Sudan University of Science and Technology
College of Graduate Studies

THE EVALUATION OF STEEL SLAG EFFECT ON THE COMPRESSIVE STRENGTH OF CONCRETE

تقييم أثر خبث الحديد على مقاومة انضغاط الخرسانة

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By: Ammar Mohamed AL Hassan Osman
Supervise by Dr: Nuha Moawia Akasha

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الآية

(رَّبِّ اغْفِرْ لِي وَلِوَالِدَيَّ وَلِمَن دَخَلَ بَيْتِيَ مُؤْمِنًا وَلِلْمُؤْمِنِينَ وَالْمُؤْمِنَاتِ
وَلَا تَزِدِ الظَّالِمِينَ إِلَّا تَبَارًا)

سورة نوح الاية (28)

Dedication

This research is dedicated to:

My father

My mother

My family

Acknowledgment

First and foremost, thank Allah for endowing me with health, and knowledge me to complete this work.

A lot of thank are due to my colleagues who were provided me with a high of information.

Also we really thank Dr.Nuha Moawia Akasha for their very helpful guides and comments.

Abstract

This study was conducted to test the possibility of benefiting from the blast furnaces slag resulting from the production of steel at Giad Factory south of the city of Khartoum –Sudan. The study aimed to determine the effect of partially replacing some of the concrete mix components with steel slag to study the effect on the compressive strength and workability of the concrete mixture.

A mix design was prepared for standard according to the British and US by using another mixes where the slag replaced by (10-20-30-40) % of the cement weight. The concrete mixes were designed according to these percentages and were tested for workability by the slump of fresh concrete and the hardened concrete was tested for compressive strength after (7-28) days. When replacing the slag with varying percentages of the cement weight the results show an increase in workability with the increase in the proportion of slag while noting that the compressive strength increased in (10-20) % replacement of slag and it gradually decreases with the increasing of proportion of slag. These results were acceptable and provide an evidence for the possibility of benefiting from the slag in concrete mixes. The study recommended conducting more tests such as test tensile strength.

المستخلص

هذه الدراسة أجريت لإختبار إمكانية الإستفادة من خبث افران صهر الحديد المنتج بمصنع جياد الواقع جنوب مدينة الخرطوم- السودان.الدراسة هدفت لتحديد أثر إحلال نسبة من مكونات الخلطة الخرسانية بالخبث لدراسة التأثير علي مقاومة الانضغاط و قابلية التشغيل. تم تصميم خلطات خرسانية مرجعية وفقاً للمواصفات البريطانية والامريكية ثم تم أحلال الخبث بنسب(10-20-30-40)% من وزن الأسمنت. تم تصميم الخلطات الخرسانية وفقا لهذه النسب ومن ثم تم قياس الهبوط للخرسانة الطازجة لكل العينات وكذلك مقاومة الانضغاط للخرسانة المتصلدة في (7-28) يوم. عند احلال الخبث بنسب متفاوتة من وزن الأسمنت أظهرت النتائج زيادة قابلية التشغيل مع زيادة نسبة الخبث بينما تلاحظ ان مقاومة الانضغاط زادت في (10-20)% من إحلال الخبث وتنقص تدريجيا كلما زادت نسبة الخبث.واعتبرت هذه النتائج مقبولة وتوفر دليلا لإمكانية الاستفادة من الخبث في الخلطات الخرسانية. أوصت الدراسة بإجراء مزيد من الاختبارات علي الخرسانة كإختبار الشد.

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CHAPTER ONE

INTRODUCTION

1.1 General Introduction

Concrete is one of the most common material and widely used in construction work. Concrete production is estimated to increase from about 10 billion tons in 1995, to nearly 16 billions tons in 2010 [E.Gjorv and Koji Sakai, 2004]. But such increase brings serious implications to the environmental.

The idea to take advantage of industrial waste, including material slag extend to long terms of leaving this waste without treatment leads to damage to the environment eloquent, where the amount of slag produced an estimated (1-0.3) tons per ton of pig iron output from the furnace blower. The fact oxides slag-forming oxides similar to the components of the cement with different proportions has sowed used with cement after treatment and grinding it to a high smoothness and called granulated slag powder of high-melting furnaces and symbolizes abbreviated(GGBFS).

Be malice on the two types, one slag furnace and high melting and the other slag steel produced by blast furnace slag arc electrode and It is the type used in the production of local slag depending on the iron user (scrap) in its production is in 1774 the first to use the slag with cement in the production of mortar each scored the first production of cement in 1892 in Germany and in the middle of the twentieth century became the slag smelting furnaces produce high single sources of the types of cement in the world. Where recognizes the quantity used in cement production by about 20% of the total produced in Europe, the amount of cement. It has reduced the cost of the cement industry and the cost of concrete production, as well as get rid of the manifestation of the pollution of the environment.

Most of these topics are discussed in this thesis with emphasis on the measurement and assessment of expansion properties; use in road, concrete and steel slag blended cement and setting up of various usability criteria related to these uses.

It is necessary to define two terms used in this thesis: steel slag and expansion property. Steel slag originates from steel producing furnaces.

The three main types, namely, basic oxygen, electric arc and open hearth. The production of steel slag prior to the 1960’s was generally conducted using open Hearth furnaces.

1.2 Problem Statement

Production of concrete may or may not require special materials, but it definitely requires materials of highest quality and their optimum proportions. The production of concrete that consistently meets requirements for workability and strength development places more stringent requirements on material selection than that for lower strength concrete.

Conformity of steel slag at physical and chemical specifications. In this research numbers of trial mixes have been considered, following the reviewed information, in order to achieve concretes compressive strengths required with replacing the steel slag with ratio from cement weight. The information obtained from literature as well as the results of experimental work described here in will be beneficial to researchers and engineers dealing with steel slag.

1.3 Objectives:

The objects of research summarized as follows:

1.Attempt to transfer the concepts of true and accurate information about constituent material for concrete mix and concrete itself and conform to standard specifications of concrete .

2. Study of the behavior of slag as local additives to detect its influence on the properties of concrete mixes.

3. Investigation of making use of slag to improve workability and compressive strength of concrete through which is reflect on other properties.

1.4 Methodology:

To achieve the above objectives the research uses the following methodology:

- Collect information on concrete mix and slag from the available references, internet and previous researches.
- take samples from grinding slag and carry out its physical and chemical tests.
- use ACI and British codes of concrete mix to make concrete cylinder and cubes , then change cement ratio by using slag in the concrete mix.
- Carry out slump tests and compressive strength tests to concrete cubes.
- Compare the results of concrete mix with slag to the results of basic concrete mix.

1.5 Hypothesises

What is steel slag?

What is the effect of steel slag on the properties of concrete?

What is the optimum dosage for partial replacement of cement by steel slag?

1.6 Research Outlines:

This thesis has been out lines as follow:-

Chapter one content the general introduction, problem statement, objectives, methodology of this research.

The basic characteristic of materials with special consideration to the factor effecting concrete strength, type of concrete accordance to different factor as general and previous study are discussed in chapter two.

Chapter three shows material making concrete proprieties, sources and manufacturing of cement, qualities and affections of compressive strength of concrete and materials selection and mix design procedures and proportions are discussed. The testing material procedure and steps cement testing, coarse aggregate testing and fine aggregate testing and mix design steps are discussed in chapter four. Presentation of the results of materials and concrete compressive strength tests for different mix proportions and compassion the results of aggregate using in concrete mix design are discussed in chapter five. The research conclusions with recommendations for future researches in chapter six.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Concrete is the most widely used material in the world. It plays an important role in infrastructure and private buildings construction. Understanding the basic behaviors of concrete is essential for civil engineering students to become civil engineering profession Concrete is a manmade building material that looks like stone. The word "concrete" is derived from the Latin concretus, meaning "to grow together." Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together. Alternatively, we can say that concrete is a composite material that consists essentially of a binding medium in which are embedded particles or fragments of aggregates. The simplest definition of concrete can be written as: (Concrete = filler + binder) Depending on what kind of binder is used, concrete can be named in different waysals. As a structural material, the compressive strength at an age of 28 days is the main design index for concrete. There are several reasons for choosing compressive strength as the representative index. First, concrete is used in a structure mainly to resist the compression force. Second, the measurement of compressive strength is relatively easier. Finally, it is thought that other properties of concrete can be related to its compressive strength through the microstructure. Pursuing high compressive strength has been an important direction of concrete development. As early as 1918, Duff Adams found that the compressive strength of a concrete was inversely proportional to the water-to-cement ratio. Hence, a high compressive strength could be achieved by reducing the w/c ratio. However, to keep a concrete workable, there is a minimum requirement on the amount of water; hence, the w/c ratio reduction is limited, unless other measures are provided to improve concrete's workability. For this reason, progress in achieving high compressive strength was very slow before the 1960s. At that time, concrete with a compressive strength of 30 MPa was regarded as high-strength concrete. Since the 1960s, the development of high-strength concrete has made significant progress due to two main factors: the invention of water-reducing admixtures and the incorporation of mineral admixtures, such as silica fume, fly ash, and slag.

2.2 Types of Concrete

2.2.1 Classification in accordance with unit weight

According to the unit weight of concretes, they can be classified into four categories shown Table (2.1). Ultra-lightweight concrete can only be used to build up nonstructural members. Lightweight concrete can be used to build both nonstructural and structural members, depending on its specified composition.

Table (2.1) Classification of concrete in accordance with unit weight

Classification	Unit weight kg/m^3
Ultra-light weight concrete	< 1200
Light weight concrete	1200< UW <1800
Normal- weight concrete	~ 2400
Heavy- weight concrete	>3200

2.2.2 Classification in accordance with compressive strength

According to its compressive strength, concrete can be classified into four categories, as listed in Table (2.2) Low-strength concrete is mainly used to construct mass concrete structures, subgrades of roads, and partitions. Moderate-strength concretes are the most commonly used concretes in buildings, bridges, and similar structures. High-strength concretes can be used to build tall building columns, bridge towers, and shear walls. Ultra-high-strength concretes have not yet been widely used in structural constructions. Only a few footbridges and some structural segments, such as girders, have been built using such concretes.

Table (2.2) Classification of concrete in accordance with compressive strength

Classification	Compressive strength(MPa)
Low- strength concrete	< 20
Moderate- strength concrete	20-50
High –strength concrete	50-150
Ultra-high- strength concrete	>150

2.2.3 Classification in accordance with additives

According to the materials other than cement, aggregate and water that are added into concrete mixtures as additives, concretes can be classified into different categories. Four examples are shown in Table (2.3) fiber-reinforced concrete (FRC) is a type of concrete with fibers incorporated. Many different fibers have been used to produce fiber-reinforced concrete, including steel, glass, polymerics, and carbon. The purpose of incorporating fibers into concrete includes toughness enhancement, tension property improvement, shrinkage control, and decoration. Macro-defect-free (MDF) is a cement based composite that incorporates a large amount of water-soluble polymer, produced in a twin-roll mixing process. It was developed to enhance the tensile and flexural properties of concrete. Concrete that has been densified with small particles. (DSP) has incorporated a large amount of silica fume, a mineral admixture with very small particles. DSP has excellent abrasion resistance and is mainly used to produce machine tools and industrial molds. Three methods have been developed to incorporate polymers into concrete: using the polymer as a binder, impregnating the polymer into normal Portland cement concrete members, and using the polymer as an admixture in ordinary Portland concrete.

Table (2.3) Concrete classification in accordance with additives

Classification	Additives
MDF	Polymers
Fiber- reinforced concrete	Different fibers
DSP concrete	Large amount of silica fume
Polymer concrete	Polymers

2.3 Previous Study

There were two case studies located in the United States that used the steel slag in an e concrete sub base pavement in Florida. The first case study was Interstate 75, which used the slag in an e concrete pavement in the late 1970’s and failed in part due to the expansion of an electric arc furnace steel slag (Armaghani et al., 1988). The second case study examined was the runway at Tampa International Airport, which resulted in the catastrophic failure of the concrete base and overlying pavement. It is unknown if the steel slag had been aged prior to its use in either of the concrete pavements. The weathering of steel slag in stockpiles did not begin in the United States until the mid to late 1980’s. There were several case studies located overseas, but these applications did not use the steel slag in traditional pavement applications.

The first international case study is the Labein-Tecnalia Kubik Building in Madrid Spain (Chica et al., 2011). The slag concrete was used in a structural application, which consisted of the basement walls and the reinforced foundation slab. The aggregates used in the construction of the basement floor slab and the walls consisted of 100% EAF slag for the fine and coarse aggregates. Two other case studies used a stainless steel slag as an aggregate in concrete. These case studies were both in Belgium, with one application as a sub base layer for a slag storage facility, and the other as a roller compacted concrete for a rural road (De Bock & VandenBergh,2004).The stainless steel slag that was used in both of the case studies originated from an electric arc furnace.

The final case study is a mixture called Ferroform and is comprised of GGBFS as a binding agent and steel slag as an aggregate, which has comparable mechanical properties as concrete. This material can be used to construct concrete blocks, natural stones, and concrete (Matsunaga et al., 2008). The Ferroform mixture is comprised of steel slag as the fine and coarse aggregate, GGBFS, fly ash and an alkali activator such as slaked lime and water. The Ferroform mixture has been used in Japan for the filling of a basement floor in 2003 and in the construction of blocks, which can be mass-produced in a manufacturing plant and are cured by steam. Ferroform blocks have also been used by Japan in the repair and construction of ports and harbor sea walls.

Ozeki (1997) reported that studies were carried out in Japan on the use of EAF slag aggregates in concrete. No additional details were provided and it was simply stated that the concrete strength and durability properties were similar between EAF and natural aggregates.

Ozkul (1996) created concrete mixtures with 100% EAF coarse aggregate and with natural sand or ladle furnace slag as the fine aggregate. The compressive and flexural strengths were similar for the two concretes, although the mix with natural sand had slightly higher compressive strengths, and, at later ages (at 28 days and 180 days), the concrete with ladle furnace slag fine aggregates had higher flexural strengths. The abrasion resistance of the concrete was improved with the slag fine aggregates. After 20 wetting/drying cycles, both concretes had about a 3% reduction in dynamic modulus. The volume expansion of the concretes after being stored in water for 180 days was similar to virgin aggregate concrete.

Papayianni and Anastasiou (2003) studied the effect of using steel slag aggregates as 100% replacements of coarse and/or fine aggregates in concrete, in combination with 30-60% replacements of cement with high calcium fly ash and 0-30% replacements of cement with ground granulated steel slag. The authors investigated the strength (compression, split tension, and flexure), modulus (static and dynamic), abrasion resistance, wet/dry durability, and outdoor exposure durability properties. However, because the w/cm ratio was not held constant for all concrete mixtures, it is difficult to definitively conclude the effects of the steel slag, although the concrete abrasion resistance improved with the inclusion of steel slag aggregates. The heavy metals present in the steel slag aggregate were not as susceptible to leaching once they were incorporated into the concrete.

Papayianni and Anastasiou (2005) utilized steel slag aggregates as coarse aggregates in a heavy-weight concrete application for radiation shielding. While the authors did not compare the findings with those of conventional concrete with virgin (natural) aggregates, they tested the effect of steel slag coarse aggregates on the concrete strength (compression, split tension, and flexure), modulus (static and dynamic), and fracture (Hillerborg's total fracture energy and impact fracture) properties. In testing for radiation shielding properties compared with conventional concrete, steel slag aggregate concretes had similar gamma ray attenuation in the energy region of ~1 MeV and better gamma ray attenuation in the energy region of 0.1 MeV, but had an increased secondary gamma ray production.

Papayianni and Anastasiou (2010a) examined the feasibility of using 100% coarse and 50% fine EAF slag aggregate in concrete with partial replacements of cement with either 30% ladle furnace slag or 50% high calcium fly ash. The concrete unit weight increased with the use of EAF slag aggregate. For concrete mixes with cement and with and without high calcium fly ash, the mixes with coarse EAF slag aggregate and with coarse and fine EAF slag aggregate had higher compressive, split tensile and flexural strengths compared with the control mix with limestone aggregates. The mix with coarse EAF slag aggregate and ladle furnace slag had similar strengths to the control mix. For concrete with plain cement, the mixes with coarse EAF slag aggregate and with coarse and fine EAF slag aggregate resulted in up to 27% higher total fracture energies compared with virgin aggregate concrete. Abrasion resistance improved with EAF slag aggregates, and the freeze/thaw durability was acceptable for all mixes except for those with the high calcium fly ash. The depth of water penetration under pressure was good for all mixes, indicating good impermeability, as was additionally evidenced by the low porosity of the concretes.

Wang (1988) utilized steel slag aggregates as partial and full replacements of fine aggregate in mortar and concrete samples. Mortar samples yielded higher compressive and flexural strengths with 100% steel slag aggregates compared with virgin sand. Additionally, concrete samples with partial and full replacements of fine aggregate with steel slag resulted in higher compressive and flexural strengths versus the control. The abrasion resistance of the concrete was reduced with increasing steel slag fine aggregate contents, although it is not clear if the test was performed on mortar or concrete samples. There is some evidence to support that the cement-aggregate bond is improved with the addition of steel slag fine aggregate, based on micro hardness results and a finding that there is a greater amount of hydration products within 50 μm of the interface between steel slag aggregate and cement versus limestone aggregate and cement. Using scanning electron microscopy, it was found that the interface within 20 μm of the paste-aggregate interface contained finer calcium hydroxide crystals and was denser for the steel slag aggregate compared with the limestone aggregate. The author postulated that the improved characteristics of the paste-aggregate interfacial zone were because of the reaction of the cement hydration products with ions from the mineral phases in the steel slag aggregate.

Wang (1992) examined 100% coarse aggregate replacements with BOF slag aggregate. Micro hardness tests revealed that the interfacial transition zone, about 25 μm away from the paste-aggregate interface, was harder for concrete with BOF aggregates compared with basalt aggregates, possibly because of the reaction of the BOF slag with cement. The compressive strength was higher for mixes with BOF coarse aggregate compared with basalt aggregate. The expansion of the samples soaked in water was the same for both BOF and basalt aggregates. Concrete samples were also subjected to a 100-minute autoclave test, which revealed that the samples remained volumetrically stable after the test.

In this research from the previous study I knew that the effect of aggregate type and size on Compressive strength of concrete how select to suitable types and size of aggregate with good specifications. and also the use of appropriate steel slag and grinding process to give the optimum mix, And the use of availability local materials to find the optimum mix proportions that to gives greater compressive strength value of concrete.

CHAPTER THREE
THEORETICAL STUDY

3.1 Introduction

Concrete is one of the most versatile and widely produced construction materials in the world [Penttala, 1997]. Its worldwide annual production exceeds 12 billion metric tons, i.e., more than two metric tons of concrete was produced each year for every person on earth in 2007. The ever-increasing population, living standards, and economic development lead to an increasing demand for infrastructure development and hence concrete materials. As a composite material, concrete is composed of different graded aggregates or fillers embedded in a hardened matrix of cementations material. The properties of major constituents of concrete mixtures, such as aggregates, cementations materials, admixtures, and water, should be understood first to better learn the properties and performance of concrete.

3.2 Material Making Concrete

3.2.1 Cement

The use of cementing materials is very old. The ancient Egyptians used calcined impure gypsum. The Greeks and the Romans used calcined lime- stone and later learned to add to lime and water, sand and crushed stone or brick and broken tiles. This was the first concrete in history. Lime mortar does not harden under water and for construction under water the Romans ground together lime and a volcanic ash or finely ground burnt clay tiles. The active silica and alumina in the ash and the tiles combined with the lime to produce what became known as pozzolanic cement from the name of the village of Pozzuoli, near Vesuvius, where the volcanic ash was first found. The name ‘pozzolanic cement’ is used to this day to describe cements obtained simply by the grinding of natural materials at normal temperature. Some of the Roman structures in which masonry was bonded by mortar, and concrete structures such as the Pantheon in Rome, have survived to this day, with the cementations material still hard and firm. In the ruins at Pompeii, the mortar is often less weathered than the rather soft stone.

Portland Cement

Cement, in the general sense of the word, can be described as a material with adhesive and cohesive properties which make it capable of bonding mineral fragments into a compact whole. This definition embraces a large variety of cementing materials.

For constructional purposes, the meaning of the term 'cement' is restricted to the bonding materials used with stones, sand, bricks, building blocks, etc. The principal constituents of this type of cement are compounds of lime, so that in building and civil engineering we are concerned with calcareous cement.

The cements of interest in the making of concrete have the property of setting and hardening under water by virtue of a chemical reaction with it and are, therefore, called hydraulic cements.

Hydraulic cements consist mainly of silicates and aluminates of lime, and can be classified broadly as natural cements, Portland cements, and high-alumina cements. The present chapter deals with the manufacture of Portland cement and its structure and properties, both when un- hydrated and in a hardened state.

Chemical Composition of Portland Cement

We have seen that the raw materials used in the manufacture of Portland cement consist mainly of lime, silica, alumina and iron oxide. These compounds interact with one another in the kiln to form a series of more complex products and, apart from a small residue of uncombined lime which has not had sufficient time to react, a state of chemical equilibrium is reached. However, equilibrium is not maintained during cooling, and the rate of cooling will affect the degree of crystallization and the amount of amorphous material present in the cooled clinker. The properties of this amorphous material, known as glass, differ considerably from those of crystalline compounds of a nominally similar chemical composition. Another complication arises from the interaction of the liquid part of the clinker with the crystalline compounds already present.

