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CIVIL ENGINEERING
FINAL YEAR PROJECT:
MIX PROPORTION AND CALCULATION FOR CONSTRUCTION OF BUILDING MATERIAL

1st Edition

Dr. AINUL HAEZAH NORUZMAN
MUHAPIS A HAKIM
ZARINAH ZAINI

For student's guide

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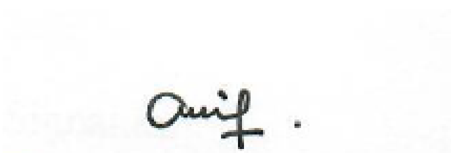
Preface

Alhamdulillah for everything

It gives us great pleasure to release the first edition of this book as a quick guide to support lecturers, students, and readers who might need to comprehend, explore, and possibly experience new knowledge when conducting research or as a teaching aid in the laboratory and class especially in Certificate and Diploma level.

The book contains basic information about building material and testing involved as well as calculation which provide step-by-step guidelines especially for beginners.

Thanks to my co-writers who have shown considerable efforts and cooperation as well as devotion towards this publication. Finally, I would like to express our thanks to the staff, our colleagues, and students who have also voluntarily contributed to this precious book.



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This book is dedicated for FYP students and researchers

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OUTCOME BASED EDUCATION

As a TVET human capital generator and national resource provider, the polytechnic bears the responsibility to develop the capacity of students with quality knowledge, skills, and behaviour to be competitive in the global economic era and in line with the advancement and speed of digital technology (Mohamed Khaled Nordin, 2008).

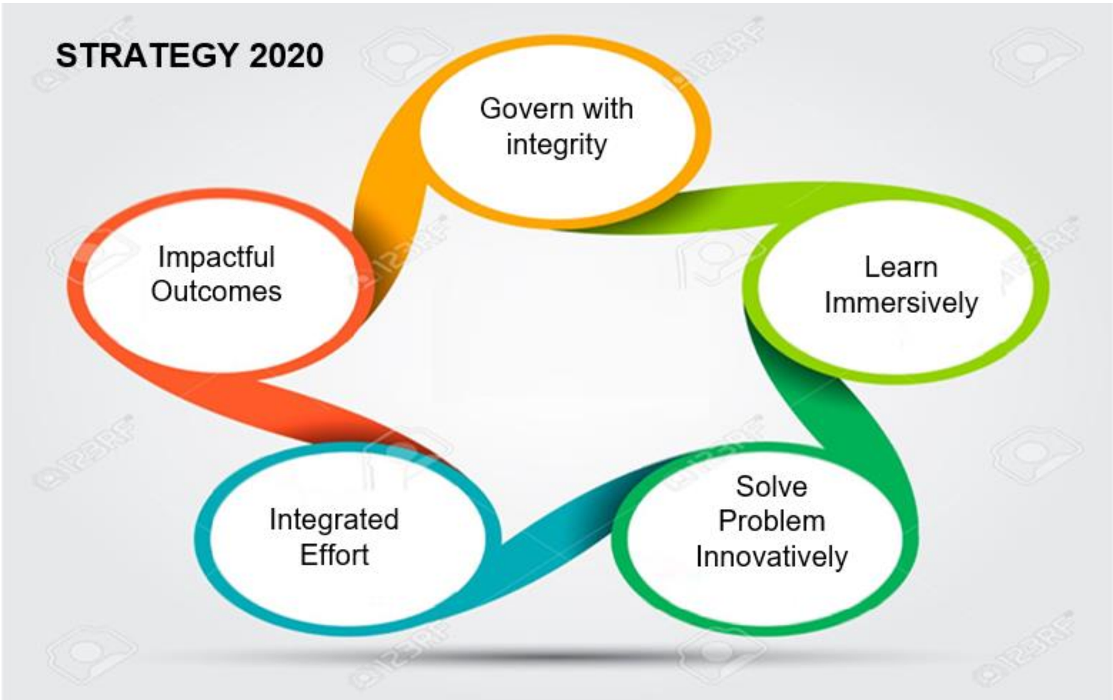
In addition, Malaysia has initiated the Outcome Based Education (OBE) in engineering education in the year 2000. OBE is a paradigm shift from the teacher-centred to the student-centred learning, where its implementation requires students to demonstrate that they have learned and acquired the required contents and skills. The new teaching and learning (T&L) approaches have transformed educational emphasis from focusing on traditional inputs, such as course credits earned and hours spent in class, to focusing on results or outcomes. They empirically measure student performance, known as programme outcomes (POs) based on the Engineering Technology Accreditation Council (ETAC). At polytechnic, POs are known as Programme Learning Outcome (PLO). ETAC states that students of the Engineering Technician Diploma Programme are expected to attain skill, knowledge, and behaviour as follows;

1. Apply appropriate techniques, resources, and modern engineering and IT tools.
2. Function effectively as an individual, and as a member in diverse technical teams.
3. Demonstrate knowledge and understanding of engineering management principles, and apply these to one's own work, as a member or leader in a technical team and to manage projects in multidisciplinary environments.
4. Communicate effectively with the engineering community and with the society at large, by being able to comprehend the work of others, document their own work, and give and receive clear instructions.

5. Recognize the need for, and have the ability to engage in independent updating in the context of specialized technical knowledge.

All of the skills, knowledge and behaviour that students acquire through the programme can help to achieve one of the missions of JPPKK which is to develop holistic, entrepreneurial, and balanced graduates.

By producing this book, it can help students in exploring information while doing their final year project, case study, and any other tasks given by their lecturers. Students can construct their knowledge effectively by experience themselves while getting involved in any task such as the Final Year Project. The existence of this book also supports and implements the PSA strategy for 2020 as mentioned in the diagram below.



The top management has initiated an excellent strategy called 5i @ PSA which consists of Govern with **Integrity**, Learn **Immersively**, and Solve problem **Innovatively** through **Integrated** effort to achieve **Impactful** Outcomes.

