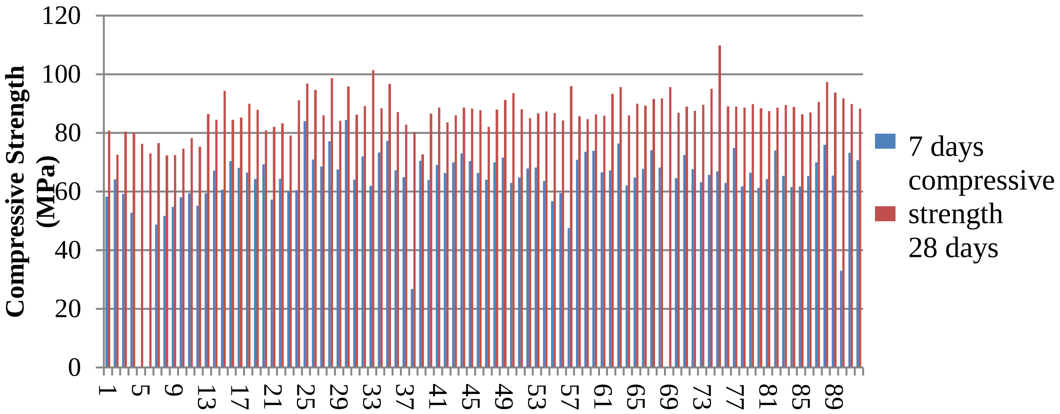

Chart 4-4: Relationship between 28 days compressive strength and 7 days compressive strength for PAC-1-31

Results discussion:

1. From **Table 4-19** we can find that the minimum compressive strength for 28 days is 72.3 MPa and the maximum compressive strength for 28days for granite is 101.4 MPa, also we can find the minimum compressive strength for 7 days is 26.8 MPa and the maximum compressive strength for 7 days for granite is 84.4 MPa.
2. From **Table 4-18** we can find that the optimum w/cm ratio used was 0.25 because it has strong inverse relationship with compressive strength, when w/c ratio is increased, the compressive strength decreases.
3. Cement Content: In order to produce high strength concrete, higher cement contents than for normal strength concrete must be used, the cement content of concrete mixes made in this mix is 496 kg/m^3.
4. Water/Cement Ratio: Lower water/cement ratios are required for producing high strength concrete than for producing normal strength concrete which is 0.25.
5. Coarse aggregate Gradation: The effect of the gradation of the coarse aggregate on the compressive strength of high strength concrete is directly related to the effect of the gradation on the mixing water requirement for a given flow.

Table 4-22: The result of hardened concrete properties Ave Compressive Strength (MPa) for 7 days, Ave Compressive Strength (MPa) for 28 days that had been casting by mix no PAC-1-8

Sample No.	Class	Mix No.	Sample Date	Compressive Strength (MPa)		Quantity (m^3)
				7 days	28 days	
C-SW-A-979	C70/85	PAC-1-8	19-Apr-13	63.2	89.6	200
C-SW-A-981-1	C70/85	PAC-1-8	19-Apr-13	65.7	95.1	493
C-SW-A-981.2			20-Apr-13	66.9	109.8	

6. From **Table 4-20** we can find that the minimum compressive strength for 28 days is 89.6 MPa and the maximum compressive strength for 28 days for granite is 109.8 MPa and maximum, also we can find the minimum compressive strength for 7 days is 63.2 MPa and the maximum compressive strength for 7 days for granite is 66.9 MPa.
7. From **Table 4-18** we can find that the optimum w/cm ratio used was 0.25 because it has strong inverse relationship with compressive strength, when w/cm ratio is increased, the compressive strength decreases.
8. Cement Content In order to produce high strength concrete, higher cement contents than for normal strength concrete must be used, the cement content of concrete mixes made in this mix is 453 kg/m^3.
9. Water/Cement Ratio Lower water/cement ratios are required for producing high strength concrete than for producing normal strength concrete which is 0.25.