Nevertheless, cement can be considered as being in frozen equilibrium, i.e. the cooled products are assumed to reproduce the equilibrium existing at the clinkering temperature. This assumption is, in fact, made in the calculation of the compound composition of commercial cements: the 'potential' composition is calculated from the measured quantities of oxides present in the clinker as if full crystallization of equilibrium products had taken place.

Four compounds are usually regarded as the major constituents of cement: they are listed in Table (3.1), together with their abbreviated symbols. This shortened notation, used by cement chemists, describes each oxide by one letter, viz.:

$CaO = C$ $SiO_2 = S$

Al_2O_3= A

and Fe_2O=F

Likewise, H_2O_3 in hydrated cement is denoted by H and SO_3 by S*.

Table (3.1) Usual Composition Limits of Portland Cement

Oxide	**Content, percent**
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-0.6
MgO	0.5-0.4
Alkalis(as Na_2O)	0.3-1.2
SO_3	2-3.5

3.2.1.1 Cement Test

- **Consistency of Standard Paste**

For the determination of the initial and final setting times and for the Le Chatelier soundness test, neat cement paste of a standard consistency has to be used. It is, therefore, necessary to determine for any given cement the water content of the paste which will produce the desired consistency.

The consistency is measured by the Vicat apparatus, using a 10 mm diameter plunger fitted into the needle holder. A trial paste of cement and water is mixed in a prescribed manner and placed in the mould. The plunger is then brought into contact with the top surface of the paste and released. Under the action of its weight the plunger will penetrate the paste, the depth of penetration depending on the consistency. This is considered to be standard, in the meaning of BS EN 196-3: 2005, when the plunger penetrates the paste to a point 6 ± 1 mm from the bottom of the mould. The water content of the standard paste is expressed as a percentage by mass of the dry cement, the usual range of values being between 26 and 33 per cent.

- **Setting Time**

The physical processes of setting were discussed; here, the actual determination of setting times will be briefly dealt with. The setting times of cement are measured using the Vicat apparatus with different penetrating attachments. The test method is prescribed by BS EN 196-3: 2005.

For the determination of the initial set, a round needle with a diameter 1.13 ± 0.05 mm is used. This needle, acting under a prescribed weight, is used to penetrate a paste of standard consistency placed in a special mould. When the paste stiffens sufficiently for the needle to penetrate no deeper than to a point 5 ± 1 mm from the bottom, initial set is said to have taken place. Initial set is expressed as the time elapsed since the mixing water was added to the cement. A minim- um time of 60 minutes is prescribed by BS EN197-1 : 2000 for cements with strengths of 42.5 MPa, 75 minutes for cements with a strength of 52.5 MPa and 45 minutes for cements with higher strengths. American Standard ASTM C 150-09 prescribes a minimum time for the initial set of 45 minutes, also using the Vicat apparatus pre-scribed in ASTM C 191-08. An alternative test

Using Gillmore needles (ASTM C 266-08) gives a higher value of setting time.

The initial setting time of high-alumina cement is prescribed by BS 915-2: 1972 (1983) as between 2 and 6 hours.

Final set is determined by a similar needle fit- ted with a metal attachment hollowed out so as to leave a circular cutting edge 5 mm in diameter and set 0.5 mm behind the tip of the needle. Fin- al set is said to have taken place when the needle, gently lowered to the surface of the paste, penetrates it to a depth of 0.5 mm but the circular cutting edge fails to make an impression on the surface of the paste. The final setting is reckoned from the moment when mixing water was added to the cement. Limits on the final setting time no longer appear in the European or ASTM standards.

If the knowledge of final setting time is required, but no test data are available, it may be useful to take advantage of the observation that, for the majority of American commercial ordinary and rapid-hardening Portland cements at room temperature, the initial and final setting times are approximately related as follows: final setting time (min) = 90 + 1.2 × initial setting time (min).

Because the setting of cement is affected by the temperature and the humidity of the surrounding air, these are specified by BS EN 196-3 : 2005: a temperature of 20 ± 2 °C (68 ± 4 °F) and minimum relative humidity of 65 per cent.

Tests have shown that setting of cement paste is accompanied by a change in the ultrasonic pulse velocity through it but it has not been possible to develop an alternative method of measurement of setting time of cement. At- tempts at using electrical measurements have also been unsuccessful, mainly because of the influence of admixtures on electrical properties.

It should be remembered that the speed of set-ting and the rapidity of hardening, i.e. of gain of strength, are independent of one another. For instance, the prescribed setting times of rapid- hardening cement are no different from those for ordinary Portland cement, although the two cements harden at different rates.

It may be relevant to mention here that the set- ting time of concrete can also be determined, but this is a different property from the setting time of cement. ASTM Standard C 403-08 lays down the procedure for the former, which uses a Proctor penetration probe applied to mortar sieved from the given concrete. The definition of this setting time is arbitrary as there is no abrupt advent of Setting in practice.

The Russians have attempted to define the setting time of concrete by the minimum resistance between two embedded met- al electrodes between which is passed a high-frequency electric current.

- **Fineness of Cement**

It may be recalled that one of the last steps in the manufacture of cement is the grinding of clinker mixed with gypsum. Because hydration starts at the surface of the cement particles, it is the total surface area of cement that represents the material available for hydration. Thus, the rate of hydration depends on the fineness of the cement particles and, for a rapid development of strength, high fineness is necessary the longterm strength is not affected. A higher early rate of hydration means, of course, also a higher rate of early heat evolution.

- **Strength of Cement**

The mechanical strength of hardened cement is the property of the material that is perhaps most obviously required for structural use. It is not surprising, therefore, that strength tests are prescribed by all specifications for cement. The strength of mortar or concrete depends on the cohesion of the cement paste, on its adhesion to the aggregate particles, and to a certain extent on the strength of the aggregate itself. The last factor is not considered at this stage, and is eliminated in tests on the quality of cement by the use of standard aggregates.

Strength tests are not made on a neat cement paste because of difficulties of moulding and testing with a consequent large variability of test results. Cement–sand mortar and, in some cases, concrete of prescribed proportions and made with specified materials under strictly controlled Conditions are used for the purpose of determining the strength of cement.

There are several forms of strength tests: direct tension, direct compression, and flexure. The latter determines in reality the tensile strength in bending because as is well known, hydrated cement paste is considerably stronger in compression than in tension.

In the past, the direct tension test on briquettes used to be commonly employed but pure tension is rather difficult to apply so that the results of such a test show a fairly large scatter. Moreover, since structural techniques are designed mainly to exploit the good strength of concrete in compression, the direct tensile strength of cement is of lesser interest than its compressive strength.

Different Cements

In the preceding section, we discussed cementitious materials on the basis of their broad com- position and rational classification. For practical purposes of selection of an appropriate Portland cement or blended cement, it is useful to consider a classification based on the relevant physical or chemical property, such as a rapid gain of strength, low rate of evolution of the heat of hydration, or resistance to sulfate attack.

In order to facilitate the discussion, a list of different Portland cements, with or without other cementitious materials, together with the American description according to ASTM Standards C 150-09 or C 595-10, where available, is given in Table 3.2.

Table (3.2) Main Types of Portland Cement

Traditional British description	ASTM description
Ordinary Portland	Type I
Rapid-hardening Portland	Type III
Extra rapid- hardening Portland	
Ultra high early strength Portland	Regulated set*
Low heat Portland	Type IV
Modified cement	Type II
Sulfate-resisting Portland	Type V
Portland blast furnace	Type IS, Type I(SM)
White Portland	
Portland-pozzolana	Type IP, Type I(PM)
Slag cement	Type S

Note: All American cement except Type IV and V are also available with an interground air-entraining agent, and are then denoted by letter A, e.g. Type IA.

*Not an ASTM description

3.2.1.2 Types of Portland Cement

- **Ordinary Portland Cement**

This is by far the most common cement in use: about 90 per cent of all cement used in the United States (total production in 2008 of about 73 million tons per annum) and a like percentage of the ordinary type in the United Kingdom (total production of 12 million tons per annum in 2005). It may be interesting to note that in 2007 the annual consumption of cement in the United Kingdom was equivalent to nearly 250 kg per head of population: the corresponding figure for the United States was 360 kg. For every man, woman and child in the world, the consumption in 2007 was 420 kg per annum, which is second only to the consumption of water. The biggest change occurred in China, where the increase between 1995 and 2004 was 90%, and the current consumption represents over 50% of the world production. The global production is forecast to reach 3.5 billion tones in 2013. With the considerable increase in the use of fly ash as a cementitious material, the quantity of concrete used is no longer proportion- al to consumption of Portland cement.

Ordinary Portland (Type I) cement is admirably suitable for use in general concrete construction when there is no exposure to sulfates in the soil or groundwater. The specification for this cement is given in European Standard BS EN 197-1: 2000. In keeping with the modern trend towards performance-oriented specifications, little is laid down about the chemical composition of the cement, either in terms of compounds or of ox- ides. Indeed, the standard requires only that it is made from 95 to 100 per cent of Portland cement clinker and 0 to 5 per cent of minor additional constituents, all by mass, the percentages being those of the total mass except calcium sulfate and manufacturing additives such as grinding aids.

The limitation on the clinker composition is that not less than two-thirds of its mass consists of C_3S and C_2 Staken together, and that the ratio of CaO to SiO_2 , also by mass, be not less than 2.0. The content of MgO is limited to a maximum of 5.0 per cent.

The minor additional constituents, referred to above, are one or more of the other cementitious materials or filler. Filler is defined as any natural or inorganic material other than a cementitious material. An example of filler is a calcareous material which, due to its particle distribution, improves the physical properties of the cement, for example, workability or water retention. Fillers are discussed more fully.

Thus, BS EN 197-1: 2000 contains no de- tailed requirements about the proportion of the various oxides in the clinker which were included in the previous versions of British Standards. As some of those requirements are still used in many countries, it is useful to mention the lime saturation factor which is to be not greater than 1.02 and not less than 0.66.

- **Rapid Hardening Portland Cement**

This cement comprises Portland cement sub- classes of 32.5 and 42.5 MPa as prescribed by BS EN 197-1: 2000. Rapid-hardening Portland cement (Type III), as its name implies, develops strength more rapidly, and should, therefore, be correctly described as high early strength cement. The rate of hardening must not be confused with the rate of setting: in fact, ordinary and rapid- hardening cements have similar setting times, prescribed by BS 12: 1996 as an initial setting time of not less than 45 minutes. The final setting time is no longer prescribed. BS EN 197-1: 2000 does not prescribe fineness.

The increased rate of gain of strength of the rapid-hardening Portland cement is achieved by a higher C3 S content (higher than 55 per cent, but sometimes as high as 70 per cent) and by a finer Grinding of the cement clinker. British Standard BS 12: 1996, unlike previous versions of BS 12, does not prescribe the fineness of cement, either ordinary or rapid-hardening. However, the standard provides for an optional controlled fineness Portland cement and so does BS EN 197-1: 2000. The range of fineness is agreed between the manufacturer and the user. Such cement is valuable in applications where makes it easier to remove excess water from the concrete during compaction because the fineness is more critical than the compressive strength.

In practice, rapid-hardening Portland cement has a higher fineness than ordinary Portland cement. Typically, ASTM Type III cements have a of 450 to 600 m^2/kg compared with 300 to 400 m^2/kg.

For Type I cement. The higher fineness significantly increases the strength at 10 to 20 hours, the increase persisting up to about 28 days. Under wet curing conditions, the strengths equalize at the age of 2 to 3 months, but later on the strength of the cements with a lower fineness surpasses that of the high fineness cements.

- **Low Heat Portland Cement**

The rise in temperature in the interior of a large concrete mass due to the heat development by the hydration of cement, coupled with a low thermal conductivity of concrete, can lead to serious cracking For this reason, it is necessary to limit the rate of heat evolution of the cement used in this type of structure: a greater proportion of the heat can then be dissipated and a lower rise in temperature results.

Cement having such a low rate of heat development was first produced for use in large gravity dams in the United States, and is known as low heat Portland cement

(Type IV). However for some time now, Type IV cement has not been produced in the United States.

- **Sulfate Resisting Cement**

In discussing the reactions of hydration of cement, and in particular the setting process, mention was made of the reaction between C3Aand gypsum ($CaSO_4 \cdot 2H_2O$) and of the consequent formation of calcium sulfa aluminate. In hardened cement, calcium aluminate hydrate can react with a sulfate salt from outside the concrete in a similar manner: the product of addition is calcium sulfa aluminate, forming within the framework of the hydrated cement paste. Because the increase in the volume of the solid phase is 227 per cent, gradual disintegration of concrete results. A second type of reaction is that of base exchange between calcium hydroxide and the sulfates, resulting in the formation of gypsum with an in- crease in the volume of the solid phase of 124 per cent.

These reactions are known as sulfate attack. The salts particularly active are magnesium sulfate and sodium sulfate. Sulfate attack is greatly accelerated if accompanied by alternating wetting and drying.

- **White Cement and Pigments**

For architectural purposes, white or a pastel colour concrete is sometimes required. To achieve best results it is advisable to use white cement with, of course, a suitable fine aggregate and, if the surface is to be treated, also an appropriate course aggregate. White cement has also the ad- vantage that it is not liable to cause staining because it has a low content of soluble alkalis.

White Portland cement is made from raw materials containing very little iron oxide (less than 0.3 per cent by mass of clinker) and manganese oxide. China clay is generally used, together with chalk or limestone, free from specified impurities. Oil or gas is used as fuel for the kiln in order to avoid contamination by coal ash. Since iron acts as a flux in clinkering, its absence necessitates higher kiln temperatures (up to 1650 °C) but sometimes cryolite (sodium aluminum fluoride) is added as a flux.

- **Portland Blast Furnace Cement**

Cements of this name consist of an intimate mixture of Portland cement and ground granulated blast furnace slag (in ASTM parlance, simply slag). This slag is a waste product in the manufacture of pig iron, about 300 kg of slag being produced for each tone of pig iron. Chemically, slag is a mixture of lime, silica, and alumina, that is, the same oxides that make up Portland cement but not in the same proportions. There exist also nonferrous slags their use in concrete may become developed in the future.

- **High Alumina Cement**

The search for a solution to the problem of attack by gypsum-bearing waters on Portland cement concrete structures in France led Jules Bied to the development of high-alumina cement, at the beginning of the twentieth century. This cement is very different in its composition, and also in some properties, from Portland cement and Port- land blended cements so that its structural use is severely limited, but the concreting techniques are similar. For full treatment of the topic.

- **Pozzolanic Cements**

Pozzolanas, being a latent hydraulic material, are always used in conjunction with Portland cement. The two materials may be inter ground or blended. Sometimes, they can be combined in the concrete mixer. The possibilities are thus similar to those of granulated blast.

Furnace slag. By far the largest proportion of pozzolanas used consists of siliceous fly ash (Class F), and we shall concentrate on that material.

European Standard BS EN 197-1 : 2000 re- cognizes two subclasses of Portland fly ash cement : Class II/ A-V with a fly ash content of 6 to 20 per cent, and Class II/ B-V with a fly ash content of 21 to 35 per cent. The British Standard for Portland pulverized-fuel ash cements, BS 6588: 1996, has somewhat different limits for the fly ash content, the maximum value being 40 per cent. There is no great significance in the precise upper limit on the fly ash content. However, BS 6610: 1991 allows an even higher content of fly ash, namely 53 per cent, in so-called pozzolanic cement. Like the high slag blast furnace cement, pozzolanic cement has low 7-day strength (minimum of 12 MPa) but also low 28-day strength: minimum of 22.5 MPa.

The concomitant advantage is a low rate of heat development so that pozzolanic cement is low heat cement. Additionally, pozzolanic cement has some resistance to sulfate attack and to attack by weak acids.

3.2.2 Properties of Aggregate

Because at least three-quarters of the volume of concrete is occupied by aggregate, it is not surprising that its quality is of considerable importance. Not only may the aggregate limit the strength of concrete, as aggregate with undesirable properties cannot produce strong concrete, but the properties of aggregate greatly affect the durability and structural performance of concrete. Aggregate was originally viewed as an inert material dispersed throughout the cement paste largely for economic reasons. It is possible, however, to take an opposite view and to look on aggregate as a building material connected into a cohesive whole by means of the cement paste, in a manner similar to masonry construction. In fact, aggregate is not truly inert and its physical, thermal, and sometimes also chemical properties influence the performance of concrete. Aggregate is cheaper than cement and it is, therefore, economical to put into the mix as much of the former and as little of the latter as possible. But economy is not the only reason for using aggregate: it confers considerable technical advantages on concrete, which has a higher volume stability and better durability than hydrated cement paste alone.

3.2.2.1 General Classification of Aggregates

The size of aggregate used in concrete ranges from tens of millimeters down to particles less than one-tenth of a millimeter in cross-section. The maximum size actually used varies but, in any mix, particles of different sizes are incorporated, the particle size distribution being referred to as grading. In making low-grade concrete, aggregate from deposits containing a whole range of sizes, from the largest to the smallest, is some- times used; this is referred to as all in or pit run aggregate. The alternative, always used in the manufacture of good quality concrete, is to obtain the aggregate in at least two size groups, the main division being between fine aggregate, often called sand (for example, in BS EN 12620 : 2002), not larger than 4 mm or 3/16in., and coarse aggregate, which comprises material at least 5 mm or 3/16in. in size.

In the United States, The division is made at No. 4 ASTM sieve, which is 4.75 mm (in.) in size (see Table 3.3). More will be said about grading later, but this basic division makes it possible to distinguish in the ensuing description between fine and coarse aggregate. It should be noted that the use of the term aggregate (to mean coarse aggregate) in contradistinction to sand is not correct.

Natural sand is generally considered to have a lower size limit of 70 or 60 μ m. Material between 60 μ m and 2 μ m is classified as silt, and particles smaller still are termed clay. Loam is a soft de- posit consisting of sand, silt, and clay in about equal proportions. Although the content of particles smaller than 75 μ m is usually reported globally, the influence of silt and of clay on the properties of the resultant concrete is often significantly different not only because these particles differ in size but also in composition. Methods of determining the proportion of material smaller than 75 μm and 20 μm, respectively, are pre- scribed in BS 812 : 103.1 : 1985 (2000) and BS 812 : 103.2 (2000).

All natural aggregate particles originally formed a part of a larger parent mass. This may have been fragmented by natural processes of weathering and abrasion or artificially by crushing. Thus, many properties of the aggregate depend entirely on the properties of the parent rock, e.g. chemical and mineral composition, petro logical character, specific gravity, hardness, strength, physical and chemical stability, pore structure, and colour. On the other hand, there are some properties possessed by the aggregate but absent in the parent rock: particle shape and size, surface texture, and absorption. All these properties may have a considerable influence on the quality of the concrete, either fresh or in the hardened state. It is only reasonable to add, however, that, although these different properties of aggregate.

Per se can be examined, it is difficult to define a good aggregate other than by saying that it is an aggregate from which good concrete (for the given conditions) can be made. While aggregate whose properties all appear satisfactory will al- ways make good concrete, the converse is not necessarily true and this is why the criterion of performance in concrete has to be used. In particular, it has been found that aggregate may appear to be unsatisfactory on some count but no trouble need be experienced when it is used in concrete. For instance, a rock sample may disrupt on freezing but need not do so when embedded in concrete, especially when the aggregate particles are well covered by a hydrated cement paste of low permeability. However, aggregate considered poor in more than one respect is unlikely to make a satisfactory concrete, so that tests on aggregate alone are of help in assessing its suitability for use in concrete.

Classification of Natural Aggregates

So far, we have considered only aggregate formed from naturally occurring materials, and the present chapter deals almost exclusively with this type of aggregate. Aggregate can, however, also be manufactured from industrial products: because these artificial aggregates are generally either heavier or lighter than ordinary aggregate they are considered.

A further distinction can be made between aggregate reduced to its present size by natural agents and crushed aggregate obtained by a deliberate fragmentation of rock.

From the petrological standpoint, the aggregates, whether crushed or naturally reduced in size, can be divided into several groups of rocks having common characteristics. The classification of BS 812:1: 1975 is most convenient and is given in Table 3.4. The group classification does not imply suitability of any aggregate for concrete-making: unsuitable material can be found in any group, although some groups tend to have a better record than others. It should also be remembered that many trade and customary names of aggregates are in use, and these often do not correspond to the correct petrographic classification. Rock types commonly used for aggregates are listed in BS 812 : 102 : 1989, and BS 812 : 104 : 1994 (2000) covers the methods of petro- graphic examination. BS 812 has been replaced by BS EN 932 and 933.

Table (3.4) Classification of Natural Aggregates According to Rock Type (BS 812:1: 1975)

Basalt group	Flint group	Gabbro group
Andesite	Chert	Basic diorite
Basalt	Flint	Basic gneiss
Basic porphyrites		Gabbro
Diabase		Hornblende-rock
Dolerites of all kinds		Norite
Including theralite		Peridotile
and teschenite		Picrite
Epidiorite		Serpentinite
Lamprophyre		
Quartz-dolerite		
Spilite		
Granite group	Gristone group	Hornfels group
Gneiss	(including fragmental	Contact-altered rocks
Granite	Volcanic rocks)	Of all kinds except
Granodiorite	Arkose	Marble
Granulite	Greywacke	
Pegmatite	Grit	
Quartz-diorite	Sandstone	
Syenite	Tuff	
Limestone group	Porphyry group	Quartzite group
Dolomite	Aplite	Ganister
Limestone	Dacite	Quartzitic sandstones

Marble	Felsite	Re-crystallized
	Granophyre	Quartzite
	Microgranite	

3.2.2.2 Aggregate Test

Because aggregate generally contains pores, both permeable and impermeable, the meaning of the term specific gravity has to be carefully defined, and there are indeed several types of specific gravity. The absolute specific gravity refers to the volume of the solid material excluding all pores, and can, therefore, be defined as the ratio of the mass of the solid, referred to vacuum, to the mass of an equal volume of gas-free distilled water, both taken at a stated temperature. Thus, in order to eliminate the effect of totally enclosed impermeable pores the material has to be pulverized, and the test is both laborious and sensitive. Fortunately, it is not normally required in concrete technology work. If the volume of the solid is deemed to include the impermeable pores, but not the capillary ones, the resulting specific gravity is prefixed by the word apparent.The apparent specific gravity is then the ratio of the mass of the aggregate dried in an oven at 100 to 110 °C (212 to 230 °F) for 24 hours to the mass of water occupying a volume equal to that of the solid including the impermeable pores. The latter mass is determined using a vessel which can be accurately filled with water to a specified volume. Thus, if the mass of the oven-dried sample is D , the mass of the vessel full of water is B , and the mass of the vessel with the sample and topped up with water is A , then the mass of the water occupying the same volume as the solid is $B – (A – D)$. The apparent specific gravity is then

D/B-A+D.