CHAPTER 1

Standard specification

1.1 Standard specifications and the importance

Standard specifications provide people and organizations with a basis for mutual understanding, and are used as a tool to facilitate communication, measurement, commerce, and manufacturing.

Standards are everywhere and play an important role in the economy, by:

- facilitating business interaction
- enabling companies to comply with relevant laws and regulations
- speeding up the introduction of innovative products to market
- providing interoperability between new and existing products, services, and processes.

Standards form the basis for the introduction of new technologies and innovations, and ensure that products, components, and services supplied by different companies will be mutually compatible.

Standards also disseminate knowledge in industries where products and processes supplied by various providers must interact with one another. Standardization is a voluntary cooperation among the industries, consumers, public authorities, researchers, and other interested parties for the development of technical specifications based on consensus.

1.2 Reference codes for concrete making

There are many reference codes of practices when dealing with the intended product samples to be used as building materials. Here is the list of the standard specifications/ relevant European standards / British standards.

CEMENT	
BS EN 197-1: 2011	Cement. Composition, specifications, and conformity criteria for common cements
BS EN 197-3: 2016	Methods of testing cement. Determination of setting times and soundness
AGGREGATE	
BS 812: 103.1: 1985/ BS EN 933-1:2012	Sieve tests/ Tests for geometrical properties of aggregates. Determination of particle size distribution. Sieving method
BS EN 933-3:2012	Test for geometrical properties of aggregates. Determination of particle shape. Flakiness index
BS 812-109:1990	Methods for determination of moisture content
BS 410:1986/ BS ISO 3310-2:2013	Specification for test sieves/ Test sieves. Technical requirements and testing. Test sieves of perforated metal plate
WATER	
BS 3148: 1990/ BS EN 1008:2002	Test for water for making concrete/ Mixing water for concrete. Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete
DESIGN AND PROPORTIONING OF CONCRETE MIXTURE	
BS 5328: Part 1: 1991/ BS EN 206: 2013	Guide to specifying concrete Concrete. Specification, performance, production and conformity
BS 5328: Part 2: 1991/ BS EN 206: 2013	Methods for specifying concrete Concrete. Specification, performance, production and conformity

BS 1881-125: 1986/ BS 1881-125:2013	Testing concrete. Methods for mixing and sampling fresh concrete in the laboratory
BS 1881-111:1983/ BS EN 12390-2:2019	Testing concrete. Method of normal curing of test specimens (20°C method)/ Testing hardened concrete. Making and curing specimens for strength tests
CONCRETE	
BS EN 12350-2: 2009	Testing fresh concrete. Slump test
BS EN 12390-3:2019	Testing hardened concrete. Compressive strength of test specimens
BS EN 12390-6: 2009	Testing hardened concrete. Tensile splitting strength test of specimens
BS EN 12390-5:2019	Testing hardened concrete. Flexural strength of test specimens
BS EN 1881-122:2011	Testing concrete. Method for determination of water absorption

List of the standard specifications/ relevant ASTM standards

CEMENT	
C 109-93	Test for compressive strength of hydraulic cement mortars (using 2-in or 50 mm cubes specimens)
C 150-94	Specification for Portland Cement
C 187-16	The method for amount of water required for normal consistency of hydraulic cement
C 191-92	Test for Time of setting of hydraulic cement by Vicat Needle
C 311	Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland-Cement Concrete
C 618	Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete

List of the standard specifications/ American Concrete Institute

ACI 116R-00	Cement and Concrete Terminology

1.3 Reference codes for polymer in concrete

List of the standard specifications/ relevant Japanese Industrial Standards

JIS A 1171	Method of making test sample of polymer modified mortar in the laboratory
JIS A 1172	Method of test for strength of polymer modified mortar
JIS A 1173	Method of test for slump of polymer modified mortar
JIS A 1174	Method of test for unit weight and air content (gravimetric) of fresh polymer modified mortar

List of the standard specifications/ American Concrete Institute

ACI 548.IR-92	Guide for the use of Polymers in Concrete
ACI 548.4-92	Standard specification for latex modified concrete (LMC) Overlays (1992)
ACI 503.5R-92	Guide for the selection of polymer adhesives with concrete

CHAPTER 2

Cement

2.1 Purpose of cement testing

The cement to be used in construction must have certain qualities in order to play its part effectively in structure. Quality tests on cement are carried out to check the strength and quality of the cement used in construction. It helps to identify the usage of cement for different purposes based on its durability and performance.

2.2 List of testing of cement

- Field testing
- Standard consistency
- Fineness
- Soundness
- Strength
- Heat of hydration
- Chemical composition

A typical example of properties of cement is shown in Table 2.1.

Table 2.1. Chemical composition and physical and mechanical properties of the cement determined using BS EN 197-:2011

Composition	**(%)**
Chemical properties	
Silicon dioxide (SiO_2)	20.1
Aluminium oxide (Al_2O_3)	4.9
Ferric oxide (Fe_2O_3)	2.4
Calcium oxide (CaO)	65
Sulphur oxide (SO_3)	2.3
Magnesium oxide (MgO)	3.1

Insoluble residue	1.9
Loss on ignition	2
Lime saturated factor	0.85
Physical/Mechanical	Value
Surface area (Blaine) m^2/kg	290
Initial setting time (min)	105
Final setting time (min)	190
Compressive strength (N/mm^2)	
1 day	13.5
3 days	20.5
7 days	28.5
28 days	35.6
Soundness (mm)	8.7

Chemical composition of cement is identified by using X-ray fluorescence (XRF). XRF is a non-destructive analytical technique used to determine the elemental composition of materials. It works on wavelength — dispersive spectroscopic principles that are similar to an electron microprobe.