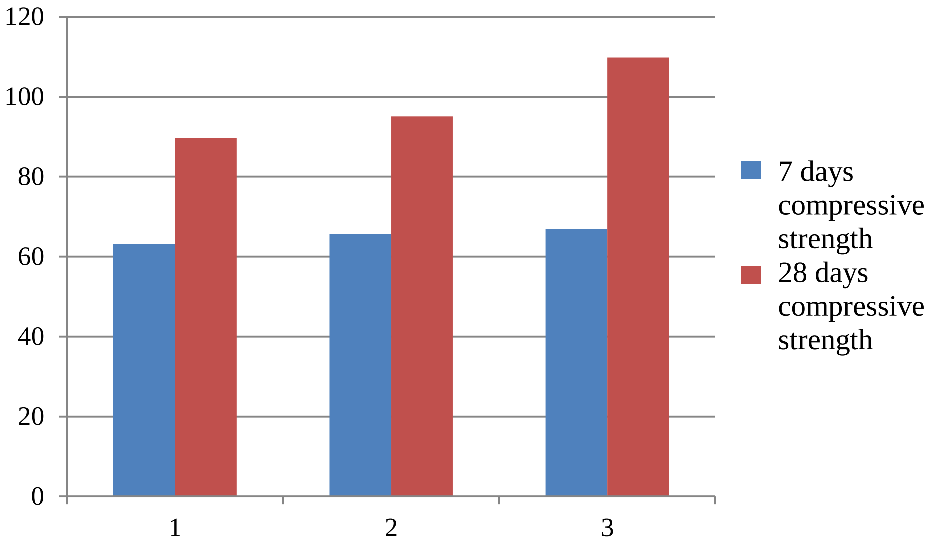

Chart 4-5: Relationship between 28 days compressive strength and 7 days compressive strength for PAC-1-8

Table 4-23: Review the main relationships between the two mixes

Comparison View	Mix No. PAC-1-31	Mix No. PAC-1-8
The maximum compressive strength for 7 days (MPa)	84.4	66.9
The minimum compressive strength for 7 days (MPa)	26.8	63.2
The maximum compressive strength for 7 days (MPa)	101.4	109.8
The minimum compressive strength for 7 days (MPa)	72.3	89.6
Cement (kg/m^3)	496	453
Fly Ash (kg/m^3)	74	55
Superplasticizer (kg/m^3)	9.92	5.52
Silica fume (kg/m^3)	50	44
Fine aggregate (kg/m^3)	567	644
Course aggregate (kg/m^3)	1008	1006
w/c	0.25	0.25

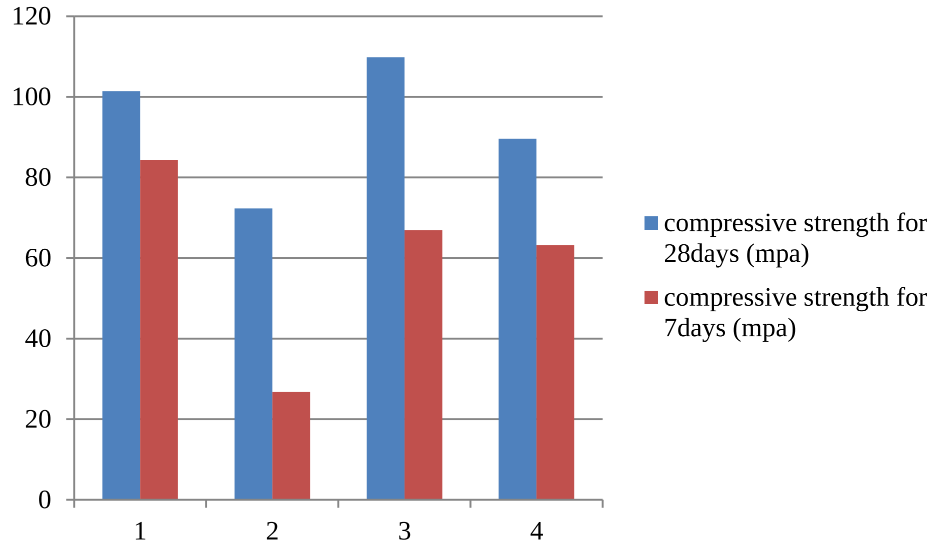

Chart 4-6: The relationship between 7 days compressive strength & 28 days compressive strength for two mixes

From **Table 4-21** with same w/c the dosage of superplactisizer for the first mix was more than the second mix because the quantity of fine aggregate is less than first mix.