The vessel referred to earlier, and known as a pycnometer, is usually a one liter jar with a watertight metal conical screw top having a small hole at the apex. The pycnometer can thus be filled with water so as to contain precisely the same volume every time.

Calculations with reference to concrete are generally based on the saturated and surface-dry.

condition of the aggregate because the water contained in *all* the pores in the aggregate does not take part in the chemical reactions of cement and can, therefore, be considered as part of the aggregate. Thus, if a sample of the saturated and surface-dry aggregate has a mass C , the gross apparent specific gravity is C/B-

A+C. This is the specific gravity most frequently and easily determined, and it is used for calculations of yield of concrete or of the quantity of aggregate required for a given volume of concrete. The apparent specific gravity of aggregate depends on the specific gravity of the minerals of which the aggregate is composed and also on the amount of voids. The majority of natural aggregates have a specific gravity of between 2.6 and 2.7, and the range of values is given in Table 3.5. The values for artificial aggregates extend from considerably below to very much above this range.

Table (3.5) Apparent Specific Gravity of Different Rock Groups (Crown copyright)

Rock group	Average specific gravity	Range of specific gravity
Basalt	**2.8**	**2.6 – 3.0**
Flint	**2.54**	**2.4 – 2.6**
Granite	**2.69**	**2.6 – 3.0**
Gritstone	**2.69**	**2.6 – 2.9**
Hornfels	**2.82**	**2.7 – 3.0**
Limestone	**2.66**	**2.5 – 2.8**
Porphyry	**2.73**	**2.6 – 2.9**
Quartzite	**2.62**	**2.6 – 2.7**

As mentioned earlier, specific gravity of aggregate is used in the calculation of quantities but the actual value of the specific gravity of aggregate is not a measure of its quality. Thus, the value of specific gravity should not be specified unless we are dealing with a material of a given petrological character when a variation in specific gravity would reflect the porosity of the particles. An exception to this is the case of mass construction, such as a gravity dam, where a minimum density of concrete is essential for the stability of the structure.

- **Bulk Density**

It is well known that in the SI system the density of a material is numerically equal to its specific gravity although, of course, the latter is a ratio while density is expressed in kilograms perliter. However, in concrete practice, expressing the density of kilograms per cubic meter is more common. In the American or Imperial system, specific gravity has to be multiplied by the unit mass of water (approximately 62.4 lb/ ft3) in order to be converted into absolute density (specific mass) expressed in pounds per cubic foot.

- Sieve Analysis

This somewhat grandiose name is given to the simple operation of dividing a sample of aggregate into fractions, each consisting of particles of the same size. In practice, each fraction contains particles between specific limits, these being the openings of standard test sieves. The test sieves used for concrete aggregate have square openings and their properties are pre- scribed by BS 410-1 and 2 : 2000 and ASTM E 11-09. In the latter standard, the sieves can be described by the size of the opening (in inches) for larger sizes, and by the number of openings per lineal inch for sieves smaller than about in. Thus a No. 100 test sieve has 100 × 100 openings in each square inch. The standard approach is to designate the sieve sizes by the nominal aperture size in millimeters or micrometers.

Sieves smaller than 4 mm (0.16 in.) are normally made of wire cloth although, if required, this can be used up to 16 mm (0.62 in.). The wire cloth is made of phosphor bronze but, for some coarser sieves, brass and mild steel can also be used. The screening area, i.e. the area of the openings as a percentage of the gross area of the sieve, varies between 28 and 56 per cent, being larger for large openings. Coarse test sieves (4 mm (0.16 in.) and larger) are made of perforated plate, with a screening area of 44 to 65 per cent.

All sieves are mounted in frames which can nest. It is thus possible to place the sieves one above the other in order of size with the largest sieve at the top, and the material retained on each sieve after shaking represents the fraction of aggregate coarser than the sieve in question but finer than the sieve above. Frames 200 mm (8 in.) in diameter are used for 5 mm (0,375 in.) or smaller sizes, and 300 or 400 mm (12 or 18 in.) diameter frames for 5 mm (0,375in.) and larger sizes.

It may be remembered that 5 mm (0,375 in., No. 4 ASTM) or 4 mm is the dividing line between the fine and coarse aggregates. The sieves used for concrete aggregate consist of a series in which the clear opening of any sieve is approximately one-half of the opening of the next larger sieve size. The BS test sieve sizes in Imperial units for this series were as follows: 3 in.1.5, in0.75. in. 375, in.01875, in., Nos. 7, 14, 25, 52, 100, and 200, and results of tests on those sieves are still used. Table 2.3 gives the traditional sieve sizes according to their fundamental description by aperture in millimeters or micrometers and also the previous British and ASTM designations and approximate apertures in inches.

Table (3.3) Traditional American and British Sieve Sizes

Aperture mm or	Approximate imperial equivatent in	Previous designation,of nearest size BS	ASTM
125mm	**5**	**-**	**5in**
106mm	**4.24**	**4in**	**4.24in**
90mm	**3.5**	**3.5in**	**3.5in**
75mm	**3**	**3in**	**3in**
63mm	**2.5**	**2.5in**	**2.5in**
53mm	**2.12**	**2in**	**2.12in**
45mm	**1.75**	**1.75in**	**1.75in**
37.5mm	**1.5**	**1.5in**	**1.5in**
31.5mm	**1.25**	**1.25in**	**1.25in**
26.5mm	**1.06**	**1in**	**1.06in**
22.4mm	**0.875**	**0.875in**	**0.875in**
19mm	**0.75**	**0.75in**	**0.75in**
16mm	**0.625**	**0.625in**	**0.625in**
13.2mm	**0.53**	**0.5in**	**0.53in**
11.2mm	**0.438**	**-**	**0.438in**
9.5mm	**0.375**	**0.375in**	**0.375in**
8mm	**0.312**	**0.312in**	**0.312in**
6.7mm	**0.265**	**0.25in**	**0.265in**
5.6mm	**0.223**	**-**	**No 3.5**
4.75mm	**0.187**	**0.1875in**	**N0 4**
4mm	**0.157**	**-**	**No 5**
3.35mm	**0.132**	**No 5**	**No 6**
2.8mm	**0.111**	**No 6**	**No 7**
2.36mm	**0.0937**	**No 7**	**No 8**
2mm	**0.0787**	**No 8**	**N0 10**
1.7mm	**0.0661**	**No 10**	**No 12**
1.4mm	**0.0555**	**No 12**	**N0 14**
1.18mm	**0.0469**	**N0 14**	**N0 16**
1mm	**0.0394**	**No 16**	**No 18**
850μm	**0.0331**	**No 18**	**No 20**
710μm	**0.0278**	**No 22**	**No 25**
600μm	**0.0234**	**No 25**	**No 30**
500μm	**0.0197**	**No 30**	**No 35**
425μm	**0.0165**	**No 36**	**No 40**
355μm	**0.0139**	**No 44**	**No 45**
300μm	**0.0117**	**No 52**	**No 50**
250μm	**0.0098**	**No 60**	**No 60**
212μm	**0.0083**	**No 72**	**No 70**
180μm	**0.007**	**No 85**	**N0 80**
150μm	**0.0059**	**No 100**	**No 100**
125μm	**0.0049**	**No 120**	**No 120**

106μm	**0.0041**	**No 150**	**No 140**
90μm	**0.0035**	**No 170**	**No 170**
75μm	**0.0029**	**No 200**	**No 200**
63μm	**0.0025**	**No 240**	**No 230**
53μm	**0.0021**	**No 300**	**No 270**
45μm	**0.0017**	**No 350**	**No 325**
38μm	**0.0015**	**-**	**No 400**
32μm	**0.0012**	**-**	**No 450**

- **Fineness Modulus**

A single factor computed from the sieve analysis is sometimes used, particularly in the United States. This is the fineness modulus, defined as of the sum of the cumulative percentages retained on the sieves of the standard series: 150,
300, 600 μ m, 1.18, 2.36, 5.00 mm (ASTM Nos. 100, 50, 30, 16, 8, 4) and up to the largest sieve size used. It should be remembered that, when all the particles in a sample are coarser than, say, 600 μ m (No. 30 ASTM), the cumulative percentage retained on 300 μm (No. 50 ASTM) sieve should be entered as 100; the same value, of course, would be entered for 150 μm (No. 100). The value of the fineness modulus is higher the coarser the aggregate.
The fineness modulus can be looked upon as a weighted average size of a sieve on which the material is retained, the sieves being counted from the finest.
Showed it to be a logarithmic average of the particle size distribution. For instance, a fineness modulus of 4.00 can be interpreted to mean that the fourth sieve, 1.18 mm (No. 16 ASTM) is the average size. However, it is clear that one parameter, the average, cannot be representative of a distribution: thus the same fineness modulus can represent an infinite number of totally different size distributions or grading curves. The fineness modulus cannot, therefore, be used as a single description of the grading of an aggregate, but it is valuable for measuring slight variations in the aggregate from the same source, e.g. as a day-to-day check. Nevertheless, within certain limitations, the fineness modulus gives an indication of the probable behavior of a concrete mix made with aggregate having a certain grading, and the use of the fineness modulus in assessment of aggregates and in mix proportioning has many supporters.

- **Maximum Aggregate Size**

It has been mentioned before that the larger the aggregate particle the smaller the surface area to be wetted per unit mass. Thus, extending the grading of aggregate to a larger maximum size lowers the water requirement of the mix, so that, for a specified workability and cement content, the water/ cement ratio can be lowered with a con- sequent increase in strength.

This behaviour has been verified by tests with aggregates up to 38.1 mm (1.5 in.) maximum size, and is usually assumed to extend to larger sizes as well. Experimental results show, however, that above the 38.1 mm (1.5 in.) maximum size the gain in strength due to the reduced water requirement is offset by the detrimental effects of lower bond area (so that volume changes in the paste cause larger stresses at interfaces) and of discontinuities introduced by the very large particles, particularly in rich mixes. Concrete be- comes grossly heterogeneous and the resultant lowering of strength may possibly be similar to that caused by a rise in the crystal size and coarseness of texture in rocks.

This adverse effect of increase in the size of the largest aggregate particles in the mix exists, in fact, throughout the range of sizes, but below 38.1 mm (1 1/2 in.) the effect of size on the decrease in the water requirement is dominant. For larger sizes, the balance of the two effects depends on the richness of the mix,

Confirmed that, for any given strength of concrete, that is, for a given water/ cement ratio, there is an optimum maximum size of aggregate

3.2.3 Slag

Extensive documentation is available on blast furnace slag utilization in Australia and overseas (Jones and Murrie, 1980; Mehta, 1989; Yang, 1991). However, published.

Data on steel slag utilization are comparatively sparse in the world.

Although in the last ten years" steel slag, as a potential pozzolanic and cementitious by-product, has attracted more attention than previously, with research on its properties, utilization and solutions to problems encountered in the utilization, there has not been a comprehensive report giving a systematic review of the state of the art. Furthermore, in some review papers on pozzolanic and cementitious by-products, steel slag continues to be neglected.

This chapter gives an overall review of the current state of research on the utilization of steel slag in engineering applications. Research on steel slag utilization may be carried out in three stages, according to production process and use of steel slag:

1. Improvement in the steel making process to achieve the purpose of pre-treating and modification of properties of steel slag;

2. Treatment of steel slag after pouring, i.e. post-treatment which is in common
3. Work on classification, selectivity's and quantification for the utilization of existing or given steel slag, treated by given methods. Slag is the glass-like by-product left over after a desired metal has been separated (i.e., smelted) from its raw ore. Slag is usually a mixture of metal oxides and silicon dioxide. However, slags can contain metal sulfides and elemental metals. While slags are generally used to remove waste in metal smelting, they can also serve other purposes, such as assisting in the temperature control of the smelting, and minimizing any re-oxidation of the final liquid metal product before the molten metal is removed from the furnace and used to make solid metal.

Iron and steel slag refers to the type of metal manufacturing slag that is generated during the process of manufacturing iron and steel products. The term "slag" originally referred to slag produced by metal manufacturing processes, however it is now also used to describe slag that originates from molten waste material when trash and other substances are disposed of at an incinerator facility.

- **Blast Furnace Slag**

Blast furnace slag is recovered by melting separation from blast furnaces that produce molten pig iron. It consists of non-ferrous components contained in the iron ore together with limestone as an auxiliary materials and ash from coke. Approximately 290 kg of slag is generated for each ton of pig iron. When it is ejected from a blast furnace, the slag is molten at a temperature of approximately 1,500℃. Depending on the cooling method used, it is classified either as air-cooled slag or granulated slag.

- **Air-Cooled Slag**

The molten slag flows into a cooling yard, where it is cooled slowly by natural cooling and by spraying with water. This results in a crystalline, rock-like air-cooled slag.

- **Granulated Slag**

The molten slag is cooled rapidly by jets of pressurized water, resulting in a vitreous granulated slag.

- **Converter Slag**

In the same way as air-cooled blast furnace slag, converter slag is cooled slowly by natural cooling and water spray in a cooling yard. It is then processed and used for various iron and steel slag (converter) applications. Approximately 110 kg of slag Is generated for each ton of converter steel.

- **Electric Arc Furnace Slag**

Electric arc furnace slag is generated when iron scrap is melted and refined. It consists of oxidizing slag that is generated during oxidation refining, and reducing slag that is generated during reduction refining. Approximately 70 kg of electric arc furnace oxidizing slag and 40 kg of reducing slag are generated for each ton of electric arc furnace steel.

- **Basic Oxygen Steelmaking**

In this process, a quantity of steel scrap (around 20 per cent) and a much larger quantity of molten iron are fed into large brick lined pots called vessels. The molten iron contains about 4% carbon.

When the steel making materials have been fed into the vessel an oxygen lance is lowered into it and 99% pure oxygen is blown onto the materials. Heat generated by the oxygen raises the temperature inside the vessel to about 1700 0c. This melts the scrap and lowers the carbon content of the molten iron and helps remove other unwanted elements.

Burnt limestone is fed into the vessel to form steel slag which absorbs impurities of the steelmaking process. Steel slag is poured off later.

Nearing the end of the blowing or "refining" cycle, after about 20 minutes, a temperature reading and a sample are taken for analysis.

If the analysis shows that everything is correct, the vessel is tilted and the steel is poured into a ladle. This process is called tapping the steel at this time alloying elements are added to bring the steel to the required specification.

Further treatment of the steel takes places in the ladle, including such things as bubbling the steel with an inert gas (e.g. nitrogen) to ensure thorough mixing of the alloying elements, injection of materials to refine impurities, and for some special steels, a vacuum degasser is used to remove dissolved gasses, particularly oxygen and hydrogen. The steel after tapping the steel, the steel slag is poured off into a slag cart and carried to the slag-treating bays for air cooling or water chilling. l now contains between 0.1 - 1.0 percent carbon.

3.2.3.1 Basic Properties

1. Chemical Composition

The primary components of iron and steel slag are limestone (CaO) and silica

(SiO_2). Other components of blast furnace slag include alumina (Al sub>2O_3) and magnesium oxide (MgO), as well as a small amount of sulfur (S), while steelmaking slag contains iron oxide (FeO) and magnesium oxide (MgO). In the case of steelmaking slag, the slag contains metal elements (such as iron) in oxide form, however because the refining time is short and the amount of limestone contained is large, a portion of the limestone auxiliary material may remain undissolved as free CaO shown Table (3.6).

These components exist in the natural world in places such as the Earth's crust, Natural rock, and minerals, and the chemical composition is similar to that of ordinary Portland cement. The shape and physical characteristics of iron and steel slag are similar to ordinary crushed stone and sand, however due to differences such as the chemical components and cooling processes, it is possible to provide different types of slag with a wide variety of unique properties. For example, there are some types of slag that harden when alkali stimulation occurs. Many applications utilizing the physical and chemical characteristics of slag have been developed and are being put to use in a broad range of fields.

Table (3.6) Usual Composition Limits of Steel Slag

Steelmaking furnace	Thomas furnace	BOS furnace	Open hearth furnace	Electric Oxidized
FeO	12-17	10-25	5-25	12-25
MnO	3.5-5.5	5-15	2-10	5-10
P_2O_5	16-22	0.5-3	0.5-3	0.5-2
SiO_2	3.5-6	12-17	15-20	10-20
CaO	42-50	35-45	35-50	40-50
AL_2O_3	1.5-2.5	-	3-10	1-3
MgO	3-4	3-15	5-20	5-10

2. Physical Properties

Compared to air-cooled blast-furnace slags, the steelmaking slags are much heavier, harder, denser, and less vesicular in nature (Lewis, 1982A). They have unusually high resistance to polishing and wear in pavement surface.

Solid steel slag exhibits both block shape and honeycomb shape. The former steel slag possesses lustre the latter is non-lustrous, and more brittle. The specific gravity of steel slag is dependent on viscosity, surface tension of liquid steel slag and amount of dioxide contained, ferrous material and porosity. Moisture content of steel slag is 0.2-2%, specific gravity is 3.2-3.6, compressive strength 169-300 MPa, Mohs'scale number 5-7 (Xiao and Feng, 1990). Grindability of steel slag is less than that of blast furnace slag. Hardness and specific gravity are greater than those of blast furnace slag.

3.2.3.2 Steel Slag use in Road Engineering

The utilization of steel slag can be divided into several different applications, including use as an asphaltic concrete aggregate, road base, airport runways and railroad ballast. A review of these applications is given below.

1. Use in Asphalt Mix Practice

As reported by Emery steel slag asphalt mixes combine a very high stability with good flow and excellent stripping resistance. Even with the high stability, the compatibility is still adequate due to the flow and heat retention qualities of the mix. The wear and skid resistance of steel slag asphalt mixes are superior to those of trap rock surface course, when comparable gradations are used.

Test sections, Polished Stone Value (PSV) tests and accident-skid resistance surveys indicate that steel slag asphalt mixes provide the required skid resistance for both highway and urban situations.

Another benefit of the use steel slag as an aggregate comes from its economic value.

Of the US highway materials dollar, approximately 30 cents is spent on aggregate, in contrast to 25 cents on steel, 19 cents on bituminous materials, 10 cents on cement, and lesser amounts on such miscellaneous items as pipe, lumber and petroleum products.

2. Use in Road Base

There is currently wide interest in Europe concerning the utilization of steel slag in. Stabilized base, and at least one company, Pelt and Hookass B.V. of the Netherlands, is using such a process commercially. The stabilized base consists of 60% blast furnace slag.

This base material is placed and compacted with highway equipment (at 10% water content) and the results appear excellent. This process is now being studied in the highway materials laboratory with particular regard to any potential long-term deleterious effects of magnesium oxide expansion.

3. Use as Railway Ballast

Railway ballast refers to permeable, granular materials, such as sand, gravel, crushed rock or slag chat, cinders and so on placed under and around the sleepers to promote track stability.

4. Steel Slag Concrete

Using steel slag to replace natural aggregate in concrete is initially based on the consideration of availability of natural resources and the good characteristics of steel slag. In nature, the resources of natural mineral aggregate with high quality which can be used will become exhausted (Collins, 1976) In Japan, the proportion of natural mineral aggregate content used in concrete diminishes year by year and is being replaced by artificial aggregate and industrial by-product aggregate (Japanese Civil Engineering Society, 1980) In recent years, shortages of high quality natural aggregate have been experienced in a number of areas of the United States.

5. Utilization in Bleed Cement Manufacture

Investigations of steel slag use in steel slag blended cement have only been carried out for about 10 years. The use of steel slags for their lime and iron oxide values is expected to increase, both as a blast furnace charge and for applications such as neutralization of acid wastes and as raw materials for production of Portland cement. These applications are being investigated along with a number of other uses (Barnes et aI., 1980). A few countries have used steel slag as an additive in manufacturing practice. A Chinese national standard for steel slag blended cement (GBn 164-82) was promulgated in 1983 and several regional standards for steel slag use in SSBC have been subsequently proposed.

3.2.4 Water

Water is an important ingredient of concrete, and a properly designed concrete mixture, typically with 15 to 25% water by volume, will possess the desired workability for fresh concrete and the required durability and strength for hardened concrete. The roles of water have been discussed earlier and are known as hydration and workability. The total amount of water in concrete and the water-to-cement ratio may be the most critical factors in the production of good-quality concrete. Too much water reduces concrete strength, while too little makes the concrete unworkable. Because concrete must be both strong and workable, a careful selection of the cement-to-water ratio and total amount of water are required when making concrete.