The advantages of using XRF analyser are it is relatively easy and requires a low-cost sample preparation, and the stability and ease of use of x-ray spectrometers make this one of the most widely used methods for analysis of major and trace elements in rocks, minerals, and sediments.

2.3 Cement compounds

A general idea of the composition of cement can be obtained as shown in Table 2.1, which gives the oxide composition its limits of Portland cements. Four compounds are usually regarded as major constituents of cement which are Tricalcium Silicate ($3CaO.SiO_2$), Dicalcium Silicate ($2CaO.SiO_2$), Tricalcium Aluminate ($3CaO. Al_2O_3$), and Tetracalcium aluminoferrite ($4CaO.Al_2O_3. FeO_3$).

In addition, there are existing minor compounds, for instance, MgO, Na_2O, and K_2O, in which their amounts are not more than a few percent of the mass of cement. They have been found to react with some aggregates, the products of reaction causing disintegration of the concrete, and have also been observed to affect the rate of the gain strength of cement [1]. The compounds present in cement which play important roles in hydration process are CaO, SiO_2, and Fe_2O_3, respectively. The function of each component is shown in Table 2.2.

Table 2.1. The main compounds of cement and their functions and composition in percentage [2]

Oxide	**Function**	**Composition (%)**
CaO	Controls strength and soundness. Its deficiency reduces strength and setting time.	60-65
SiO_2	Gives strength. Excess of it causes slow setting.	17-25
Al_2O_3	Responsible for quick setting, if in excess, it lowers the strength.	3-8
Fe_2O_3	Gives colour and helps in fusion of different ingredients.	0.5-6
MgO	Imparts colour and hardness. If in excess, it causes cracks in mortar and concrete and unsoundness.	0.5-4
Na_2O + K_2O	These are residues, and if in excess, cause efflorescence and cracking.	0.5-1.3
TiO_2		0.1-0.4
P_2O_5		0.1-0.2
SO_3	Makes cement sound.	1-2

CHAPTER 3

Aggregates

3.1 Aggregates in concrete

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are essential ingredients in concrete. It is known that the aggregates occupy most of the volume of concrete. Aggregates, which account for 60 to 80 percent of the total volume of concrete, are divided into two distinct categories, which are fine and coarse aggregates.

Table 3.1. Proportional ranges in concrete

Cement	7-15%
Aggregates	**60-80%**
Water	14-18%
Air	2-8%

For a good concrete mix, aggregates need to be clean, hard, strong, and free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Consequently, the selection of aggregates is an important process. Although some variations in aggregate properties are expected, the characteristics considered include:

- grading
- durability
- particle shape and surface texture
- abrasion and skid resistance
- unit weight and voids
- absorption and surface moisture

3.2 Grading of fine aggregates

As stated in ASTM C 33, fine aggregates consist of natural sand, manufactured sand or combination of both. The sieve sizes used are as follows;

Table 3.1. Grading of fine aggregates

Sieve size	**Percent passing**
9.5 mm (3.8-in)	100
4.75 mm (No.4)	95-100
2.36 mm (No. 8)	80-100
1.18 mm (No. 16)	50 to 85
600 µm (No.30)	25 to 60
300 µm (No.50)	5 - 30
150 µm (No.100)	0 - 10

Fine aggregates should have not more than 45% passing of any sieve, and retain on the next consecutive sieve. BS 882:1992 requires fine aggregates to satisfy the overall grading limits as shown in Table 3.2.

Table 3.2. BS and ASTM Grading Requirements for Fine Aggregates [1]

Sieve size		Percentage by mass passing sieves				
		BS 882:1992				ASTM C33-93
BS	ASTM No.	Overall grading	coarse grading	medium grading	fine grading	
10.0 mm	3/18 in	100				100
5.0 mm	3/16 in	89-100				95-100
2.36 mm	8	60-100	60-100	65-100	80-100	80-100
1.18 mm	16	30-100	30-90	45-100	70-100	50-85
600 µm	30	15-100	15-54	25-80	55-100	25-60
300 µm	50	5-70	5-40	5-48	5-70	10-30
150 µm	100	0-15				2-10

Example 3.2.1: Calculation of Sieve Analysis Data for Fine Aggregates

Sieve size (mm)	Retained Weight (g)	Passing Weight (g)	Cumulative percentage passing (%)
5	5	495	99.0
2.36	50	445	89.0
1.18	115	330	66.0
0.6	105	225	45.0
0.3	123	102	20.4
0.15	85	17	3.4
Pan	17	0	0

<u>Calculation of cumulative:</u>

Cumulative percentages $= \frac{mass\ passing}{mass\ of\ dry\ sample} x\ 100$

Mass of dry = 500 (constant)

Sieve size = 0.6 mm

Cumulative percentages $= \frac{225}{500} x\ 100\% = 45\ \%$

Fineness modulus: $\frac{Total\ cumulative\ passing\ percentages}{100}$

$= \frac{323}{100}$

$= 3.23$

Example 3.2.2: Calculation for Sieve Analysis and Graph of Particle Size Distribution

Sieve Size	Mass of each sieve (g)	Weight Retained (g)	Net Weight (g)	Retained Weight	Passing Weight	Cumulative Percentage Passing (%)
5	499	499	0	0	500	100
2.36	488	513	25	25	475	95
1.18	353	520	167	192	308	62
0.6	304	398	94	286	214	43
0.3	275	442	167	453	47	9
0.15	258	298	40	493	7	1
pan	354	363	7	500	0	0