Table 4-24: Relationship between the course aggregate and the maximum strength

Coarse Aggregate	Maximum Strength
1008	101.4
1006	109.8

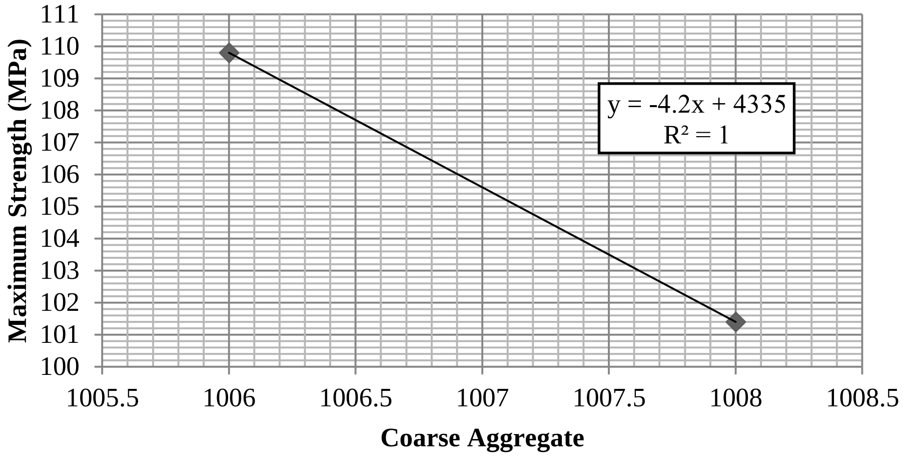

Chart 4-7: Relationship between the course aggregate and the maximum strength

From **Table 4-22** found that when we increase the amount of course aggregate the maximum strength was increases with in the allowable limits.

Table 4-25: Relationship between fine aggregate and minimum strength

Fine Aggregate	Minimum Strength
567	72.3
644	89.6

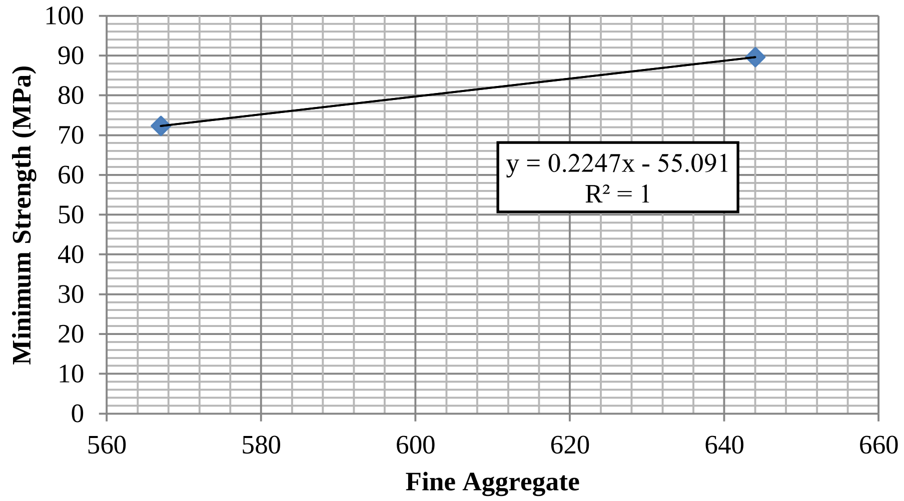

Chart 4-8: Relationship between fine aggregate and minimum strength

From Chart 4-8 it was found that when we increase the amount of fine aggregate the strength increases.