3.3 Fresh Concrete

Although fresh concrete is only of transient interest, we should note that the strength of concrete of given mix proportions is very seriously affected by the degree of its compaction. It is vital, therefore, that the consistency of the mix be such that the concrete can be transported, placed, compacted, and finished sufficiently easily and without segregation. This chapter is therefore de- voted to the properties of fresh concrete which will contribute to such an objective.

Before considering fresh concrete, we should observe that the first three chapters discussed only two of the three essential ingredients of concrete: cement and aggregate.

The third essential ingredient is water, and this will be considered below.

It may be appropriate to add, at this stage, that many, if not most, concrete mixes contain also admixtures.

Density of Fresh Concrete

Density, also called unit mass or unit weight in air, can be determined experimentally by using ASTM standard C 138-09 or BS EN 12350-6: 2009. Theoretically, density is the sum of masses of all the ingredients of a batch of concrete divided by the volume filled by the concrete. Alternatively, knowing the density of fresh concrete, the yield per batch can be determined as the mass of all the ingredients in a batch divided by the density.

Definition of Workability

A concrete which can be readily compacted is said to be workable, but to say merely that work- ability determines the ease of placement and the resistance to segregation is too loose a description of this vital property of concrete. Further-more, the desired workability in any particular case would depend on the means of compaction available; likewise, workability suitable for mass concrete is not necessarily sufficient for thin, inaccessible, or heavily reinforced sections. For these reasons, workability should be defined as a physical property of concrete alone without reference to the circumstances of a particular type of construction.

To obtain such a definition it is necessary to consider what happens when concrete is being compacted. Whether compaction is achieved by ramming or by vibration, the process consists essentially of the elimination of entrapped air from the concrete until it has achieved as close a con- figuration as is possible for a given mix. Thus, the work done is used to overcome the friction between the individual particles in the concrete and also between the concrete and the surface of the mould or of the reinforcement. These two can be called internal friction and surface friction, respectively. In addition, some of the work done is used in vibrating the mould or in shock and, indeed, in vibrating those parts of the concrete which have already been fully consolidated. Thus the work done consists of a 'wasted' part and 'useful' work, the latter, as mentioned before, comprising work done to overcome the internal friction and the surface friction. Because only the internal friction is an intrinsic property of the mix, workability can be best defined as the amount of useful internal work necessary to pro- duce full compaction. This definition was developed by Glanville et al.

Who exhaustively examined the field of compaction and workability.

The ASTM C 125-09a definition of workability is somewhat more qualitative: "property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity". The ACI definition of workability, given in ACI 116R-90, is: "that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished".

Another term used to describe the state of fresh concrete is consistency. In ordinary English usage, this word refers to the firmness of form of a substance or to the ease with which it will flow. In the case of concrete, consistency is some- times taken to mean the degree of wetness; within limits, wet concretes are more workable than dry concretes, but concretes of the same consistency may vary in workability. The ACI definition of consistency is: "the relative mobility or ability of freshly mixed concrete or mortar to flow"; this is measured by slump.

Technical literature abounds with variations of the definitions of workability and consistency but they are all qualitative in nature and more reflections of a personal viewpoint rather than of scientific precision. The same applies to the plethora of terms such as: flowability, mobility, and pumpability. There is also a term 'stability' which refers to the cohesion of the mix, that is, its resistance to segregation. These terms do have specific meaning but only under a set of given circum- stances; they can rarely be used as an objective and quantifiable description of a concrete mix.

A good review of the attempts to define the various terms is presented by Bartos among others.

3.3.1 Concrete Test

1\ Testing of Fresh Concrete

Slump Test

This is a test used extensively in site work all over the world. The slump test does not measure the workability of concrete, although ACI.

116R-90 describes it as a measure of consistency, but the test is very useful in detecting variations in the uniformity of a mix of given nominal proportions.

The slump test is prescribed by ASTM C 143-10 and BS 1881:103 : 1993. The mould for the slump test is a frustum of a cone, 300 mm (12 in.) high. It is placed on a smooth surface with the smaller opening at the top, and filled with concrete in three layers. Each layer is tamped 25 times with a standard 16 mm (5/8 in.) diameter steel rod, rounded at the end, and the top surface is struck off by means of a sawing and rolling motion of the tamping rod. The mould must be firmly held against its base during the entire operation; this is facilitated by handles or foot-rests brazed to the mould.

Immediately after filling, the cone is slowly lifted, and the unsupported concrete will now slump – hence the name of the test. The decrease in the height of the slumped concrete is called slump, and is measured to the nearest 5 mm (in.). The decrease is measured to the highest point according to BS EN 12350-2: 2009, but to the "displaced original center" according to ASTM C 143-10 shown fig (3.1). In order to reduce the influence on slump of the variation in the surface friction, the inside of the mould and its base should be moistened at the beginning of every test, and prior to lifting of the mould the area immediately around the base of the cone should be cleaned of concrete which may have dropped accidentally.

If instead of slumping evenly all round as in a true slump (1), one half of the cone slides down an inclined plane, a shear slump is said to have taken place, and the

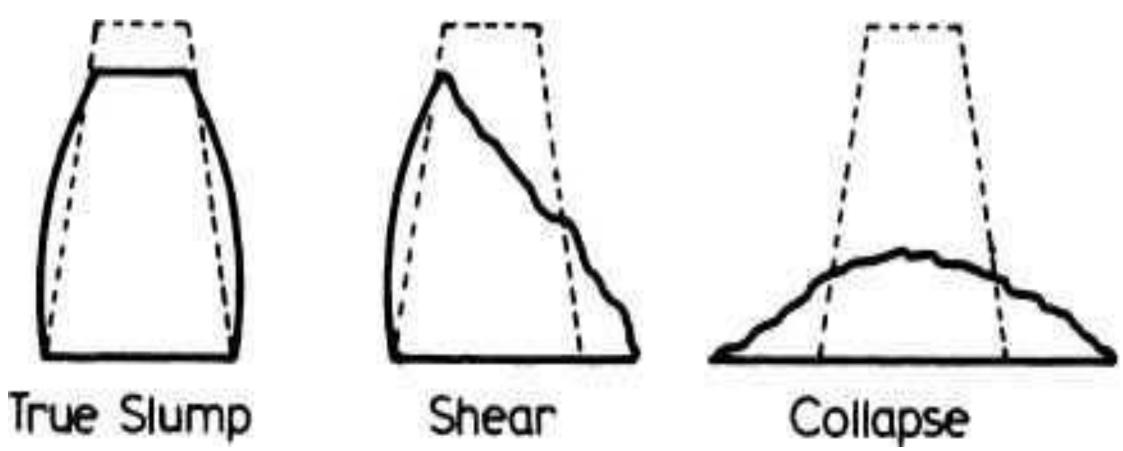


Fig (3.1) Slump: True, Shear, and Collapse

Mixes of stiff consistency have a zero slump, so that, in the rather dry range, no variation can be detected between mixes of different workability. Rich mixes behave satisfactorily, their slump being sensitive to variations in workability. However, in a lean mix with a tendency to harshness, a true slump can easily change to the shear type, or even to collapse (1), and widely different values of slump can be obtained in different samples from the same mix.

The approximate magnitude of slump for different workabilities (in a modified form of Bartos' proposals) is given in Table (3.7) gives the proposed European classification of BS EN 206-1: 2000 shown Table (3.8). One reason for the difference between the two tables is that the European approach is to measure slump to the nearest 10 mm. It should be remembered, however, that with different aggregates, especially a different con- tent of fine aggregate, the same slump can be re- corded for different workabilities, as indeed the slump bears no unique relation to the workability as defined earlier. Moreover, slump does not measure the ease of compaction of concrete and, as slump occurs under the self-weight of the test concrete only.

Table (3.7) Description of Workability and Magnitude of Slump

Description of workability	**Slump**	
	Mm	**In**
no slump	0	0
Very low	5-10	0.25-0.5
Low	15-30	0.75-1.25
Medium	35-75	1.5-3
High	80-155	3.25-6
Very high	160 to collapse	6.5 to collapse

Table (3.8) Classification of Workability and Magnitude of Slump According to BS EN 206-1: 2000

Classification of workability	**Slump mm**
S1	10-40
S2	50-90
S3	100-150
S4	160

Despite these limitations, the slump test is very useful on the site as a check on the batch- to-batch or hour-to-hour variation in the materials being fed into the mixer. An increase in slump may mean, for instance, that the moisture content of aggregate has unexpectedly increased; another cause would be a change in the grading of the aggregate, such as a deficiency of sand. Too high or too low a slump gives immediate warning and enables the mixer operator to remedy the situation. This application of the slump test, as well as its simplicity, is responsible for its widespread use.

A mini-slump test was developed for the purpose of assessing the influence of various water- reducing admixtures and super plasticizers on neat cement paste.

The test may be useful for that specific purpose, but it is important to re- member that the workability of concrete is affected also by factors other than the flow properties of the constituent cement paste.

-Strength of Concrete

Strength of concrete is commonly considered its most valuable property, although, in many practical cases, other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. Moreover, the strength of concrete is almost invariably a vital element of structural design and is specified for compliance purposes.

The mechanical strength of cement gel was discussed in this chapter some empirical relations concerning the strength of concrete will be discussed.

-Water/Cement Ratio

In engineering practice, the strength of concrete at a given age and cured in water at a prescribed temperature is assumed to depend primarily on two factors only: the water/ cement ratio and the degree of compaction. The influence of air voids on strength was discussed, and at this stage we shall consider fully-compacted concrete only: for mix proportioning purposes, this is taken to mean that the hardened concrete contains about 1 per cent of air voids.

From time to time, the water/ cement ratio rule has been criticized as not being sufficiently fundamental. Nevertheless, in practice the water/ cement ratio is the largest single factor in the strength of fully compacted concrete. Perhaps the best statement of the situation is that by Gilkey:

“For a given cement and acceptable aggregates, the strength that may be developed by a workable, properly placed mixture of cement, aggregate, and water (under the same mixing, curing, and testing conditions) is influenced by the:

(a) Ratio of cement to mixing water.

(b) Ratio of cement to aggregate.
(c) Grading, surface texture, shape, strength and stiffness of aggregate particles.
(d) Maximum size of the aggregate.
” We can add that factors (*b*) to (*d*) are of lesser
importance than factor (*a*) when usual aggregates up to 40 mm (1 1/2 in.) maximum size are employed. Those factors are, nevertheless, present because, as pointed out by Walker.
“The strength of concrete results from: (1) the strength of the mortar; (2) the bond between the mortar and the coarse aggregate; and (3) the strength of the coarse aggregate particle, i.e. its ability to resist the stresses applied to it”.

-Effect of Age on Strength of Concrete

The relation between the water/ cement ratio and the strength of concrete applies to one type of cement and one age only, and also assumes wet- curing conditions. On the other hand, the strength versus gel/ space ratio relationship has a more general application because the amount of gel present in the cement paste at any time is itself a function of age and type of cement. The latter relation thus allows for the fact that different cements require a different length of time to pro- duce the same quantity of gel. The rate of gain of strength of different cements was typical strength time curves. The influence of the curing conditions on the development of strength is considered in but here we are concerned with the practical problem of strength of concrete at different ages.

In concrete practice, the strength of concrete is traditionally characterized by the 28-day value, and some other properties of concrete are often referred to the 28-day strength. There is no scientific significance in the choice of the age of 28 days; it is simply that early cements gained strength slowly and it was necessary to base the strength description on concrete in which a significant hydration of cement had already taken place. The specific choice of a multiple of weeks was, in all likelihood, made so that testing, like placing, would fall on a working day. In modern Portland cements, the rate of hydration is much greater than in the past, both because they have a much higher fineness and because they have a higher CS3 content. This is, however, not necessarily the case with all blended cements.

2\ Testing of Hardened Concrete

We have seen that the properties of concrete are a function of time and ambient humidity, and this is why, in order to be of value, tests on concrete have to be performed under specified or known conditions. Different test methods and techniques are used in different countries and sometimes even in the same country. Because many of these tests are used in laboratory work, and especially in research, knowledge of the influence of the test methods on the measured property is of importance. It is, of course, essential to distinguish between the effects of test conditions and the intrinsic differences in the concretes being tested.

Tests can be made for different purposes but the main two objectives of testing are quality control and compliance, now called conformity, with specifications. Additional tests can be made for specific purposes, e.g. compressive strength tests to determine the strength of concrete at transfer of pre stress or at the time of the removal of form- work. It should be remembered that tests are not an end in themselves: in many practical cases, they do not lend themselves to a neat, concise interpretation, so that, in order to be of real value, tests should always be used against the back- ground of experience. Nevertheless, because tests are generally performed for the purpose of comparison with a specified, or some other, value, any departure from the standard procedure is un- desirable as it may lead to a dispute or to confusion.

Tests can be broadly classified into mechanical tests to destruction and non-destructive tests which allow repeated testing of the same specimen and thus make possible a study of the change in properties with time. Non-destructive tests also permit testing concrete in an actual structure.

Tests for Strength in Compression

The most common of all tests on hardened concrete is the compressive strength test, partly be- cause it is an easy test to perform, and partly because many, though not all, of the desirable characteristics of concrete are qualitatively related to its strength; but mainly because of the intrinsic importance of the compressive strength of concrete in structural design. Although invariably used in construction, the compressive strength test has some disadvantages, but it has become, in French parlance, a part of the engineer's baggage cultural.

The strength test results may be affected by variation in: type of test specimen; specimen size; type of mould; curing; preparation of the end surface; rigidity of the testing machine; and rate of application of stress. For this reason, testing should follow a single standard, with no departure from prescribed procedures.

Compressive strength tests on specimens treated in a standard manner which includes full compaction and wet curing for a specified period give results representing the potential quality of the concrete. Of course, the concrete in the structure may actually be inferior, for example, due to inadequate compaction, segregation, or poor curing. These effects are of importance if we want to know when the formwork may be removed, or when further construction may continue, or the structure be put into service. For this purpose, the test specimens are cured under conditions as nearly similar as possible to those existing in the actual structure. Even then, the effects of temperature and moisture would not be the same in a test specimen as in a relatively large mass of concrete. The age at which *service* specimens are tested is governed by the information required. On the other hand, standard specimens are tested at prescribed ages, generally 28 days, with additional tests often made at 3 and 7 days. Two types of compression test specimens are used: cubes and cylinders. Cubes are used in Great Britain, Germany, and many other countries in Europe. Cylinders are the standard specimens in the United States, France, Canada, Australia, and New Zealand. In Scandinavia, tests are made on both cubes and cylinders. The use of one or other type of specimen in a given country is so ingrained that the European Standard BS EN 206:1996 al- lows the use of both cylinders and cubes. Indeed, European standards use both types of strength.

- **Cube Test**

The specimens are cast in steel or cast-iron moulds of robust construction, generally 150 mm (or 6 in.) cubes, which should conform within narrow tolerances to the cubical shape, prescribed dimensions and planeness.

The mould and its base must be clamped together during casting in order to prevent leakage of mortar. Before assembling the mould, its mating surfaces should be covered with mineral oil, and a thin layer of similar oil must be applied to the inside surfaces of the mould in order to prevent the development of bond between the mould and the concrete.

The standard practice prescribed by BS EN 12390-1: 2000 is to fill the mould in one or more layers. Each layer of concrete is compacted by a vibrating hammer, or using a vibrating table, or by as quare steel. Ramming should continue until full compaction without segregation or laitance has been achieved because it is essential that the concrete in the cube be fully compacted if the test result is to be representative of the properties of fully-compacted concrete. If, on the other hand, a check on the properties of the concrete as placed is required, then the degree of compaction of the concrete in the cube should simulate that of the concrete in the structure. Thus, in the case of precast members compacted on a vibrating table, the test cube and the member may be vibrated simultaneously, but the disparity of the two masses makes the achievement of the same degree of compaction extremely difficult, and this method is not recommended.

According to BS EN 12390-2 : 2009, after the top surface of the cube has been finished by means of a float, the cube is stored undisturbed for 16 to 72 hours at a temperature of 20 ± 5 °C (68 ± 9 °F) and a relative humidity preventing de-hydration. At the end of this period, the mould is stripped and the cube is further cured in water or in a chamber with a relative humidity of not less than 95 per cent and at 20 ± 2 °C (68 ± 4 °F).

In the compression test, the cube, while still wet, is placed with the cast faces in contact with the platens of the testing machine, i.e. the position of the cube when tested is at right angles to that as-cast. According to BS 1881-116: 1983 (withdrawn), the load on the cube should be applied at a constant rate of stress equal to 0.2 to 0.4 MPa/ second (30 to 60 psi/ second). ASTM C 39-09a prescribes a rate of 0.25 ± 0.05 MPa/ sec (35 ± 7 psi/ sec). Because of the non-linearity of the stress–strain relation of concrete at high stresses, the rate of increase in strain must be increased progressively as failure is approached, i.e. the speed of the movement of the head of the testing machine has to be increased. The requirements for testing machines are discussed.

From the preceding discussion it can be seen that there is no unique simple relation between the strengths of cubes and cylinders made from the same concrete. And yet, European legislation, which made it possible for a contractor in any European Union country to bid for, and build, concrete structures in any country, made it highly desirable to describe the strength of concrete in a manner that allowed such construction in an unequivocal manner. Consequently, European Standards chose to assume that the strength of a cube is 5/4 of the strength of the cylinder and all mixes therefore describe strength by a double number, e.g. 40/ 32, meaning that cube strength of 40 MPa is equivalent to cylinder strength of 32 MPa. However, in concrete made with light- weight aggregate, the ratio is much higher than5/4.

The compressive strength, known also as the crushing strength, is reported to the nearest 0.5MPa or 50 psi; a greater precision is usually only apparent.

- **Cylinder Test**

The standard cylinder is 6 in. in diameter, 12 in. long, or 150 by 300 mm, but in France the size is 159.6 by 320 mm; the diameter of 159.6 mm gives a cross-sectional area of 20 000 mm^2.

Cylinders are cast in a mould generally made of steel or cast iron, with a clamped base; cylinder moulds are specified by ASTM C 470-09, which allows also the use of single-use moulds, made of plastic, sheet metal and treated cardboard.

Details of moulds may seem to be trivial but non-standard moulds can result in a misleading test result. For example, if the mould has a low rigidity, some of the compaction effort is dissipated so that the compaction of the concrete in the mould may be inadequate; a lower strength would be recorded. Conversely, if the mould allows leakage of mix water, the strength of concrete would increase. Excessive re-use of moulds intended for single use or for limited re-use leads to their distortion and to an apparent loss of strength.

The method of making test cylinders is pre- scribed by BS EN 12390-2 : 2009 and by ASTM C 192-07. The procedure is similar to that used with cubes, but there are differences in detail between the British and American standards.

The testing of a cylinder in compression requires that the top surface of the cylinder is in contact with the platen of the testing machine. This surface, when finished with a float, is not smooth enough for testing and requires further preparation; this is a disadvantage of cylinders tested in compression. Treatment of the top end of cylinders by capping is considered in a later section, but even though the cylinders will be capped, ASTM C 192-07 and C 31-09 do not al- low depressions or excrescences greater than 3mm (1/8 in.); these could result in air pockets.

Chapter Four
EXPERIMENTAL METHODOLOGY

4.1 Test of materials:

Quality control of materials can only be ensured through certain standard test procedures designed by ASTM, BIS, RDSO and others described as follow:

4.1.1 Cement Tests: there are different tests of cement described as follows:

4.1.1.1 Consistency

The aim of test is it determine the quantity of water required to produce cement paste of standard consistency as per IS: 4031 (Part 4) - 1988.

- **Procedure is summarized as follow:**

(1) Weigh approximately 400g of cement and mix it with a weighed quantity of water the time of gauging should be between 3 to 5 minutes.
(2) Fill the Vicat mould given fig (4.1) with paste and level it with a trowel.
(3) Lower the plunger gently till it touches the cement surface.
(4) Release the plunger allowing it to sink into the paste.
(5) Note the reading on the gauge.
(6) Repeat the above procedure taking fresh samples of cement different quantities of water until the reading on the gauge is 5 to 7mm.

Express the amount of water as a percentage of the weight of dry cement to the first place of decimal.

4.1.1.2 Initial and Final Setting Time

The aim of test is it determine the initial and the final setting time of cement as per IS: 4031 (Part 5) - 1988.

- **Procedure is summarized as follow:**

1. Prepare a cement paste by gauging the cement with 0.85 times the water required to give a paste of standard consistency.
2. Start a stop-watch, the moment water is added to the cement.
3. Fill the Vicat mould completely with the cement paste gauged as above, the mould resting on a non-porous plate and smooth off the surface of the paste making it level with the top of the mould. The cement block thus prepared in the mould is the test block.

A) Initial Setting Time

1. Place the test block under the rod bearing the needle. Lower the needle gently in order to make contact with the surface of the cement paste and release quickly, allowing it to penetrate the test block.
2. Repeat the procedure till the needle fails to pierce the test block to a point 5.0 ± 0.5mm measured from the bottom of the mould.

The time period between the time, water is added to the cement and the time, the needle fails to pierce the test block by 5.0 ± 0.5mm measured from the bottom of the mould, is the initial setting time.

B) Final Setting Time:-

1. Replace the above needle by the one with an annular attachment.
2. The needle makes an impression therein, while the attachment fails to do so.

The period elapsing between the time, water is added to the cement and the time, the needle makes an impression on the surface of the test block, while the attachment fails to do so, is the final setting time.

Fig (4.1) Vicat Apparatus

4.1.2 Tests on Aggregates:-

4.1.2.1 Sieve Analysis

The aim of test is it determine the particle size distribution of fine and coarse aggregates by sieving as per IS: 2386 (Part I) – 1963 shown fig (4.2).