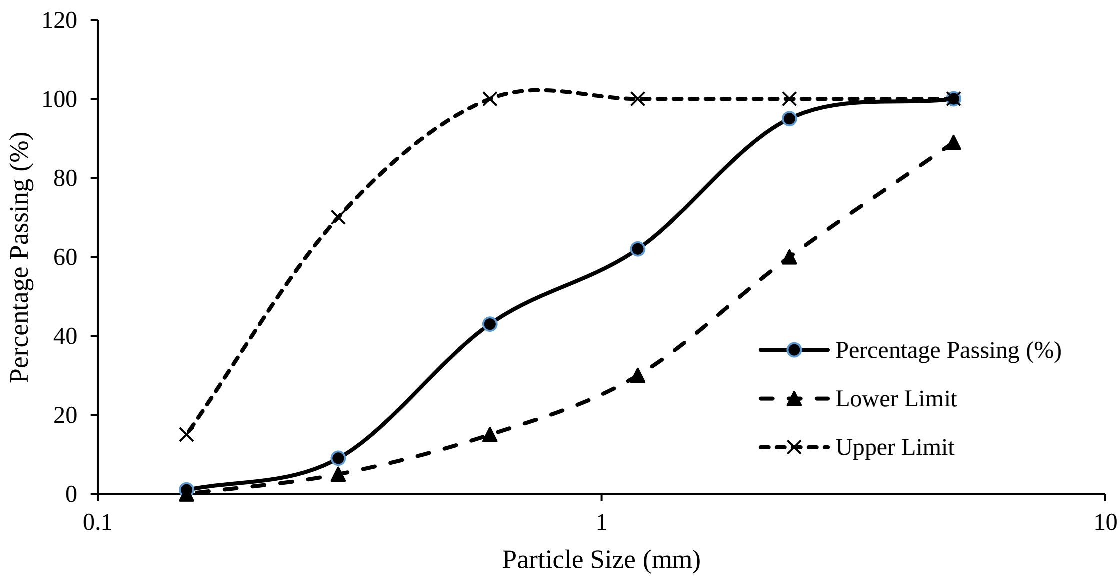


Figure 3.1. Particle size distribution of fine aggregates

The sand used in the concrete making meets the limitations provided by the standard specifications by ASTM C33.

CHAPTER 4

Water for making concrete

4.1 Quality of water

The quality of the water plays an important role in the preparation of concrete. Impurities in water may interfere with the setting of the cement and may adversely affect the strength and durability of the concrete especially corrosion of the reinforcement.

4.2 Sources of water

Generally, water used in concrete mixture is usually tap water or potable water. However, there are various existing and new sources of water available which may be suitable for a complete or partial replacement of potable water for concrete making. The sources include reclaimed water, groundwater, treated water from sewer, and water from a ready-mix concrete plant.

According to [3], some important definitions are as follows;

a) Potable water: water which is suitable for human consumption.

b) Recycled water: water which is treated up to an acceptable limit which is suitable for its intended uses.

c) Blackish water: wastewater generated from toilet, urinals, which is directly contaminated by human, etc.

d) Grey water: wastewater from wash basin, showers, laundries, and kitchen.

Furthermore, there are also limitations and guidelines from the standard specifications for quality of water regarding the application of water as mixing water in concrete.

Table 4.1. Guidelines for mixing water in concrete

IS 3025-1984	Methods of sampling and test for water and wastewater
IS 456-2000	Plain and reinforced concrete — code of practice
AS 1379-1997	Specifications and supply of concrete
ASTM C94-1996	Specifications for ready-mix concrete
ACI 318 M-08	Building code requirements for structural concrete and commentary
ASTM 1602M-06	Standard test method for mixing water used in the production of hydraulic cement concrete
EN 1008-2002(E)	Mixing water for concrete — specifications for sampling, resting, and assessing the suitability of water, including water recovered from processes in the concrete industry as mixing water for concrete

The examples below are the characteristics of wastewater from the paint industry. The water tested meets the tolerable limit given by literature as shown in Table 4.2.

Table 4.2. Physico-chemical characteristics of the effluents (All values in mg/l except for turbidity and temperature value)

Parameter	Units	Parameter limits of effluents standard*	Tolerable limit**	Reference
pH	7.12	5.5-9.0	6.0-8.0	[4],[5]
Alkalinity (as $CaCO_3$)	9951	-	1000	[4],[6]
BOD	13363.00	50	-	-
COD	77800.00	100	-	-
TSS	8200.00	100	2000	[6]
TDS	5460.00	-	<6000	[7]
DO	2.72	-	-	-
Temperature, °C	19.91	-	-	
Turbidity, NTU	23.64	-	2000	[8]
Tri-chromium (Cr^{3+})	0.1376	1	-	-
Sulfate (SO_4^{2-})	4514.00	-	1000	[5]
Chloride (Cl^-)	56.23	-	500	[5]
Nitrate (NO_3^{2-})	27.53	-	500	[5]

Table 4.2 Physico-chemical characteristic of the effluents (All values in mg/l except for turbidity and temperature value) (continued)

Parameter	**Units**	**Parameter limits of effluents standard***	**Tolerable limit****	**Reference**
Sulphide (S^{2-})	<0.002	0.5	-	-
Cadmium (Cd^{2+})	0.0004	0.02	-	-
Lead (Pb^{2+})	0.1302	0.5	500	[5]
Phosphates (PO_4^{3})	222.00	-	100	[9]
Zinc (Zn^{2+})	1.0488	1	500	[6]
Iron (Fe^{2+})	1.7051	5	Combined total <2000	[9]
Calcium (Ca^{2+})	72.75	-		
Magnesium (Mg^{2+})	9.7165	-		
Sodium (Na^{+})	1199.00	-		
Copper (Cu^{2+})	2.6921	1	500	[6]
Manganese (Mn^{2+})	0.9147	1	500	[6]
Nickel (Ni^{2+})	0.0873	1	-	-
Mercury (Hg^{2+})	3.4998	0.05	-	-

*Department of Environment Malaysia

** Tolerable limit for water impurities as mixing water in concrete

CHAPTER 5

Standard Mix Proportion

5.1 Proportioning

The process of selecting quantity of cement, fine and coarse aggregates, as well as water in concrete to obtain desired strength and quality is called proportioning of concrete.