Table 4-26: Relationship between maximum strength and superplasticizer

Superplasticizer	Maximum Strength
9.92	101.4
5.52	109.8

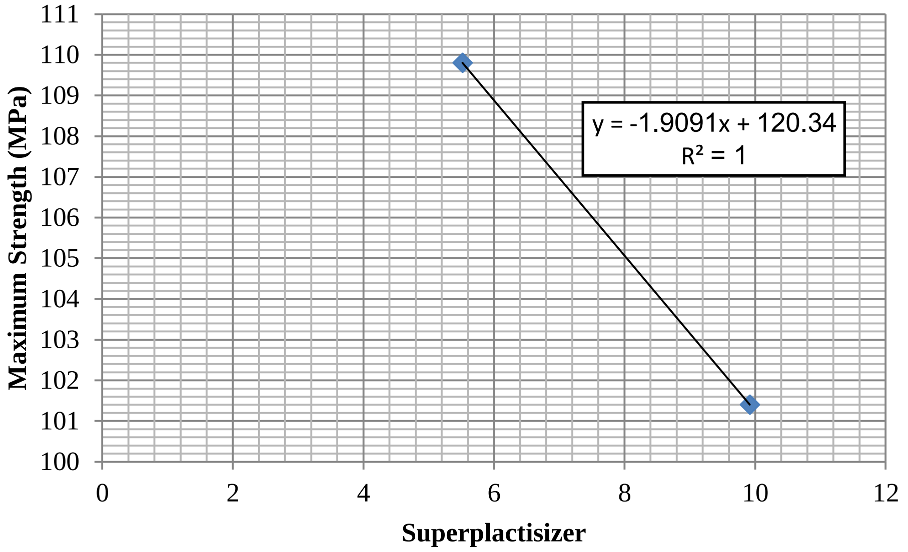

Chart 4-9: Relationship between maximum strength and superplasticizer

From Chart 4-9 the compressive strength was decreased because the dosage of Superplasticizer was increases (opposite result of Superplasticizer).

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

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CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the findings of this study the following conclusions were made:

1. If we are using local aggregate with supplementary materials (silica fume and fly ash) and ordinary Portland cement with their optimum proportioning can be successfully used with other chemical admixtures (Super-plasticizer) to produce high strength concrete.
2. The results of the present investigation indicated that the maximum compressive strength occurred at about 8% Silica fume content.
3. The present study shows that the maximum values of compressive strength for different grades were obtained at water-cementitious materials ratios is 0.25.
4. Compressive strength of concrete increases as superplasticizer dosage increases, up to a dosage which causes a concrete mix to become segregated and unworkable. The addition of too much superplasticizer to a high strength concrete mix may result in significant retardation of concrete hardening. The brand of superplasticizer used affect both the workability and the compressive strength of high strength concrete
5. High strength concrete with compressive strength as high 85N/mm² can be obtained using OPC by using lower water-cement Ratio along with superplasticizer is the most vital factor to be considered in HSC productions.

5.2 Recommendations

5.2.1 Recommendations from the Study

1. Recommended that to use the local crushed aggregate (basalt) in high strength concrete in Sudan.
2. The cement and other ingredients quality must be checked by Appling the required tests.

3. Washing course aggregate to increase the concrete strength and not recommended to wash sand because it is difficult practically unless in super construction.
4. Mixing water should be pure and avuncular from any impurities.
5. Operate the cooling system of patching plant before enough time from casting.
6. Select ideal methods of curing (chemical curing) to get HSC.
7. Make sure these (admixtures) before usages are powerful and efficient to actualize the expected consequences.
8. Temperature degree of HSC should be less than 22C.

5.2.2 Recommendations for Further Studies

1. Consideration of harm full effect of use of supplementary materials in special case.
2. Decrease the amount of additives as possible to avoid negative impacts.
3. Regards to cost consideration, try to reduce Silica fume content and Super-plasticizer or replace it by others local materials if available.

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APPENDICIES

Appendix A

Concrete Compressive Strength and Slump Test Results for Trial Mixes