- **Procedure is summarized as follow:**

1. The test sample is dried to a constant weight at a temperature of 110 + 5oC and weighed.

2. The sample is sieved by using a set of IS Sieves.
3. On completion of sieving, the material on each sieve is weighed.
4. Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight.
5. Fineness modulus is obtained by adding cumulative percentage of aggregates retained on each sieve and dividing the sum by 100.

- **Results is summarized as follow:**

1. The results should be calculated and reported as:
2. The cumulative percentage by weight of the total sample.
3. The percentage by weight of the total sample passing through one sieve and retained on the next smaller sieve, to the nearest 0.1 percent.
4. The results of the sieve analysis may be recorded graphically on a semi-log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate.

Fig (4.2) Sieves Size

4.1.2.2 Specific Gravity and Water Absorption

The aim of test is it determining the specific gravity of aggregates given fig (4.3).

- **Procedure is summarized as follow:**

(1) Determine and record the weight of the empty clean and dry pycnometer, WP.
(2) Place 125g of a dry soil sample (passed through the sieve No. 10) in the pycnometer. Determine and record the weight of the pycnometer containing the dry soil, WPS.

(3) Add distilled water to fill about half to three-fourth of the pycnometer. Soak the sample for 10 minutes.

(4) Apply a partial vacuum to the contents for 10 minutes longer, to remove the entrapped air.

(5) Stop the vacuum and carefully remove the vacuum line from pycnometer.

(6) Fill the pycnometer with distilled (water to the mark), clean the exterior surface of the pycnometer with a clean, dry cloth.

Determine the weight of the pycnometer and contents, WB.

(7) Empty the pycnometer and clean it. Then fill it with distilled water only (to the mark). Clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and distilled water, WA.

(8) Empty the pycnometer and clean it.

Calculations

$$\text{Specific gravity } (G_S) = \frac{W0}{W0+(WA-WB)}$$

Where:

W0 = weight of sample of oven-dry soil, g = WPS - WP

WA = weight of pycnometer filled with water

WB = weight of pycnometer filled with water and soil

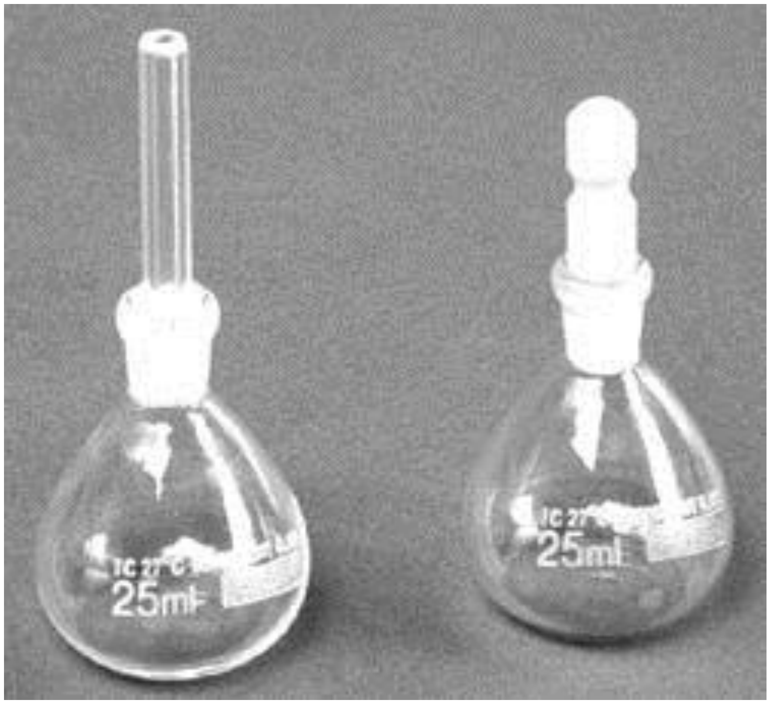


Fig (4.3) Specific Gravity Apparatus (pycnometer)

4.1.2.3 Bulk Density and Voids

This method of test covers the procedure for determining unit weight or bulk density and void of aggregates.

- **Procedure is summarized as follow:**

1. Measure the volume of the cylindrical metal measure by pouring water into the metal measure and record the volume “V” in liter.
2. Fill the cylindrical metal measure about one-third full with thoroughly mixed aggregate and tamp it 25 times using tamping bar.
3. Add another layer of one-third volume of aggregate in the metal measure and give another 25 strokes of tamping bar.
4. Finally fill aggregate in the metal measure to over-flowing and tamp it 25 times.
5. Remove the surplus aggregate using the tamping rod as a straightedge.
6. Determine the weight of the aggregate in the measure and record that weight “W” in kg.

- **Calculation for Compacted Bulk Density**

Compacted unit weight or bulk density = W/V

Where,

W = Weight of compacted aggregate in cylindrical metal measure, kg

V = Volume of cylindrical metal measure, liter

- **Calculation of Voids**

The percentage of voids is calculated as follows:

Percentage of voids = [(G – ϒ)/G]*100

Where

G = Specific gravity of the aggregate

ϒ = Bulk density in kg/liter

4.2 Tests on Fresh Concrete

Concrete is tested to ensure that the material that was specified and bought is the same material delivered to job site. There are a dozen different tests for freshly mixed concrete as follow:

4.2.1 Workability (Slump Test):-

The aim of test is it determines the workability of fresh concrete by slump test as per IS: 1199 – 1959 shown fig (4.4).

- **Procedure is summarized as follow:**

(1) The internal surface of the mould is thoroughly cleaned and applied with a light coat of oil.

(2) The mould is placed on a smooth, horizontal, rigid and non-absorbent surface.

(3) The mould is then filled in four layers with freshly mixed concrete, each approximately to one-fourth of the height of the mould.

(4) Each layer is tamped 25 times by the rounded end of the tamping rod.

(5) After the top layer is rotted, the concrete is struck off the level with a trowel.

(6)The mould is removed from the concrete immediately by raising it slowly in the vertical direction.

(7)The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured. This difference in height in mm is the slump of the concrete.

The slump measured should be recorded in mm of subsidence of the specimen during the test. Any slump specimen, whom collapses or shears off laterally, gives incorrect result and if this occurs, the test should be repeated with another sample.

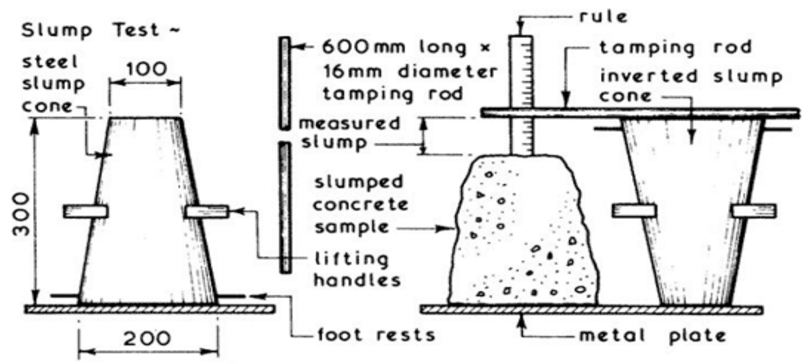


Fig (4.4) Slump Test Mould

4.3 Tests on Hardened Concrete

There are a dozen different tests for harden concrete as follow:

4.3.1 Compression Test:-

The aim of test is it determine the compressive strength of concrete specimens as per IS: 516 – 1959 using crashing machine shown fig (4.6).

- **Procedure is summarized as follow:**

1. The specimens, prepared according to IS: 516 - 1959 and stored in water, should be tested immediately on removal from the water and while still in wet condition. Specimens when received dry should be kept in water for 24hrs before they are taken for testing. The dimensions of the specimens, to the nearest 0.2mm and their weight should be noted before testing.
2. The bearing surfaces of the compression testing machine should be wiped clean and any loose sand or other material removed from the surfaces of the specimen, which would be in contact with the compression platens.
3. In the case of cubical specimen, the specimen should be placed in the machine in such a manner that the load could be applied to the opposite sides of the cubes, not to the top and the bottom. The axis of the specimen should be carefully aligned with the centre of thrust of the spherical seated

platen. No packing should be used between the faces of the test specimen and the steel platen of the testing machine. As the spherically seated block is brought to rest on the specimen, the movable portion should be rotated gently by hand so that uniform seating is obtained.

4. The load should be applied without shock and increased continuously at a rate of approximately 140kg/sq.cm/minute until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen should then be recorded and the appearance of the concrete and any unusual features in the type of failure should be noted.

- **Calculation of compression test**

The measured compressive strength of the specimen should be calculated by dividing the maximum load applied to the specimen during the test by the cross - sectional area, calculated from the mean dimensions of the section and should be expressed to the nearest kg/sq.cm. An average of three values should be taken as the representative of the batch, provided the individual variation is not more than ±15% of the average. Otherwise repeat tests should be done. A correction factor according to the height/diameter ratio of the specimen after capping should be obtained from the curve given shown fig (4.5).

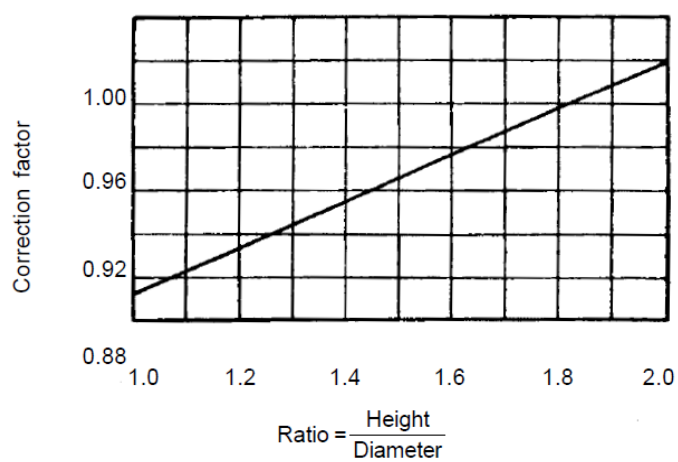


Fig (4.5) Correction factor for height-diameter ratio of a core

The product of this correction factor and the measured Compressive strength is known as the corrected compressive Strength, this being the equivalent strength of cylinder having a Height/diameter ratio of two. The equivalent cube strength of the

Concrete should be determined by multiplying the corrected Cylinder strength by 1.25.

The following information should be included in the report on each test specimen:

1. Identification mark.
2. Date of test.
3. Age of specimen.
4. Curing conditions, including date of manufacture of specimen.
5. Weight of specimen.
6. Dimensions of specimen.
7. Cross-sectional area.
8. Maximum load.
9. Compressive strength.
10. Appearance of fractured faces of concrete and type of Fracture, if unusual.

Fig (4.6) Crashing Machine

4.4 Concrete Mix Design

4.4.1American Method of Selection of Mix Proportions

The ACI Standard Practice ACI 211.1-91de- scribes a method of selection of mix proportions of concrete containing Portland cement alone or together with other cementitious materials, and containing also admixtures. It should be emphasized that the method provides a first approximation of mix proportions to be used in trial mixes. In essence, the method of ACI 211.1-91 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 de- scribed.

Step 1: Target means strength, Choice of slump

Required increase in strength Table (4.1)

At the time of mix proportioning, the slump will have been determined by the exigencies of construction. It should be noted that slump should be specified not only at the minimum end, but a maximum value should also be specified. This is necessary to avoid segregation when the mix, which has not been selected to have a higher slump, suddenly becomes ‘wet’ given in Table (4.2).

Table (4.1) Required Increase in Strength for Specified Compressive Strength When no Test Records are Available to ACI 318-05

Specified compressive strength MPa	Required increase in strength MPa
Less than 21	7
21 to 35	8.5
35 or more	10

Table (4.2) Suggested Values of Slump for Deferent Type of Structures ACI 211.1-91

Type of construction	Range of slump (mm)
Reinforced foundation, wall	20 – 80
Plain footing, caissons	20 – 80
Beam,reinforced wall	20 – 100
Bullding ,columns	20 – 100
Pavement ,slabs	20 – 80
Mass concrete	20 – 80

Step 2: Choice of maximum size of aggregate

This, too, will have been decided, usually by the structural designer, bearing in mind the geometric requirements of member size and spacing of reinforcement, or alternatively for reasons of availability.

Step 3: Estimate of water content and air content

The water content required to produce a given slump depends on several factors: the maximum size of aggregate, its shape, texture, and grading; the content of en-trained air; the use of admixtures with plasticizing or water-reducing properties; and the temperature of concrete. Tables relating slump to these properties have to be used, unless direct experience is available.

Can be used; a selection of these is given in Table (4.3) For use in practice, notes to this table and comments in ACI 211.1-91, which are not reproduced here, should be taken into account.

The values of Table (4.3) are typical for well- shaped angular aggregates having what is considered to be 'good' grading. When the coarse aggregate is rounded, the water requirement per cubic meter of concrete can be expected to be reduced by about 18 kg in the case of non-air en trained concrete, and by 15 kg for air-entrained concrete. Water-reducing admixtures, and even more so super plasticizers, will significantly re- duce the values of water given in Table (4.3). It should be remembered that the liquid part of ad- mixtures constitutes a part of the mix water.

Table (4.3) also gives the values of the amount of entrapped air which can be expected. These are useful in the calculation of density of compacted concrete and of yield.

Table (4.3) Approximate Mixing Water and Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregate in ACI 211.1-91

Slump, mm	**Water, Kg/m³ Of concrete**						
	9.5	**12.5**	**19**	**25**	**37.5**	**50**	**75**
Non-air							
25-50	207	199	190	179	166	154	130
75-100	228	216	205	193	181	169	145
150-175	243	228	216	202	190	178	160
Amount of entrapped air %	3	2.5	2	1.5	1	0.5	0.3
Air-in							

25-50	181	175	168	160	150	142	122
75-100	202	193	184	175	165	157	133
150-175	216	205	197	184	174	166	154
Extreme exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5

Step 4: Selection of water/cement ratio

There are two criteria for the selection of the water/ cement ratio: strength and durability. As far as the compressive strength is concerned, the average value aimed at must exceed the specified 'minimum' strength by an appropriate margin

The term 'cement' refers to the total mass of cementations materials used; their choice is governed by numerous factors, such as heat development, rate of gain of strength, and resistance to various forms of attack, so that the type of blended cement to be used has to be established at the outset of mix proportioning. It is for the actual cement to be used that the relation between strength and the water/ cement ratio has to be established over a certain range of strengths.

As far as durability is concerned, the water/ cement ratio may well be specified by the structural designer or by an appropriate design code. What is vital is that the water/ cement ratio chosen is the Lower of the two values emanating from strength and durability requirements. Given in Table (4.4)

When different cementitious materials are used, it should be remembered that they have varying values of specific gravity: typical values are 3.15 for Portland cement, 2.90 for ground granulated blast furnace slag, and 2.30 for fly ash.

Table (4.4) Relation Between Water/Cement Ratio and Average Compressive Strength of Concrete According to ACI 211.1-91

Compressive strength at 28 day (N/mm^2)		Effective water/cement ratio
	Non-air-entrained concrete	Air-entrained concrete
45	0.38	-
40	0.43	-
35	0.48	0.4
30	0.55	0.46
25	0.62	0.53
20	0.7	0.61
15	0.8	0.71

Step 5: Calculation of cement content

The outcome of Steps 3 and 4 gives the cement content directly: it is the water content divided by the water/ cement ratio. If, however, from durability considerations, there is a requirement for certain minimum cement content, the larger of the two values must be used.

Occasionally, from heat development considerations, the specification imposes maximum cement content. Clearly, this must be observed. Heat development is of particular concern in mass concrete, and mix proportioning for that type of concrete is specifically covered in ACI 211.1-91.

Step 6: Estimate of coarse aggregate content

Here, the assumption is made that the optimum ratio of the bulk volume of coarse aggregate to the total volume of concrete depends only on the maximum size of aggregate and on the grading of fine aggregate. The shape of the coarse aggregate particles does not directly enter the relation because, for instance, a crushed aggregate has a greater bulk volume for the same mass (that is, a lower bulk density) than a well-rounded aggregate. Thus, the shape factor is automatically taken into account in the determination of the bulk density. Table (4.5) gives values of the optimum volume of coarse aggregate when used with fine aggregates of different fineness moduli.

This volume is converted into mass of coarse aggregate per cubic meter of concrete by multiplying the value from the table by the oven-dry rodded mass of the aggregate (in kg/m^3).

Table (4.5) Bulk Volume of Coarse Aggregate per Unit Volume of Concrete

Maximum size of Aggregate (mm)	**Bulk volume**			
	2.4	**2.6**	**2.8**	**3.00**
9.5	0.5	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.6
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.8	0.78	0.76
150	0.87	0.85	0.83	0.81

Step 7: Estimate of fine aggregate content

At this stage, the mass of fine aggregate is the only remaining unknown quantity. The absolute volume of this mass can be obtained by subtracting the sum of the absolute volumes of water, cement, entrained air, and coarse aggregate from The volume of concrete that is $1m^3$.

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 multiplied by the density of water (1000 kg/m^3). The absolute volume of fine aggregate is converted into mass by multiplying this volume by the specific gravity of the fine aggregate and by the density of water.

Alternatively, the mass of fine aggregate can be obtained directly by subtracting the total mass of other ingredients from the mass of a unit volume of concrete, if this can be estimated from experience. This approach is slightly less accurate than the absolute volume method.

Step 8: Adjustments to mix proportions

As in any process of selection of mix proportions, trial mixes have to be made. Advice, by way of some rules of thumb, for adjustments to the mix, is given in ACI 211.1-91.

In general terms, it is important to remember that, if workability is to be changed, but the strength is to remain un- affected, the water/ cement ratio must remain un-altered. Changes can be made in the aggregate/ cement ratio or, if suitable aggregates are avail- able, in the grading of the aggregate; the influence of grading on workability.

Conversely, changes in strength but not in workability are made by varying 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/water+cement+aggregate

is approximately constant. The above mix proportioning method of the

American Concrete Institute can readily be programmed for computer use; an example of manual calculation is given later in this section.

4.4.2 British Method of Mix Selection (mix design)

The current British method is that of the Department of the Environment revised in 1997.

Similarly to the ACI approach, the British method explicitly recognizes the durability requirements in the mix selection. The method is applicable to normal weight concrete made with Port- land 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 sizes of aggregate are re- cognized: 40, 20, and 10 mm.

In essence, the British method consists of 5 steps, as follows.

Step 1. This deals with compressive strength for the purpose of determining the water/cement ratio. The concept of target mean strength is introduced, this being equal to the specified characteristic strength plus a margin to allow for variability. The target mean strength is thus similar in concept to the mean compressive strength of ACI 318R-02.Table (4.6),Table (4.7) gives calculate the target mean strength.

Table (4.6) Standard Deviation

Defective rate%	K
10	1.28
5	1.64
2.5	1.96
1	2.33

Table (4.7) Required Increase in Strength

Strength N/mm^2	Standard deviation N/mm2	
	<20	**>20**
10	2	4
20	4	8
30	4	8
40	4	8
50	4	8

The relation between strength of concrete and the water/ cement ratio is dealt with rather ingeniously. Certain strengths are assumed at water/ cement ratio of 0.5 for different cements and types of aggregate Table (4.8). The latter factor recognizes the significant influence of aggregate on strength. The data of Table 3.8 apply to a hypothetical concrete of medium richness cured in water at 20 °C (68 °F); richer mixes would have a relatively higher early strength because they gain strength more rapidly.

Table (4.8) Approximate Compressive Strength of Concrete Made with a Free Water/ Cement Ratio of 0.5 According to the 1997 British Method

Type of Cement	Type of Coarse aggregate	Compressive Strength MPa			
		3	7	28	91
OPC type I	Uncrushed	22	30	42	49
Sulfate-resisting typeV	Crushed	27	36	49	56
Rapid-hardening typeIII	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

From Table (4.8), we find the appropriate value of strength (at a water/ cement ratio of 0.5) corresponding to the type of cement, type of aggregate, and age which are to be used. Turning to Fig (4.7), we mark a point corresponding to this strength at a water/ cement ratio of 0.5. Through this point, we now draw a curve 'parallel' (or, strictly speaking, affine) to the neigh bouring curves. Using this new curve, we read off (as abscissa) the water/ cement ratio corresponding to the specified target mean strength (as the ordinate). A possible need for a lower water/ cement ratio for reasons of durability must not be forgotten. Table (4.9) givens max free water/cement ratio.