Good proportioning choices may lead towards the resulting concrete as follows;

- Provide sufficient workability that can be placed in the formwork economically.
- The concrete possesses maximum density when it is at hardened state at matured age.
- The cost of materials and labour required to form concrete should be minimum.

5.2 Basic data required for mix proportioning.

According to [10], there are a few basic data required for mix proportioning as shown in Table 5.1.

Table 5.1. Basic data for mix proportioning

Grade designation	It gives compressive strength characteristic to concrete. The target mean strength of concrete is fixed by adding a suitable margin to the strength characteristic depending on the quality control to be envisaged.
Type of cement	The type and grade of cement mainly influences the rate of development of compressive strength of concrete.
Maximum water-cement ratio	Maximum water-cement ratio to be used for a particular work is governed by the desired strength, and limited by the durability requirements.
Maximum nominal size of aggregate	The maximum nominal size of aggregates to be used in concrete is governed by the size of the section to be concreted and spacing of the reinforcement.

Minimum cement content	The minimum cement content to be used is governed by the respective environmental exposure conditions.
Workability	The desired workability for a particular job depends on the shape and size of section to be concreted, denseness of reinforcement, method of transportation, and placing and compaction of concrete.
Exposure conditions	The anticipated environmental exposure conditions in which the structure is intended to serve during its service span define the durability requirements.
Type of aggregate	It influences the workability and strength of concrete. The relative proportions of coarse and fine aggregates are determined by the characteristics of the aggregates such as grading, shape, size, and surface texture.
Method of transporting and placing	It influences workability of the mix.
Use of admixtures	Admixtures are used to enhance and modify one or more properties of concrete in fresh as well as hardened states.

5.3 Concrete mix design

A proper mix design can give the specified properties such as workability, strength, and durability with economy. The determinations of the proportions of concrete to obtain the required strengths shall be made as follows;

a) Nominal mix concrete

Low grade concrete mixes are normally used for small and unimportant works. In this method, fine aggregate quantity is fixed irrespectively of cement and coarse aggregate proportions. Water cement ratio is also not specified. As a result, the quality of concrete mix varies, and required strength may not be obtained.

b) Design mix concrete

The design is done according to the requirements of concrete strength. Higher grade of concrete is preferred for this type of mix design. The concrete's desirable properties would be achieved either in fresh state or in hardened state.

Advantages of concrete mix design

- Quality concrete
- Use of locally available materials
- Required proportion of each ingredient
- Desired properties of mix

5.4 Mix design

A typical example of mix design as stated by IS 456-2000 is as follows;

Grade	Mix ratio
M10	1:3:6
M15	1:2:4
M20	1:1.5:3
M25	1:1:2

5.5 The mix design of concrete following BS 5328: Part 2: 1991

The example of calculation of mix proportion concrete Grade 25 is as follows;

Casting Date		Grade 25
Coarse Aggregate	10 mm	Sizes
Fine Aggregate Proportion	45%	Percentage passing 600µm
Cement content	C	380 kg/m^3
Total Aggregate	TA	1830 kg/m^3
Fine Aggregate	F	45% x 1830 kg/m^3 = 824 kg/m^3
Coarse Aggregate	CA	1830 kg/m^3 – 824 kg/m^3 = 1006 kg/m^3
Water	0.55 w/c	0.5 x 380 kg/m^3 = 209 kg/m^3
Slump (75 mm)	Medium workability	
<u>Total mould (Nos.)</u> Cube (20) Cylinder (10) Prism (10)	<u>Volume</u> 100 mm x 100 mm x 100 mm = (1 x 10^{-3} m^3) x 20 = 0.02 m^3 100 mm x 200 mm = (1.57 x 10^{-3} m^3) x 10 = 0.0157 m^3 100 mm x 100 mm x 500 mm = (5 x 10^{-3} m^3) x 10 = 0.05 m^3	
Total volumes	0.02 m^3 + 0.0157 m^3 + 0.05 m^3 = 0.227 m^3	
Cement	380 kg/m^3 x 0.227 m^3 = 86.26 kg	
Fine Aggregate	824 kg/m^3 x 0.227 m^3 = 187.04 kg	
Coarse Aggregate	1006 kg/m^3 x 0.227 m^3 = 228.36 kg	
Water	209 kg/m^3 x 0.227 m^3 = 47.44 kg	

CHAPTER 6

Setting Time

6.1 Definition of setting time

Setting time is defined as the time taken for a cementitious mixture to reach a specified degree of rigidity measured by the standard procedure ASTM C125 from when mixing water is added to the mixture. The formation of hydration products commences immediately after the mixing water gets in contact with the hydraulic cement particles.

The rigid behaviour of the concrete matrix defines the initial and final setting time of hydrating concrete with the initial setting time of the concrete, denoting the beginning of hardening of the mixture, and the final setting time defining the state of sufficient hardness of the concrete mixture [11].

In order to study the behaviour of cement paste, an attempt is made to determine the setting time of cement using the Vicat needle according to ASTM C191 [12] , and cement paste is mixed to normal consistency according to ASTM C187 [13].

The penetration of the needle is taken every 30 minutes until there is no noticeable penetration. The initial and final settings correspond to the time when penetrations are at 25 mm and 0 mm, respectively. The initial set is said to have taken place when the needle (1.13 mm dia.) of the Vicat apparatus is at 25 mm above the bottom of the paste taken in the Vicat mould. Final set is said to have occurred when the needle penetrates the cement paste to a maximum depth of 1 mm. In both cases, the setting time is counted from the moment mixing water is added to the cement. Vicat apparatus is shown in Figure 5.1.