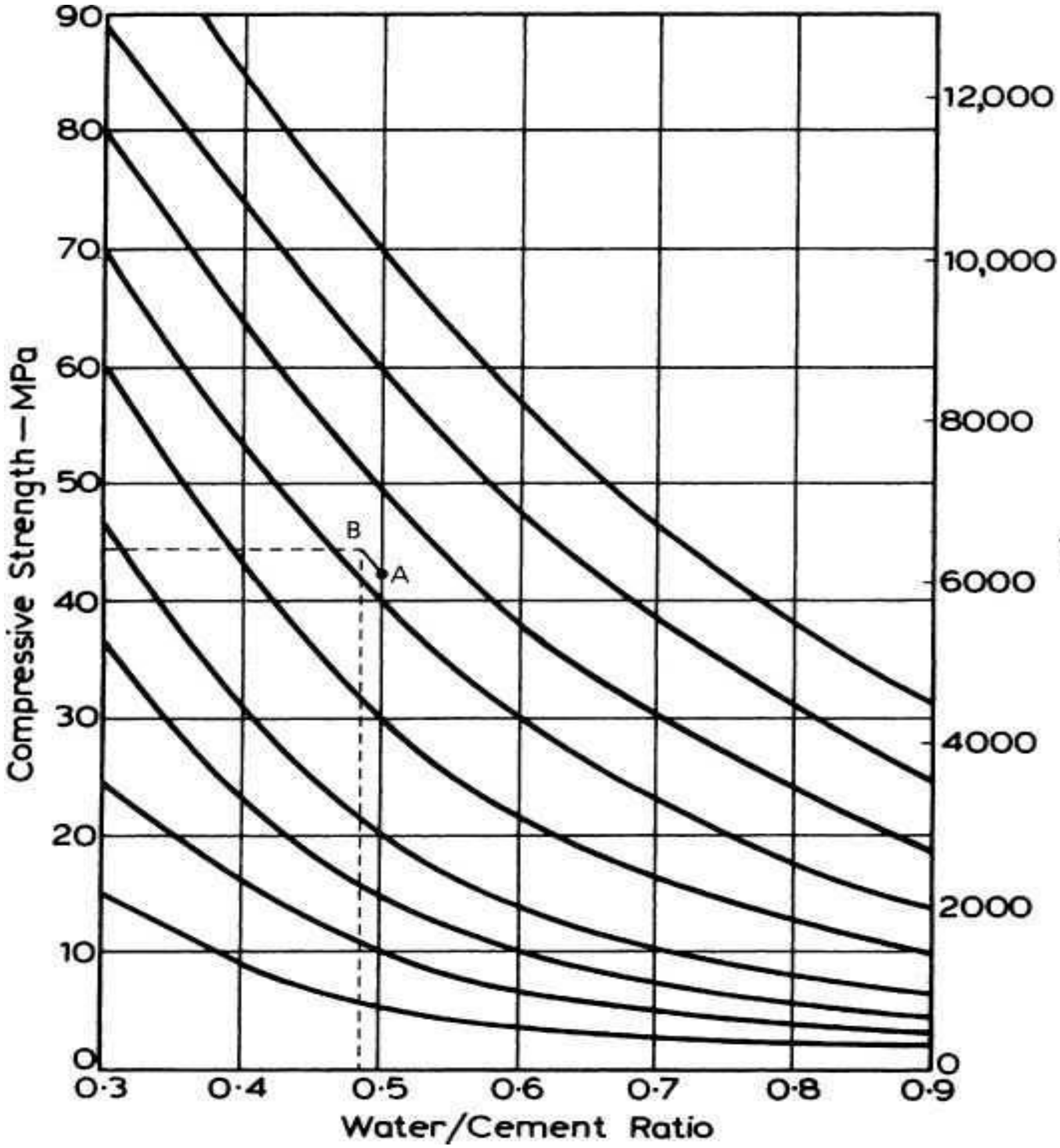


Fig (4.7) Relation between compressive strength and free water/cement ratio for use in the British mix selection method (see Table 4.8) (Crown copyright)

Table (4.9) Requirement of BS8110 to Ensure Durability Under Specified Exposure Condition of Reinforced Concrete

Condition of exposure		Nominal cover of concrete in (mm)			
Mild	25	20	20	20	20
Moderate	-	35	30	25	20
Severe	-	-	40	30	25
Very severe	-	-	50*	40*	30*
Extreme	-	-	-	60*	50*
Maximum W/C	0.65	0.6	0.55	0.5	0.45
Minimum content of cement Kg	275	300	325	350	400
Minimum grade Mpa	30	35	40	45	50

Step 2. This deals with the determination of the water content for the required workability, expressed either as slump or as Vebe time, recognizing the influence of the maximum size of aggregate and its type, namely crushed or uncrushed. The relevant data are given in Table (4.10) it can be noted that the compacting factor is not used in mix selection, although it can be used for control purposes.

Table (4.10) Approximate Free Water Contents Required to Give Various Levels of Workability According to the 1997 British Method (Crown copyright)

Aggregate			**Water content Kg/m^3**		
Max size	**Type**	**Slump**	**0-10**	**10-30**	**30-60**
10	**Uncrushed**		**150**	**180**	**205**
	Crushed		**180**	**205**	**230**

20	Uncrushed	135	160	180
	Crushed	170	190	210
40	Uncrushed	115	140	160
	Crushed	155	175	190

Step 3. This determines the cement content, which is simply the water content divided by the water/cement ratio. This cement content must not conflict with any minimum value specified for reasons of durability or a maximum value specified for reasons of heat development.

Step 4. This deals with the determination of the total aggregate content. This requires an estimate of the fresh density of fully compacted concrete, which can be read of Fig (4.8) for the appropriate water content (from Step 2) and specific gravity of the aggregate. If this is unknown, the value of 2.6 for un- crushed aggregate and 2.7 for crushed aggregate can be assumed. The aggregate content is obtained by subtracting from the fresh density the value of the cement content and

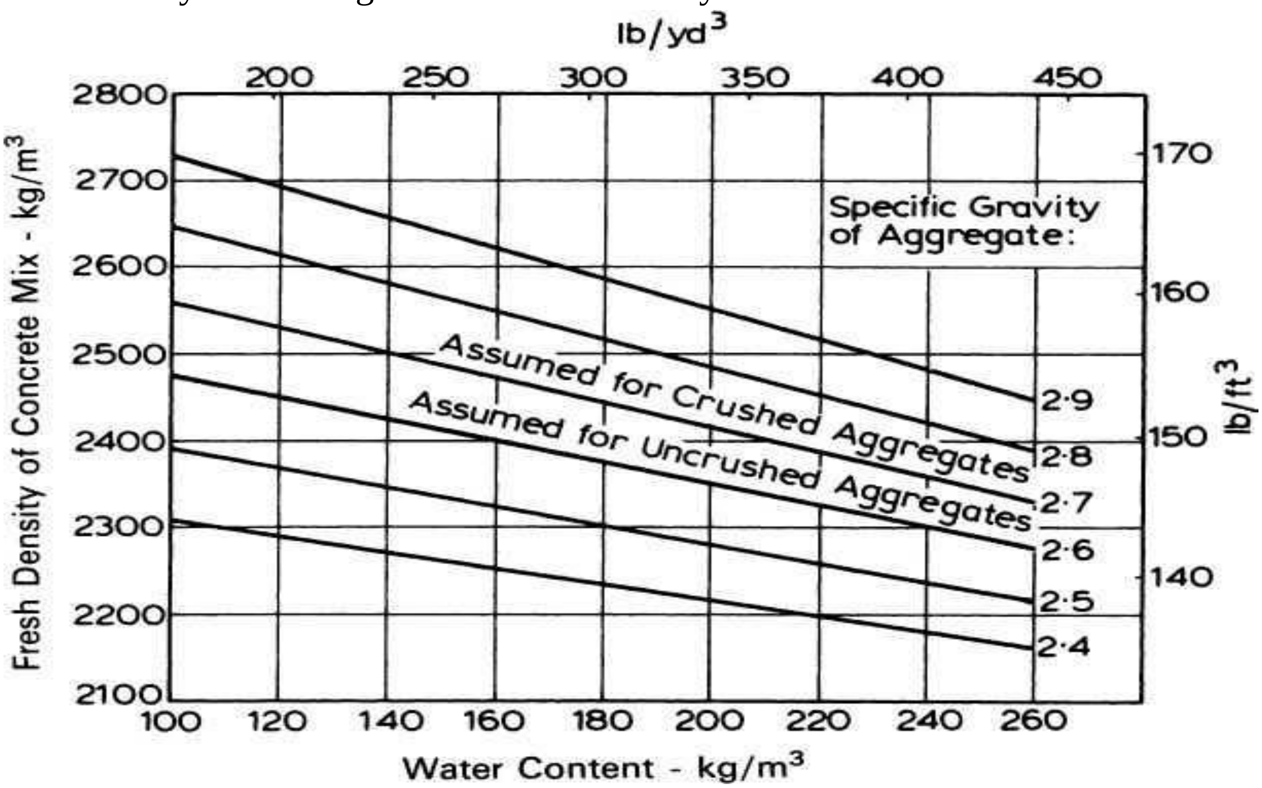
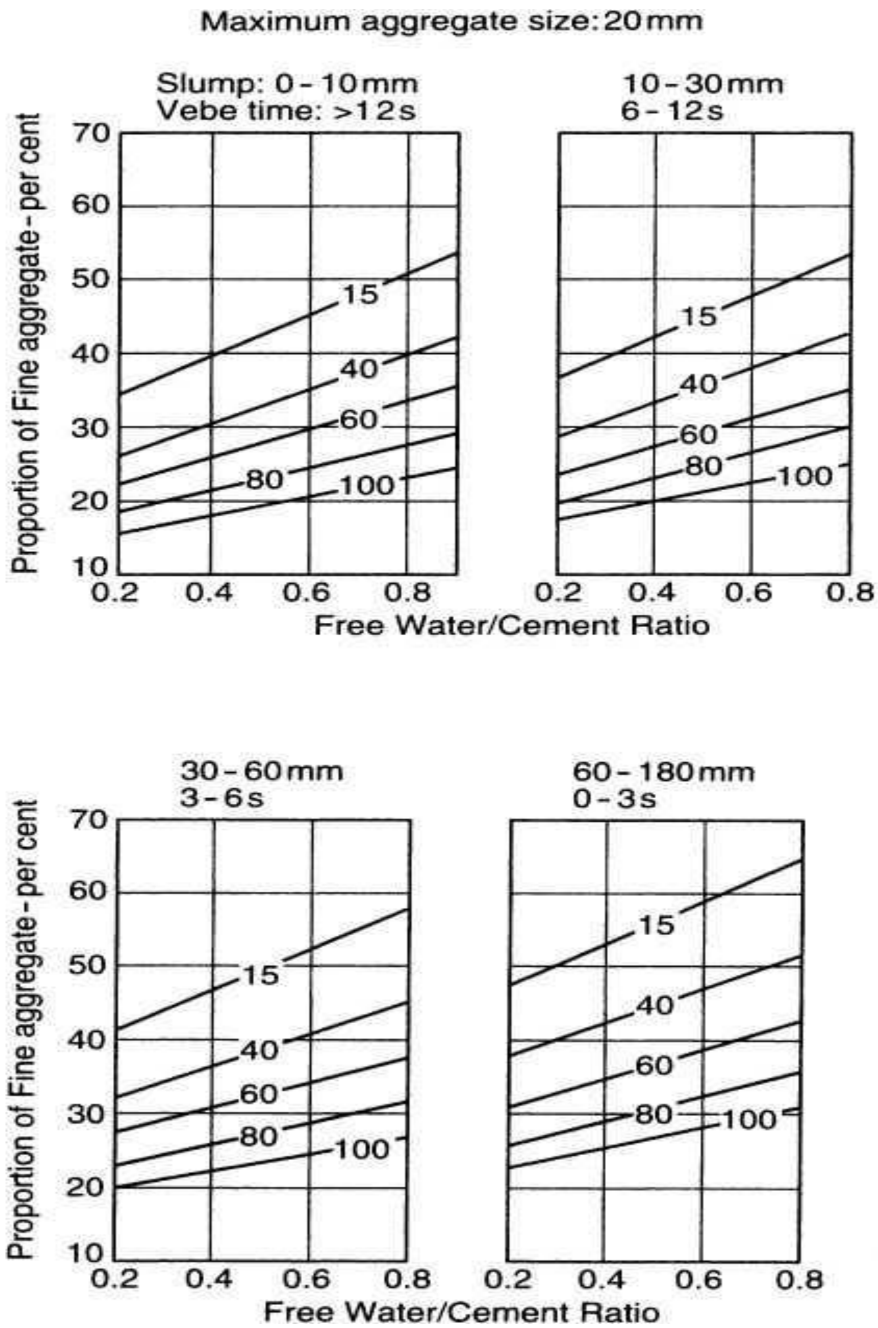


Fig (4.8) Estimated wet Density for Fully Compacted Concrete (Specific gravity is given for saturated and surface-dry aggregate) (Crown copyright)

Step 5. This determines the proportion of fine aggregate in the total Aggregate, using the recommended values of Fig (4.9); only data for 20 and 40 mm aggregates are shown. The governing factors are: the maxim- um size of aggregate, the level of workability, the water/cement ratio, and the percentage of fine aggregate passing the 600 μ m sieve. Other aspects of the grading of the fine aggregate are ignored and so is the grading of the coarse aggregate. Once the proportion of fine aggregate has been obtained, multiplying it by the total aggregate content gives the content of fine aggregate.



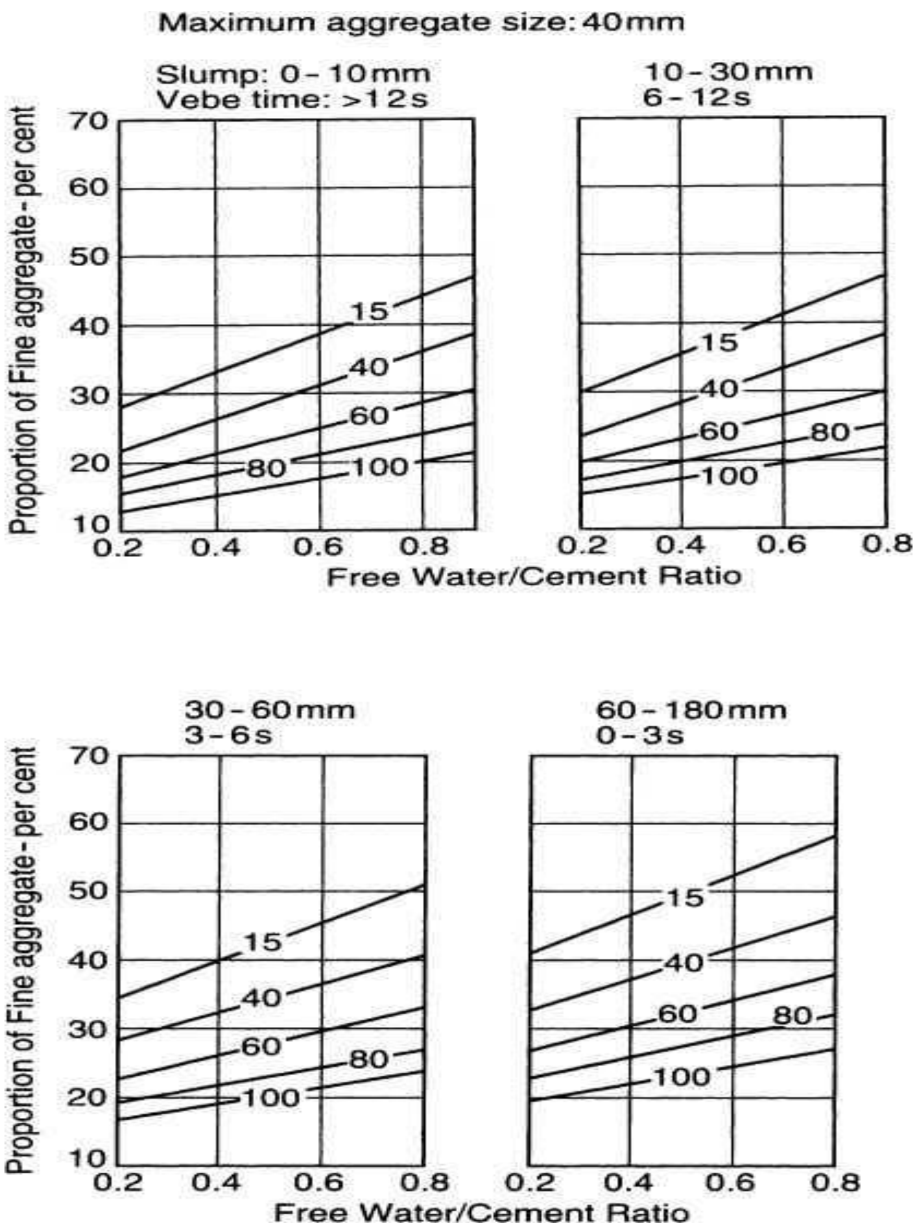


Fig (4.9) Recommended Proportion of Fine Aggregate (expressed as percentage of total aggregate) as a Function of Free Water/Cement Ratio for Various Workabilities and Maximum Sizes (Numbers refer to percentage of fine aggregate passing 600 µm sieve) (Building Re- search Establishment; Crown copyright)

Chapter Five

ANALYSIS AND DISCUSSIONS OF RESULTS

5.1 General

It was conducted laboratory tests on the components of concrete mix (cement, coarse aggregate, fine aggregate, slag and fresh concrete, concrete hardened) in order to see how quality grade of these components and their influence on the compressive strength of concrete.

5.2 Presentation of Result Tests

Laboratory tests have been obtained for the results as shown below:-

5.2.1 Results of Cement Tests:-

From tests was made of cement (consistency, the initial and the final setting time, Analysis Chemical, Compressive strength) to ordinary Portland cement results were as shown in table (5.1), (5.2) below:

Table (5.1) Analysis Chemical of Portland Cement

Oxide	%
Na_2O	0.537
MgO	1.807
AL_2O_3	5.84
SiO_2	23.453
P_2O_5	0.123
SO_3	5.069
Cl	0.02
K_2O	0.304
CaO	58.051
TiO_2	0.485
Cr_2O_3	0.012
MnO	0.099
Fe_2O_3	3.99
CuO	0.09
ZnO	0.007
Rb_2O	0.002
SrO	0.065
Y_2O_3	0.002
ZrO_2	0.01
NiO	0.009
BaO	0.025

Table (5.2) Cement Test

Consistency %	Initial setting time(min)	Final setting time(min)	Compressive strength N/mm2 28 day
33	43	183	42.9

5.2.2 Aggregate Tests

5.2.2.1 The Results of Fine Aggregate Tests

Calculations of sieve analysis of fine aggregate a sample of fine aggregate with mass of 500 g is passed through the sieves shown table (5.3), table (5.4).

Table (5.3) Sieve Analysis of Sand (ASTM)

Sieve size	Mass retained(g)	Percentage retained	Cumulative retained	Cumulative percentage passing	Cumulative percentage retained
4.75mm	0	0	0	100	0
2.36mm	14	2.8	14	97.2	2.8
1.18mm	71	14.2	85	83	17
600µm	121	24.2	206	58.8	41.2
300µm	202	40.4	408	18.4	81.6
150µm	80	16	488	2.4	97.2
Pan	12	2.4	500	-	-
Total	500	-	-	-	240.2

Fineness modulus= 240.2/100= 2.4

Table (5.4) Sieve Analysis of Sand (BS)

Sieve size	Mass retained(g)	Percentage retained	Cumulative retained	Cumulative percentage passing	Cumulative percentage retained
5mm	0	0	0	100	0
2.36mm	14	2.8	14	97.2	2.8
1.18mm	71	14.2	85	83	17
600µm	121	24.2	206	58.8	41.2
300µm	202	40.4	408	18.4	81.6
150µm	80	16	488	2.4	97.2
Pan	12	2.4	500	-	-
Total	500	-	-	-	240.2

Fineness modulus= 240/100= 2.4

5.2.2.2 Results of Coarse Aggregate Tests

a sample of coarse aggregate with mass of 1000g is passed through the sieves shown in the following and masses retained on each sieve are as shown table (5.5),table (5.6).