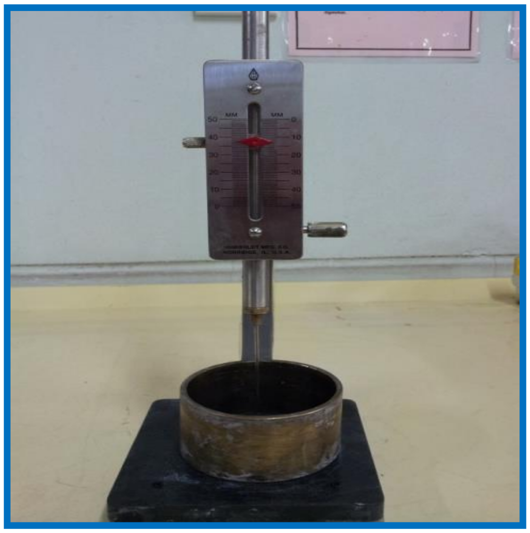


Figure 5.1. Vicat apparatus

The cement paste should meet the ASTM C150 which ideally requires initial setting time of cement which should not be less than 45 minutes while the final setting time should not exceed 375 minutes.

CHAPTER 7

Mechanical Properties

7.1 Compressive strength

The measurements of compressive strengths for all specimens are conducted in accordance to BS EN 12390-3:2009 [14]. The specimens are tested using 2000 kN capacity standard digital testing machine to determine data of compressive strength. The test is performed on three specimens of each composition, and the average values are recorded. A typical testing operation is shown in Figure 7.1. Although the machine automatically generates the compressive strength data, the following stress equation, as shown in Equation 7.1, is also used to validate the results.

$$f_c = \frac{F}{A_c} \quad (7.1)$$

Where,

f_c = the compressive strength, in N/mm^2

F = the maximum load at failure, in N

A_c = the cross-sectional area of the specimen, in mm^2

Figure 7.1. Testing for compressive strength

7.2 Indirect tensile strength

The split tensile strength of the normal concrete and polymer-modified concrete is determined using 100 mm Ø x 200 mm cylinders as stated in BS EN 12390-6: 2009 [15]. The test specimens of cylindrical shapes are used in this test. A 25 mm x 250 mm rectangular plywood board is used as capping material at the top and bottom of all the tested specimens to ensure uniform distribution of load. A constant loading rate is selected and applied until the specimen is split into hemispheres. Figure 7.2 shows an indirect tensile strength testing. For the tensile splitting test results, even though they are automatically generated by the testing machine, the results obtained are further validated with the aid of the following formula as shown in Equation 7.2.

$$f_{ct} = \frac{2F}{\pi L d} \qquad (7.2)$$

Where,

f_{ct} = Tensile splitting strength, in N/mm^2

F = Maximum load, in N

L = Length of the line of contact of the specimen, in mm

d = Designated cross-sectional dimension, in mm

Figure 7.2. Testing for indirect tensile test

7.3 Flexural strength

Flexural strength is conducted following the BS EN 12390-5: 2009 [16]. The dimension of the prism used is 100 mm x 100 mm x 500 mm. The arrangement of the testing is shown in Figure 7.3. The flexural strength is obtained by the equation as shown in Equation 7.3.

.

$$f_{cf} = \frac{F l_r}{d_1 (d)_2{}^2} \tag{7.3}$$

Where,

f_{cf} = flexural strength, in N/mm^2

F = maximum load, in N

l_r = distance between the support rollers, in mm

d_1 *and* d_2 = lateral dimensions of the specimen, in mm

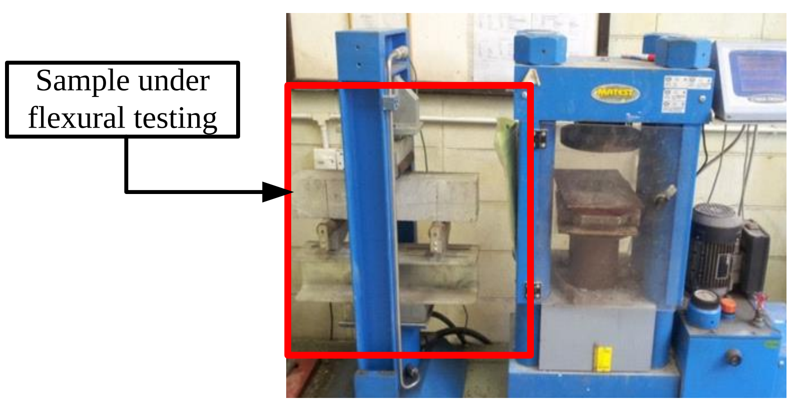


Figure 7.3. Testing for flexural strength

CHAPTER 8

Durability Properties

8.1 Water absorption

The test is conducted as the specification of BS 1881: Part 122: 2011 [17] which specifies a method for the determination of water absorption of concrete specimens cored from a structure or precast component. The objective is to determine the percentage of water absorbed by normal concrete and concrete companions.

The coring operation machine and cored component from concrete cube are shown in Figures 8.1 and 8.2. The cores of 75 mm Ø and 100 mm length are taken from 32 days old samples, and oven dried for 72 hours at 105 °C.

Oven dried samples are allowed to cool in the desiccator for 24 hours. At the end of drying and cooling, the core samples are weighed and immersed in a water container for 30 minutes at temperature 25 °C.

After removal from water, the specimens are wiped with dry clothes to remove the surface water and weighed. The measured absorption of each test specimen is then calculated, as the increase in the weight resulting from the immersion is expressed as a percentage of the mass of the dry specimen as shown in Equation 8.1.

$$W_a = \frac{W_s - W_d}{W_s}\ x\ 100 \qquad (8.1)$$

Where,

W_a= Water Absorption, in %

W_s= Weight of saturated samples, kg

W_d= Weight of oven dried and desiccated samples, kg

The performances of the specimens in terms of water absorption are classified based on the ratings given by the Concrete Society [18] as presented in Table 8.1.