Table (5.5) Sieve Analysis of Coarse Aggregates (ASTM)

Sieve size(mm)	Mass retained(g)	Cumulative retained	Cumulative percentage passing	Cumulative percentage retained
37.5	0	0	100	0
25	0	0	100	0
19	198.9	198.9	80.1	19.9
12.5	588..97	787.87	21.21	78.79
9.5	212.13	1000	-	100
Pan	-	-	-	-

Table (5.6) Sieve Analysis of Coarse Aggregates (BS)

Sieve size(mm)	Mass retained(g)	Cumulative retained	Cumulative percentage passing	Cumulative percentage retained
37.5	0	0	100	0
20	148.6	148.6	85.14	14.86
14	430.8	579.4	42.06	57.94
10	420.6	1000	-	100
Pan	-	-	-	-

Maximum aggregate size =20mm

5.2.3 Slag Test

Table (5.7) Analysis Chemical of Steel Slag

Oxide		
Na_2O	0.569	%
MgO	7.047	%
Al2O3	9.384	%
SiO_2	26.151	%
P_2O_5	0.475	%
SO_3	0.207	%
Cl	0.031	%
K_2O	0.073	%

CaO	26.752	%
TiO_2	0.835	%
Cr_2O_3	1.060	%
MnO	4.484	%
Fe_2O_3	22.526	%
NiO	0,011	%
CuO	0,027	%
ZnO	0.076	%
SrO	0.065	%
ZrO_2	0.027	%
Nb_2O_5	0.010	%
BaO	0.191	%

5.2.4 Concrete mix design Proportions

5.2.4.1 British Method

Table (5.8): Details of Concrete Mix Proportion for ($20N/mm^2$) of Concrete for Slag

S N	Slag%	W/C Ratio	Mix Proportion(kg/m^3) cement	slag	sand	agg	water
1	0	0.6	300	0	665	1235	180
2	10	0.6	270	30	665	1235	180
3	20	0.6	240	60	665	1235	180
4	30	0.6	210	90	665	1235	180
5	40	0.6	180	120	665	1235	180

Table (5.9): Details of Concrete Mix Proportion for ($25N/mm^2$) of Concrete for Slag

S N	Slag%	W/C Ratio	Mix Proportion(kg/m^3) cement	slag	sand	agg	water
1	0	0.52	350	0	630	1220	180
2	10	0.52	315	35	630	1220	180
3	20	0.52	280	70	630	1220	180
4	30	0.52	245	105	630	1220	180
5	40	0.52	210	140	630	1220	180

Table (5.10): Details of Concrete Mix Proportion for (30N/mm^2) of Concrete for Slag

S N	Slag%	W/C Ratio	Mix Proportion(kg/m^3) cement	slag	sand	agg	Water
1	0	0.49	370	0	620	1210	180
2	10	0.49	333	37	620	1210	180
3	20	0.49	296	74	620	1210	180
4	30	0.49	259	111	620	1210	180
5	40	0.49	222	148	620	1210	180

Table (5.11): Details of Concrete Mix Proportion for (35N/mm^2) of Concrete for Slag

S N	Slag%	W/C Ratio	Mix Proportion(kg/m^3) cement	slag	sand	agg	Water
1	0	0.45	400	0	595	1205	180
2	10	0.45	360	40	595	1205	180
3	20	0.45	320	80	595	1205	180
4	30	0.45	280	120	595	1205	180
5	40	0.45	240	160	595	1205	180

Table (5.12): Details of Concrete Mix Proportion for (40N/mm^2) of Concrete for Slag

S N	Slag%	W/C Ratio	Mix Proportion(kg/m^3) cement	slag	sand	agg	Water
1	0	0.41	440	0	565	1195	180
2	10	0.41	396	44	565	1195	180
3	20	0.41	352	88	565	1195	180
4	30	0.41	308	132	565	1195	180
5	40	0.41	264	176	565	1195	180

5.2.4.2 American Method

Table (5.13): Details of Concrete Mix Proportion for (20N/mm^2) of Concrete for Slag

S N	Slag%	W/C Ratio	Mix Proportion(kg/m^3) cement	slag	sand	agg	water
1	0	0.58	320	0	760	1060	185
2	10	0.58	288	32	760	1060	185
3	20	0.58	256	64	760	1060	185
4	30	0.58	224	96	760	1060	185
5	40	0.58	192	128	760	1060	185

Table (5.14): Details of Concrete Mix Proportion for (25N/mm^2) of Concrete for Slag

S N	Slag%	W/C Ratio	Mix Proportion(kg/m^3) cement	slag	sand	agg	water
1	0	0.5	370	0	720	1060	185
2	10	0.5	333	37	720	1060	185
3	20	0.5	296	74	720	1060	185
4	30	0.5	259	111	720	1060	185
5	40	0.5	222	148	720	1060	185

Table (5.15): Details of Concrete Mix Proportion for (30N/mm^2) of Concrete for Slag

S N	Slag%	W/C Ratio	Mix Proportion(kg/m^3) cement	slag	sand	agg	water
1	0	0.44	420	0	675	1060	185
2	10	0.44	378	42	675	1060	185
3	20	0.44	336	84	675	1060	185
4	30	0.44	294	126	675	1060	185
5	40	0.44	252	168	675	1060	185

Table (5.16): Details of Concrete Mix Proportion for (35N/mm^2) of Concrete for Slag

S N	Slag%	W/C Ratio	Mix Proportion(kg/m^3) cement	slag	sand	agg	water
1	0	0.4	465	0	645	1060	185
2	10	0.4	418.5	46.5	645	1060	185
3	20	0.4	372	93	645	1060	185
4	30	0.4	325.5	139.5	645	1060	185
5	40	0.4	279	186	645	1060	185

Table (5.17): Details of Concrete Mix Proportion for (40N/mm^2) of Concrete for Slag

S N	Slag%	W/C Ratio	Mix Proportion(kg/m^3) cement	slag	sand	agg	water
1	0	0.38	490	0	620	1060	185
2	10	0.38	441	49	620	1060	185
3	20	0.38	392	98	620	1060	185
4	30	0.38	343	147	620	1060	185
5	40	0.38	294	196	620	1060	185

5.2.5 Fresh and hardened Concrete Tests

5.2.5.1 Concrete mixtures according to British Standards

Table (5.18): Compressive Strength for Fcu 20 N/mm^2

S N	Slag%	Fcu at 7 day	Fcu at28 day	Slump
1	0	18.37	27.64	60
2	10	18.76	28.41	65
3	20	19.28	29.27	70
4	30	18.17	27.16	75
5	40	16.75	26.32	85

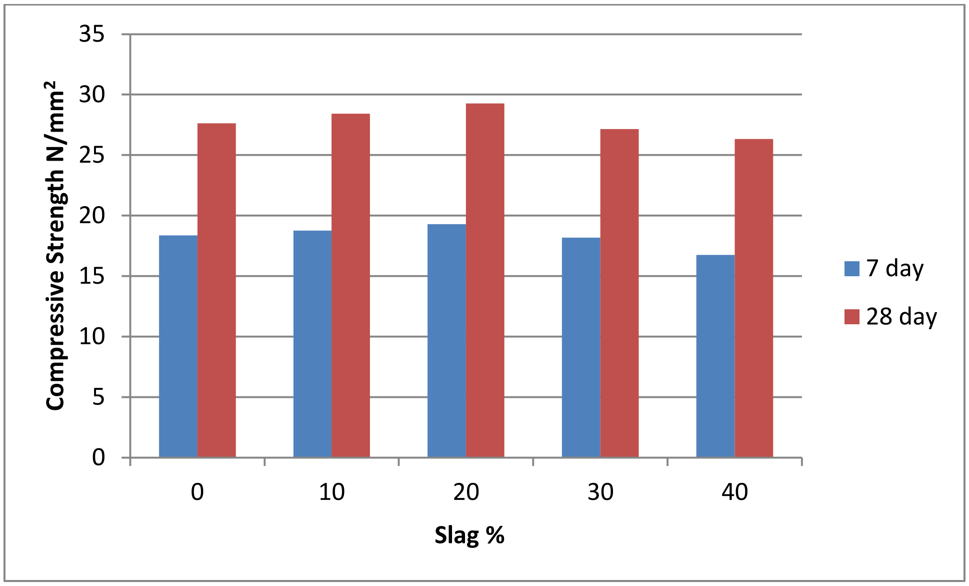


Fig (5.1) Compressive Strength for Fcu 20 N/mm^2

Table (5.19): Compressive Strength for Fcu 25 N/mm^2

S N	Slag%	Fcu at 7 day	Fcu at28 day	Slump
1	0	23.45	31.50	58
2	10	23.87	32.15	60
3	20	24.36	32.86	65
4	30	23.1	31.08	75
5	40	21.00	29.79	80

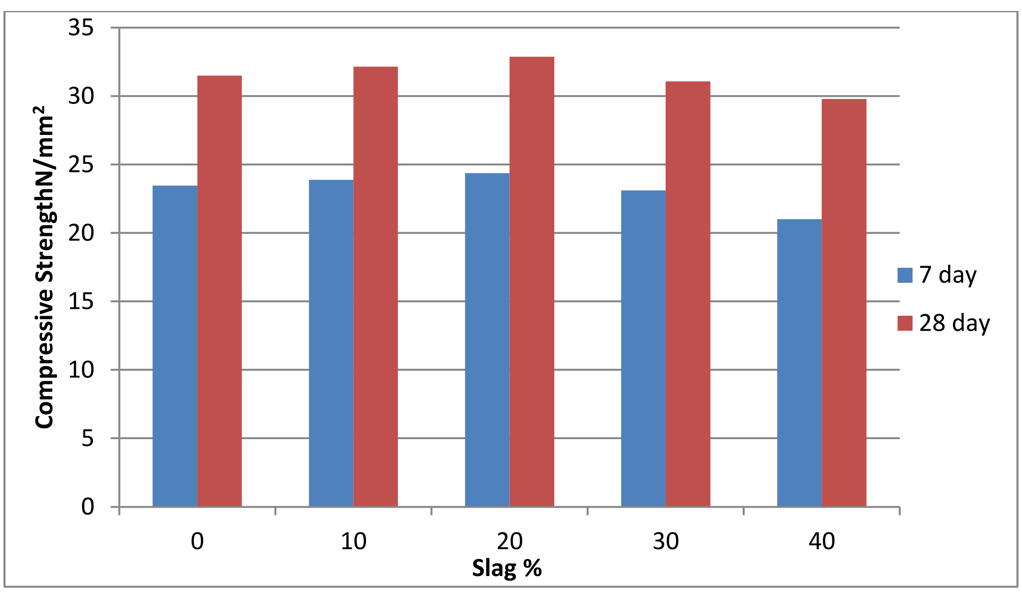


Fig (5.2) Compressive Strength for Fcu 25 N/mm^2

Table (5.20): Compressive Strength for Fcu 30 N/mm^2

S N	Slag%	Fcu at 7 day	Fcu at28 day	Slump
1	0	26.72	36.16	58
2	10	27.02	36.65	60
3	20	27.27	36.94	66
4	30	26.18	35.42	70
5	40	23.80	34	77

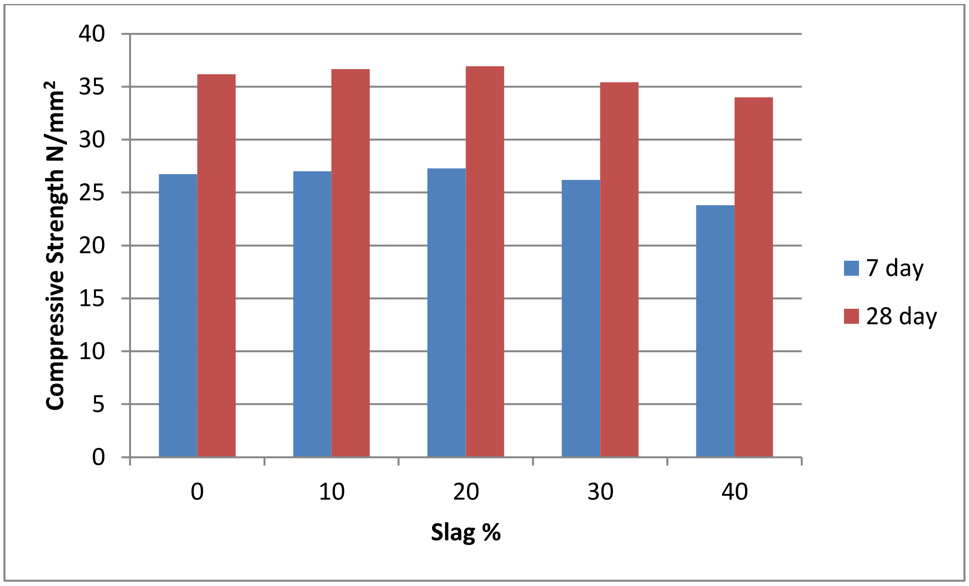


Fig (5.3) Compressive Strength for Fcu 30 N/mm^2

Table (5.21): Compressive Strength for Fcu 35 N/mm^2

S N	Slag%	Fcu at 7 day	Fcu at28 day	Slump
1	0	28.91	40.34	55
2	10	29.82	41.65	60
3	20	28.98	40.56	63
4	30	28.14	39.28	65
5	40	26.92	37.80	70

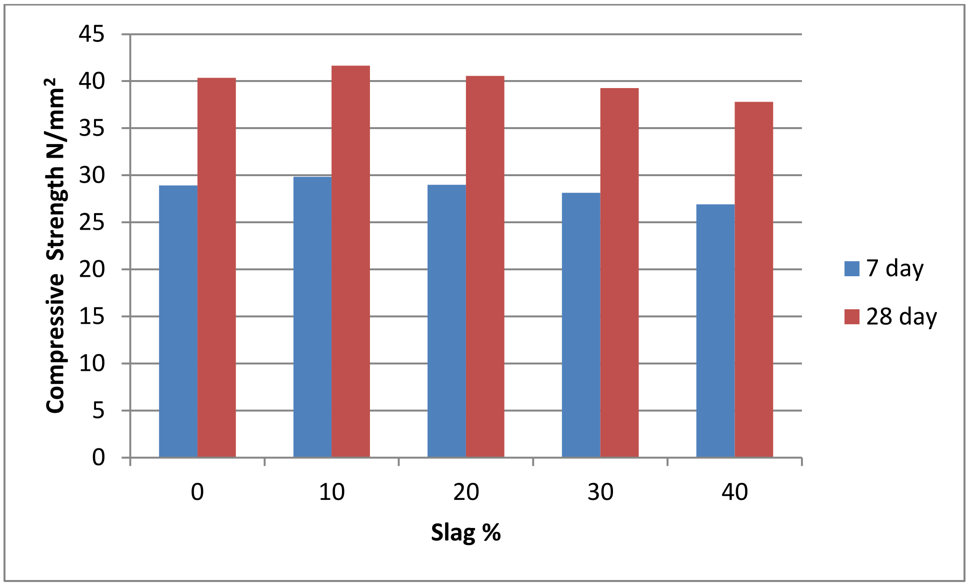


Fig (5.4) Compressive Strength for Fcu 35 N/mm^2

Table (5.22): Compressive Strength for Fcu 40 N/mm^2

S N	Slag%	Fcu at 7 day	Fcu at28 day	Slump
1	0	32.85	45.80	50
2	10	33.86	47.15	55
3	20	33.10	46.10	58
4	30	32.18	44.90	60
5	40	31.35	43.80	65

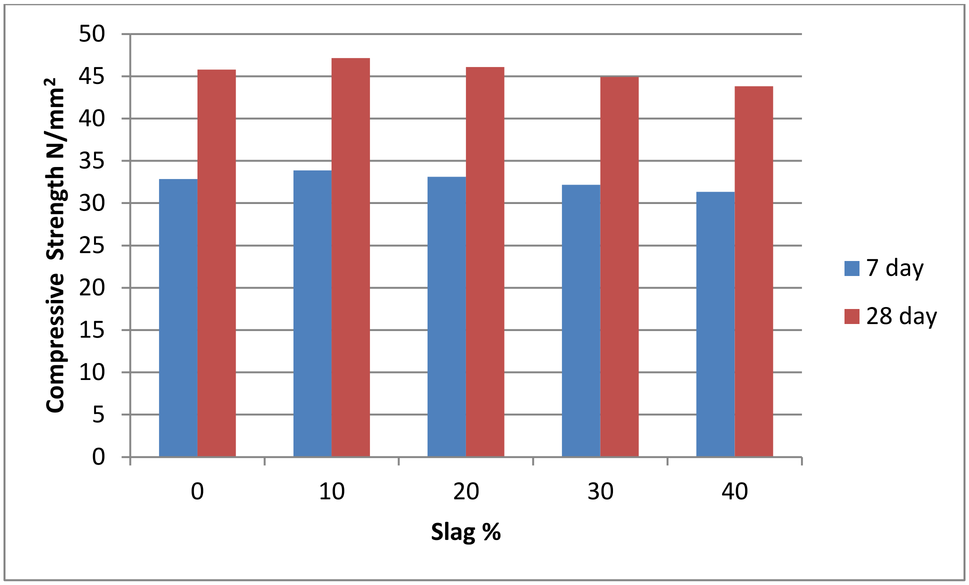


Fig (5.5) Compressive Strength for Fcu 40 N/mm^2

5.2.5.2 Concrete mixtures according to American Standards

Table (5.23): Compressive Strength for fc' 20 N/mm^2

S N	Slag%	fc' at 7 day	fc' at 28 day	Slump
1	0	18.53	27.90	75
2	10	18.92	28.65	80
3	20	19.2	29.50	96
4	30	18.12	27.25	105
5	40	17.64	26.46	110

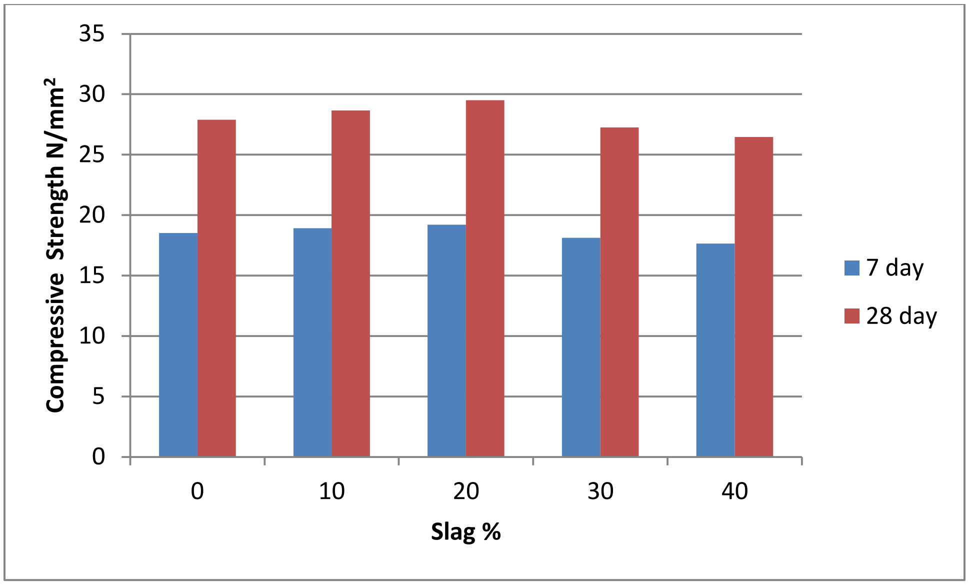


Fig (5.6) Compressive Strength for fc' 20 N/mm^2

Table (5.24): Compressive Strength for fc' 25 N/mm^2

S N	Slag%	fc' at 7 day	fc' at 28 day	Slump
1	0	22.16	30.50	70
2	10	22.97	31.04	75
3	20	23.45	31.64	80
4	30	22.02	29.80	85
5	40	21.48	29.50	90

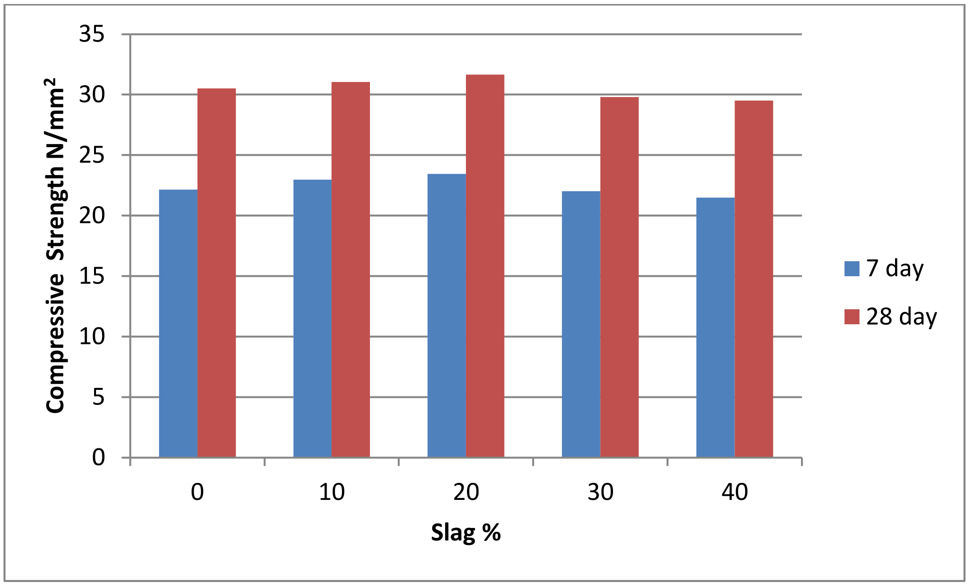


Fig (5.7) Compressive Strength for fc' 25 N/mm^2

Table (5.25): Compressive Strength for fc' 30 N/mm^2

S N	Slag%	fc' at 7 day	fc' at 28 day	Slump
1	0	25.93	35.16	72
2	10	26.71	36.40	78
3	20	26.31	35.60	83
4	30	25.3	34.35	85
5	40	24.62	33.72	88

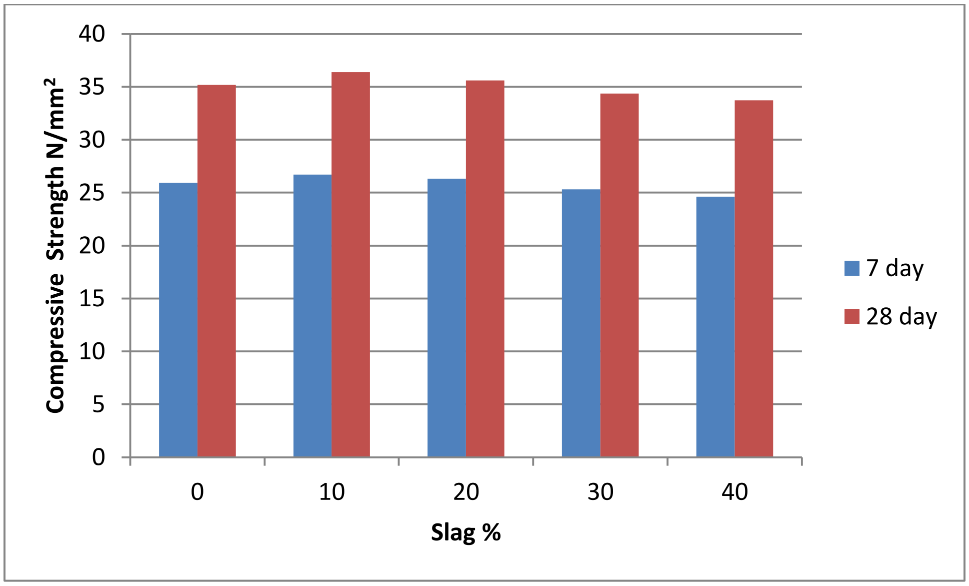


Fig (5.8) Compressive Strength for fc' 30 N/mm^2

Table (5.26): Compressive Strength for fc' 35 N/mm^2

S N	Slag%	fc' at 7 day	fc' at 28 day	Slump
1	0	28.6	40.06	70
2	10	29.15	41.33	75
3	20	28.70	40.20	80
4	30	27.83	39.02	83
5	40	27.02	37.66	85

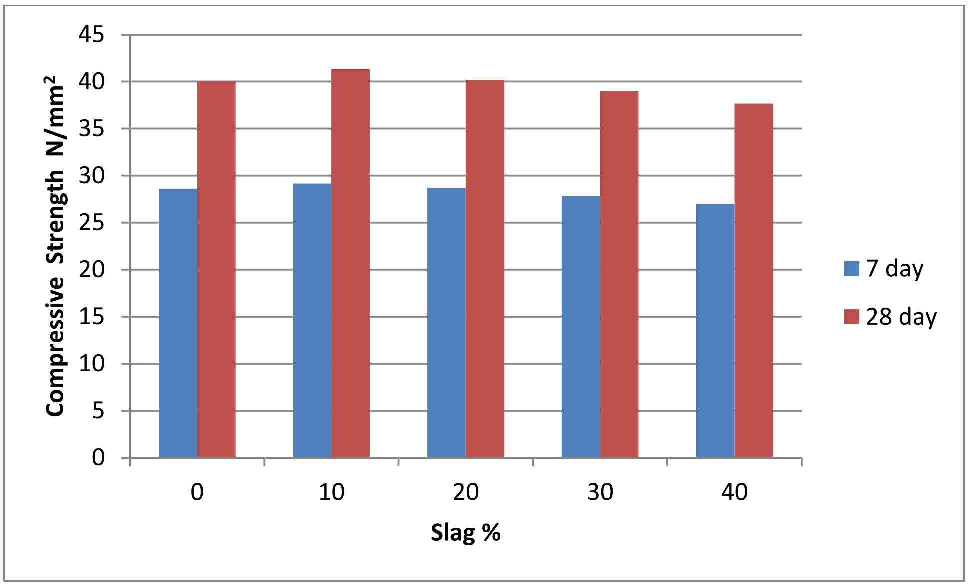


Fig (5.9) Compressive Strength for fc' 35 N/mm^2

Table (5.27): Compressive Strength for fc' 40 N/mm^2

S N	Slag%	fc' at 7 day	fc' at 28 day	Slump
1	0	32.97	45.70	58
2	10	33.12	46.87	60
3	20	33.00	45.86	65
4	30	31.80	44.39	70
5	40	31.00	43.51	77

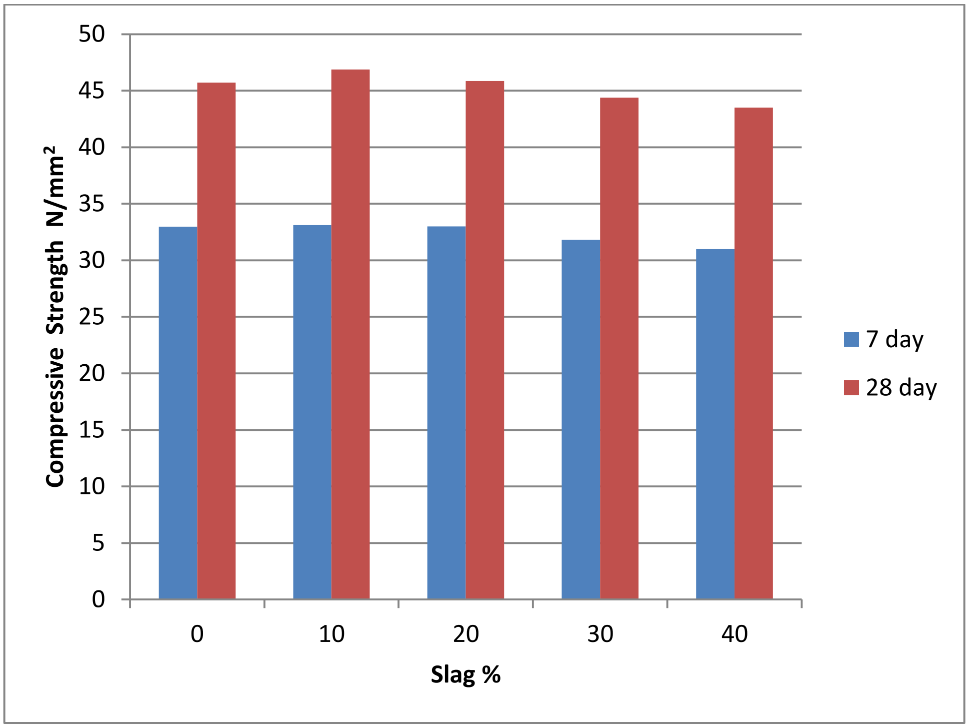


Fig (5.10) Compressive Strength for fc' 40 N/mm^2

5.3 Results Discussion

The results obtained from the different tests are summarized and discussed as following:

1. Fresh concrete

The basic of evaluation of workability of concrete and the effect of replaced the slag with cement for concrete on slump test for each concrete mixes.

Tables (5.18 to 5.27) shown the results of slump test for fresh concrete when replacing the slag with varying percentages of the cement weight the results showed an increase in workability with the increase in the proportion of slag.

2. Hardened Concrete:

1. In all cases compressive strength increased by age of concrete as shown Fig (5.1-5.10).

2. Compressive strength of concrete increased with replacing the steel slag to the ratio of (10-20) % of cement weight, comparison to standard mix as shown Fig (5.1-5.10).

3. Compressive strength of concrete decreased with increasing replacing the steel slag to the ratio of (30- 40) % of cement weight, comparison to standard mix as shown Fig (5.1-5.10).

4. The maximum compressive strength obtained at replacing the steel slag to the ratio 20% of cement weight at 7 days and at 28 days.

From the previous indicators it has been obtained that the optimum ratio of replacement the steel slag with cement which can be added to concrete to improve the compressive strength it is 20%.

Chapter Six
CONCLUSION & RECOMMENDATIONS

6.1 Conclusions

From this research and result obtained it can be conclude that:

1. In all cases compressive strength increase by age of concrete.
2. Maximum 28 days compressive strength of concrete was obtained by addition of 20% steel slag in concrete mixes.
3. In all age the compressive strength of (10-20) % steel slag in concrete mixes is more than 30% and 40%.
4. For fresh concrete the value of slump increased with increased amounts of steel slag.

6.2 Recommendations

From this research it can be recommended that:

- Use different types of steel slag.
- A number of additional laboratory experiments on the concrete hardened, such as tensile test.
- Study the possibility of replaced the steel slag for sand or aggregates.
- Use of slag partial replacement of cement for the concrete exposed to normal environmental conditions.

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APPENDIX

APPENDIX
1 mix design form (BS)

Stag item	reference and calculation	values
1		
1.1 required strength	specified	20 N/mm^2
	Table 4.6	proportion defective 5 %
1.2 standard deviation	table 4.7	8 N/mm^2
1.3 margin	C1	(k=1.64)1.64*8=13.12 N/mm^2
1.4 target mean strength	C2	20 +13.12=33.12 N/mm^2
1.5 slump		30-60 mm
1.6 max agg size		20 mm
1.7 free water content	table 4.10	180 Kg/m^3
1.8 free water/cement ratio	table 4.8fig 4.7	0.62
1.9 max free water/cement ratio	table 4.9	0.6
	Use the lower value	0.6
2		
2.1 cement content	C3	180 /0.6 =300Kg/m^3
2.2 max cement content	specified	550 Kg/m^3
2.3 min cement content	specified	300 kg/m^3
2.4 modified free water/cement ratio		180 /300=0.6
3		
3.1 relative density of agg (SSD)	specified	2.6
3.2 concrete density	fig4.8	2375
3.3 specific gravity dry sand	specified	2.526
3.4 total agg content	C4	2375 -180 -300=1895kg/m^3
3.5 grading of fine agg	BS882	%passing 600µm 58.6
3.6 proportion of fine agg	fig 4.9	35 %
3.7 fine agg content	C5	1895*0.35=663 Kg/m^3
3.8 coarse agg content	C6	1895-663=1232kg/m^3

	Cement (kg)	Water (kg)	Sand (kg)	Course Agg (kg)
Per m^3 (nears 5kg)	300	180	665	1235

Stag item	reference and calculation	values
1		
1.1 required strength	specified	25 N/mm^2
	Table 4.6	proportion defective 5 %
1.2 standard deviation	table 4.7	8 N/mm^2
1.3 margin	C1	(k=1.64)1.64*8=13.12 N/mm^2
1.4 target mean strength	C2	13.12+25=38.12 N/mm^2
1.5 slump		30-60 mm
1.6 max agg size		20 mm
1.7 free water content	table 4.10	180Kg/m^3
1.8 free water/cement ratio	table 4.8fig 4.7	0.52
1.9 max free water/cement ratio	table 4.9	0.55
		Use the lower value
2		
2.1 cement content	C3	180/0.52 =346 Kg/m^3
2.2 max cement content	specified	550 Kg/m^3
2.3 min cement content	specified	325 kg/m^3
2.4 modified free water/cement ratio		180 /346=0.52
3		
3.1 relative density of agg (SSD)	specified	2.6
3.2 concrete density	fig 4.8	2375
3.3 specific gravity dry sand	specified	2.526
3.4 total agg content	C4	2375-180-346=1849 kg/m^3
3.5 grading of fine agg	BS882	%passing 600µm58.6
3.6 proportion of fine agg	fig 4.9	34 %
3.7 fine agg content	C5	1849*0.34=628 Kg/m^3
3.8 coarse agg content	C6	1849-628=1220kg/m^3

	Cement (kg)	Water (kg)	Sand (kg)	Course Agg (kg)
Per m^3 (nears 5kg)	350	180	630	1220

Stag item	reference and calculation	values
1		
1.1 required strength	specified	30 N/mm^2
	Table 4.6	proportion defective 5 %
1.2 standard deviation	table 4.7	8 N/mm^2
1.3 margin	C1	(k=1.64)1.64*8=13.12N/mm^2
1.4 target mean strength	C2	13.12 +30=43.12N/mm^2
1.5 slump		30-60 mm
1.6 max agg size		20 mm
1.7 free water content	table 4.10	180 Kg/m^3
1.8 free water/cement ratio	table 4.8fig 4.7	0.49
1.9 max free water/cement ratio	table 4.9	0.55
		Use the lower value
2		
2.1 cement content	C3	180 /0.49 =367 Kg/m^3
2.2 max cement content	specified	550 Kg/m^3
2.3 min cement content	specified	325 kg/m^3
2.4 modified free water/cement ratio		180/367=0.49
3		
3.1 relative density of agg (SSD)	specified	2.6
3.2 concrete density	fig 4.8	2375
3.3 specific gravity dry sand	specified	2.526
3.4 total agg content	C4	2375-180 -367=1828 kg/m^3
3.5 grading of fine agg	BS882	%passing 600µm 58.6
3.6 proportion of fine agg	fig 4.9	33.8 %
3.7 fine agg content	C5	1828*0.338= 617.8 Kg/m^3
3.8 coarse agg content	C6	1828-617.8=1210 kg/m^3

	Cement (kg)	Water (kg)	Sand (kg)	Course Agg (kg)
Per m^3 (nears 5kg)	370	180	620	1210

Stag item	reference and calculation	values
1		
1.1 required strength	specified	35 N/mm^2
	Table 4.6	proportion defective 5 %
1.2 standard deviation	table 4.7	8 N/mm^2
1.3 margin	C1	(k=1.64)1.64*8=13.12N/mm^2
1.4 target mean strength	C2	13.12 +35=48.12N/mm^2
1.5 slump		30-60 mm
1.6 max agg size		20 mm
1.7 free water content	table 4.10	180 Kg/m^3
1.8 free water/cement ratio	table 4.8fig 4.7	0.45
1.9 max free water/cement ratio	table 4.9	0.5
		Use the lower value
2		
2.1 cement content	C3	180/0.45 =400 Kg/m^3
2.2 max cement content	specified	550 Kg/m^3
2.3 min cement content	specified	350 kg/m^3
2.4 modified free water/cement ratio		180 /400=0.45
3		
3.1 relative density of agg (SSD)	specified	2.6
3.2 concrete density	fig 4.8	2375
3.3 specific gravity dry sand	specified	2.526
3.4 total agg content	C4	2375-180 -400=1795 kg/m^3
3.5 grading of fine agg	BS882	%passing 600µm 58.6
3.6 proportion of fine agg	fig 4.9	33 %
3.7 fine agg content	C5	1795 *0.33=592 Kg/m^3
3.8 coarse agg content	C6	1795-592=1202.6 kg/m^3

	Cement (kg)	Water (kg)	Sand (kg)	Course Agg (kg)
Per m^3 (nears 5kg)	400	180	595	1205

Stag item	reference and calculation	values
1		
1.1 required strength	specified	40 N/mm^2
	Table 4.6	proportion defective 5 %
1.2 standard deviation	table 4.7	8 N/mm^2
1.3 margin	C1	(k=1.64)1.64*8=13.12N/mm^2
1.4 target mean strength	C2	13.12 +40=53.12N/mm^2
1.5 slump		30-60 mm
1.6 max agg size		20 mm
1.7 free water content	table 4.10	180 Kg/m^3
1.8 free water/cement ratio	table 4.8fig 4.7	0.41
1.9 max free water/cement ratio	table 4.9	0.5
		Use the lower value
2		
2.1 cement content	C3	180/0.41 =439 Kg/m^3
2.2 max cement content	specified	550 Kg/m^3
2.3 min cement content	specified	350 kg/m^3
2.4 modified free water/cement ratio		180/439=0.41
3		
3.1 relative density of agg (SSD)	specified	2.6
3.2 concrete density	fig 4.8	2375
3.3 specific gravity dry sand	specified	2.526
3.4 total agg content	C4	2375-180-439=1756 kg/m^3
3.5 grading of fine agg	BS882	%passing 600µm58.6
3.6 proportion of fine agg	fig 4.9	32 %
3.7 fine agg content	C5	1756*0.32=562 Kg/m^3
3.8 coarse agg content	C6	1756 -562=1194kg/m^3

	Cement (kg)	Water (kg)	Sand (kg)	Course Agg (kg)
Per m^3 (nears 5kg)	440	180	565	1195

2 mix design form (ACI)

Stag item	reference and calculation	values
1		
1.1 required strength	specified	20 N/mm^2
1.2 increases in strength	table 4.1	7
1.3 target mean strength		20 +7=27
1.4 slump	table 4.2	20-100 mm
1.5 max agg size		20 mm
1.6 free water content	table 4.3	185 Kg/m^3
1.7 water volume		0.185 m^3
1.8 air content	table 4.3	2.0 %
2		
2.1 free water/cement ratio	table 4.4	0.58
2.2 cement content	C1	185/0.58=319 Kg/m^3
2.3 cement volume	C2	0.319/3.15=0.101m^3
3		
3.1 specific gravity for dry course agg	specified	2.675
3.2 specific weight-rodded agg	specified	1.6 ton/m^3
3.3 specific gravity dry sand	specified	2.526
3.4 modulus of fineness	specified	2.4
3.5 course agg. Bullk volume	table 4.5	0.66 m^3
3.6 weight of dry course agg	C3	1.6*0.66=1.056 ton/m^3
3.7 dry course agg solid volume	C4	1.056/2.675= 0.394 m^3
4		
4.1 total volume		0.101 +0.185+0.394+0.02=0.7m^3
4.2 dry sand volume	C5	1 -0.7=0.3m^3
4.3 dry sand weight	C6	300 *2.526=757.8 Kg/m^3

	Cement (kg)	Water (kg)	Sand (kg)	Course Agg (kg)
Per m^3 (nears 5kg)	320	185	760	1060

Stag item	reference and calculation	values
1		
1.1 required strength	specified	25 N/mm^2
1.2 increases in strength	table 4.1	8.5
1.3 target mean strength		8.5+25=33.5
1.4 slump	table 4.2	20-100 mm
1.5 max agg size		20 mm
1.6 free water content	table 4.3	185 Kg/m^3
1.7 water volume		0.185 m^3
1.8 air content	table 4.3	2.0 %
2		
2.1 free water/cement ratio	table 3.4	0.5
2.2 cement content	C1	185/0.5=370Kg/m^3
2.3 cement volume	C2	0.37/3.15=0.1174m^3
3		
3.1 specific gravity for dry course agg	specified	2.675
3.2 specific weight-rodded agg	specified	1.6 ton/m^3
3.3 specific gravity dry sand	specified	2.526
3.4 modulus of fineness	specified	2.4
3.5 course agg. Bullk volume	table 4.5	0.66 m^3
3.6 weight of dry course agg	C3	1.6*0.66=1.056 ton/m^3
3.7 dry course agg solid volume	C4	1.056/2.675= 0.394 m^3
4		
4.1 total volume		0.117+0.185+0.394+0.02=0.716m^3
4.2 dry sand volume	C5	1 -0.176=0.2835m^3
4.3 dry sand weight	C6	283.5*2.526=716.12Kg/m^3

	Cement (kg)	Water (kg)	Sand (kg)	Course Agg (kg)
Per m^3 (nears 5kg)	370	185	720	1060

Stag item	reference and calculation	values
1		
1.1 required strength	specified	30N/mm^2
1.2 increases in strength	table 4.1	8.5
1.3 target mean strength		8.5+30=38.5
1.4 slump	table 4.2	20-100 mm
1.5 max agg size		20 mm
1.6 free water content	table 4.3	185 Kg/m^3
1.7 water volume		0.185 m^3
1.8 air content	table 4.3	2.0 %
2		
2.1 free water/cement ratio	table 4.4	
2.2 cement content	C1	185/0.44=420Kg/m^3
2.3 cement volume	C2	0.420/3.15=0.113m^3
3		
3.1 specific gravity for dry course agg	specified	2.675
3.2 specific weight-rodded agg	specified	1.6 ton/m^3
3.3 specific gravity dry sand	specified	2.526
3.4 modulus of fineness	specified	2.4
3.5 course agg. Bullk volume	table 4.5	0.66 m^3
3.6 weight of dry course agg	C3	1.6*0.66=1.056 ton/m^3
3.7 dry course agg solid volume	C4	1.056/2.675= 0.394 m^3
4		
4.1 total volume		0.133+0.185+0.394+0.02=0.732m^3
4.2 dry sand volume	C5	1 -0.732=0.268m^3
4.3 dry sand weight	C6	268*2.526=675Kg/m^3

	Cement (kg)	Water (kg)	Sand (kg)	Course Agg (kg)
Per m^3 (nears 5kg)	420	185	675	1060

Stag item	reference and calculation	values
1		
1.1 required strength	specified	35N/mm^2
1.2 increases in strength	table 4.1	8.5
1.3 target mean strength		8.5+35=43.5
1.4 slump	table 4.2	20-100 mm
1.5 max agg size		20 mm
1.6 free water content	table 4.3	185 Kg/m^3
1.7 water volume		0.185 m^3
1.8 air content	table 4.3	2.0 %
2		
2.1 free water/cement ratio	table 4.4	0.4
2.2 cement content	C1	185/0.4=462Kg/m^3
2.3 cement volume	C2	0.462/3.15=0.146m^3
3		
3.1 specific gravity for dry course agg	specified	2.675
3.2 specific weight-rodded agg	specified	1.6 ton/m^3
3.3 specific gravity dry sand	specified	2.526
3.4 modulus of fineness	specified	2.4
3.5 course agg. Bullk volume	table 4.5	0.66 m^3
3.6 weight of dry course agg	C3	1.6*0.66=1.056 ton/m^3
3.7 dry course agg solid volume	C4	1.056/2.675= 0.394 m^3
4		
4.1 total volume		0.146+0.185+0.394+0.02=0.745m^3
4.2 dry sand volume	C5	1 - 0.745=0.255m^3
4.3 dry sand weight	C6	255*2.526=644Kg/m^3

	Cement (kg)	Water (kg)	Sand (kg)	Course Agg(kg)
Per m^3 (nears 5kg)	465	185	645	1060

Stag item	reference and calculation	values
1		
1.1 required strength	specified	$40N/mm^2$
1.2 increases in strength	table 4.1	10
1.3 target mean strength		40+10=50
1.4 slump	table 4.2	20-100 mm
1.5 max agg size		20 mm
1.6 free water content	table 4.3	$185\ Kg/m^3$
1.7 water volume		$0.185\ m^3$
1.8 air content	table 4.3	2.0 %
2		
2.1 free water/cement ratio	table 4.4	0.38
2.2 cement content	C1	$185/0.38=4868Kg/m^3$
2.3 cement volume	C2	$0.4868/3.15=0.0.154m^3$
3		
3.1 specific gravity for dry course agg	specified	2.675
3.2 specific weight-rodded agg	specified	$1.6\ ton/m^3$
3.3 specific gravity dry sand	specified	2.526
3.4 modulus of fineness	specified	2.4
3.5 course agg. Bullk volume	table 4.5	$0.66\ m^3$
3.6 weight of dry course agg	C3	$1.6*0.66=1.056\ ton/m^3$
3.7 dry course agg solid volume	C4	$1.056/2.675= 0.394\ m^3$
4		
4.1 total volume		$0.154+0.185+0.394+0.02=0.754m^3$
4.2 dry sand volume	C5	$1 - 0.7546=0.00.2454m^3$
4.3 dry sand weight	C6	$245.4*2.526=620Kg/m^3$

	Cement (kg)	Water (kg)	Sand (kg)	Course Agg (kg)
Per m^3 (nears 5kg)	490	185	620	1060