Table 8.1. Water absorption rate

Very low absorption	$<$ 3 %
Low water absorption	3 – 4 %
High absorption concrete	$>$ 4 %

Figure 8.1. The coring machine

Figure 8.2. The concrete cores sample

CHAPTER 9

Polymer in Concrete

9.1 Polymer-based admixture

A polymer-based admixture, which is also called a cement modifier, is defined as admixture which consists of a polymeric compound as the main ingredient effective at modifying or improving the strength and durability properties of cement mortar and concrete. The cement mortar and concrete which are made by mixing with the polymer-based admixtures are called polymer modified mortar (PMM) and polymer modified concrete (PMC), respectively [19].

Polymer modified mortars and concretes have a monolithic co-matrix in which the organic polymer matrix and the cement gel matrix are homogenized. Several types of polymer in cementitious materials, such as latexes, redispersible polymer powder, water-soluble polymer, liquid resins, and monomer modified concrete are used. Polymers are preferred in the cement composites due to high performance, multi-functionality, and sustainability compared to conventional concrete. The synergic action between these two materials offers useful properties, and yields composites with excellent strength and durability properties.

As for the polymer latexes used in the concrete mix, understanding the polymer properties is beneficial and important to enhance the quality of concrete properties. Organic polymer is combined with cement and aggregate matrix to produce concrete polymer composites. Latex is commonly used in cement concrete mix in the form of liquid or powder.

9.2 Properties of polymer latexes

In order to investigate the latex to be used in cementitious material, polymer latexes are tested to determine the physical properties. The tests include pH value, specific gravity, viscosity, and total solid content. The details of the experiment are stated in the following section.

9.2.1 pH

The pH meter is used to determine the nature of liquid. It is an instrument to measure the degree of acidity or alkalinity of a solution. The pH of the hydrogen ion concentration is evaluated as the negative logarithm of the hydrogen ion $[H^+]$. The formula of pH is expressed as shown in Equation 9.1.

$$pH = - \text{Log } [H^+] \tag{9.1}$$

9.2.2 Specific gravity

Density is a physical property of matter that expresses a ratio of mass to volume. The density depends on the atomic mass of an element or compound [20]. The pycnometer is an instrument used for measuring fluid density, also known as specific gravity bottle. The operation of pycnometer is based on the Archimedes' principle.

A flask is made to hold a known volume of liquid at a specified temperature (usually 20 °C). The bottle is weighed, filled with the liquid in which specific gravity is found, and weighed again. The difference in weights is divided by the weight of an equal volume of water to give the specific gravity of the liquid. The specific gravity can be determined by using Equation 9.2.

$$Specific\ gravity = \frac{Mass\ of\ unit\ volume\ of\ the\ substance}{Mass\ of\ unit\ volume\ of\ water} \quad (9.2)$$

9.2.3 Viscosity

Viscosity is testing the flowability of liquid product. The viscosity is measured by using Brookfield Viscometer Cole-Parmer, in accordance with ASTM D 14717 [21]. The instrument is shown in Figure 9.1.

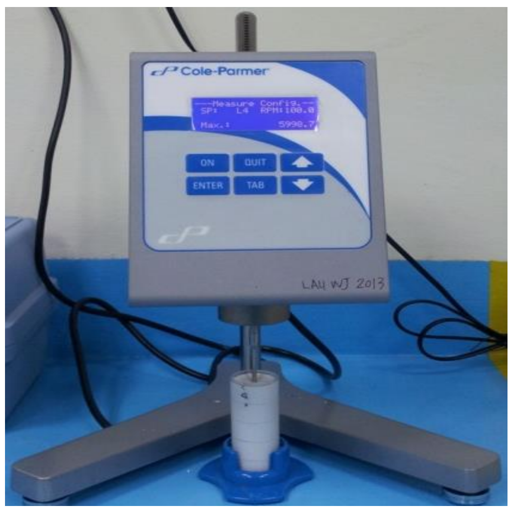


Figure 9.1. Brookfield Cole-Parmer

9.2.4 Determination of total solids content

The total solid content (TSC) of polymer is the mass percentage of the solid material determined in accordance with ISO 124 [22]. The WLP is measured by evaporating known mass of WLP to dryness at constant temperature of 70 °C in a conventional oven. The initial mass of sample and the mass after drying the sample are recorded. The TSC is expressed as a percentage of the original weight as shown in Equation 9.3.

$$TSC = \frac{m_1}{m_0} x\ 100 \qquad (9.3)$$

Where,

m_0 = the mass in grams of the test portion before drying

m_1 = the mass in grams of final dried material

Calculation of the amount of polymer latex used in concrete is tabulated in Table 9.1.

Table 9.1. Total solid contents

WLP	5 % by weight of cement	
WLP - Total solid (%)	42 %	
WLP - Total water (%)	58 %	
Cement	380 kg/m^3	
Water	209 kg/m^3	
<u>Calculation:</u> WLP – 5 % Water in WLP Mixing water	 5/100 x 380 kg/m^3 19 kg/m^3 x 58 % 209 kg/m^3 – 11.02 kg/m^3	 = 19 kg/m^3 = 11.02 kg/m^3 = 197.98 kg/m^3
<u>Calculation:</u> WLP – 10 % Water in WLP Mixing water	 10/100 x 380 kg/m^3 38 kg/m^3 x 58 % 209 kg/m^3 – 22.04 kg/m^3	 = 38 kg/m^3 = 22.04 kg/m^3 = 186.96 kg/m^3

CHAPTER 10

Brick

10.1 General brick

Bricks are the oldest manufactured building materials used by mankind. Brickmaking has transformed from a handicraft to a mechanised industry. They come in various shapes, colours, textures, strength, and quality depending on the materials and manufacturing methods. Bricks, on the other hand, play a major role in the creation and renovation of the built environment [23].

Bricks are a durable material that has high compressive strength, making it suitable for use in construction and civil engineering projects as a structural element for any projects, including buildings, tunnels, bridges, walls, floors, archways, chimneys, fireplaces, patios, or sidewalks. Beyond the mechanical properties of bricks, there are also aesthetic appeals to the material that favour their use in architectural applications [24].

10.2 Advantages of bricks

In construction applications, bricks offer several advantages over alternative materials that serve the same purpose:

- Bricks are a durable material, and can last hundreds or thousands of years.
- Bricks are fireproof and can withstand exposure to high temperatures.
- Bricks offer good noise reduction and sound isolation capabilities.
- Bricks do not require the application of paints or other finishes for protection from the environment.
- As a modular building component, problems with individual bricks can be addressed without the need to tear down and rebuild the entire structure.

- Since clay is available almost everywhere, bricks can be fabricated locally, eliminating the costs associated with their shipment. This can mean that construction using bricks as the material may be less expensive than with using stone, concrete, or steel.
- Bricks are simpler to work with because of their uniformity in size, unlike stone which needs to be sized and dressed.
- Bricks are easy to handle, and skilled tradespeople that can construct with bricks are plentiful.

10.3 Types of bricks

There are several types of bricks that can be classified as building material:

- Burnt clay brick
- Fly ash brick
- Fired brick
- Concrete brick
- Engineering brick

10.4 Brick masonry

The brick masonry is made up of brick units bonded together with mortar. The strength of brick masonry depends on the quality of bricks, quality of mortar, and method of the bonding tool [25].

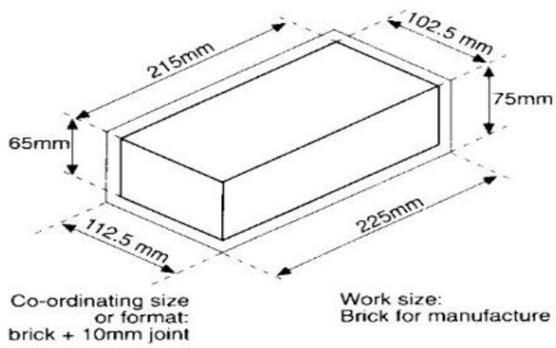
- Bricks are in uniform shapes and sizes; hence they can be laid in any definite pattern.
- They can easily be handled due to light in weight and small in size.
- No dressing required.
- The art of bricklaying is easier than stone masonry construction.
- Ornamental work can easily be done with bricks.
- Light partitions and filler walls can easily be constructed.

10.5 Types of brick masonry bonds

Bonding is the process of arranging bricks with mortar to tie them together. The vertical joints provided in the brick masonry should not continue. Without proper bonding in between bricks, it is not possible to construct the wall.

- Stretcher Bond
- Header bond
- English bond
- Flemish bond

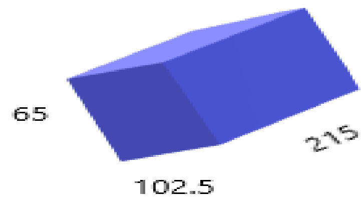
10.6 Calculation of brick proportions



Example 10.6.1

The example of calculation for sand cement brick mixture based on the material density with ratio of 1:3.

Dimension of the brick



ρ_{sand}= 1640 kg/m³

ρ_{cement} = 1440 kg/m³

The quantity of sand cement bricks to be produced is 100 units.

Volume per brick

$V = 1.4324 \times 10^{6}\ mm^3$

$= 1.4324 \times 10^{-3}\ m^3$

Volume for 100 brick

$V100 = 1.4324 \times 10^{-1}\ m^3$

+ 10% (Balance @ Excess of the mixture)

$V100 = 1.5756 \times 10^{-1}\ m^3$

Ratio of 1:3 @ 4 Portions

1 Portion cement of the mixture

$V_{Cement} = \frac{1.5756 \times 10^{-1}}{4} m^3 \times 1$ Portion

$= 3.9391 \times 10^{-2}\ m^3$

3 Portion sand of the mixture

$V_{Sand} = \frac{1.5756 \ x \ 10^{-1}}{4} m^3$ x 3 Portion

$= 1.1182 \times 10^{-1} m^3$

Calculation of the sand & cement mass ($\rho = \frac{m}{V}$)

- Cement

$$\rho \ cement = \frac{Mcement}{Vcement}$$

$$1640 \text{ kg/m}^3 = \frac{M}{3.9391 \ x \ 10^{-2}} m^3$$

$$M = 1440 \frac{kg}{m^3} \times 3.9391 \times 10^{-2} m^3$$

$M_{Cement} = 56.72$ kg

- Sand

$$\rho \ sand = \frac{Msand}{Vsand}$$

$$1640 \text{ kg/m}^3 = \frac{m}{1.1182 \ x \ 10^{-1}} m^3$$

$$MSand = 1640 \frac{kg}{m^3} \times 1.1182 \times 10^{-1} m^3$$

MSand = 193.8 kg

Example 10.6.2

The example of calculation of sand cement brick with coconut shells (TK) as additives

*TK needs to be converted into the size or fineness level of sand (d < 2mm)

$\rho\ cement = 1440$ kg/m³

$\rho\ sand = 1640$ kg/m³

$\rho\ coconut\ shell = 700$ kg/m³

Ratio = 1:3

Quantity/Number of the sand cement bricks is 100

V100 Bricks = 1.5756×10^{-1} m³

Example, 20% of TK and sand

$V_{Sand} = 1.1182 \times 10^{-1}$ m³

20% TK 80 % Sand

VTK = 20% x 1.1182×10^{-1} m³ = 2.2364×10^{-2} m³

$$\rho\ TK = \frac{M\ TK}{V\ TK}$$

$$700\ \frac{kg}{m^3} = \frac{M\ tk}{2.2364\ x\ 10^{-2}}\ m^3$$

$$MTK = 700\ \frac{kg}{m^3} \times 2.2364 \times 10^{-2}\ m^3$$

$$= 15.7\ kg$$

$$\boldsymbol{\rho\ sand = \frac{M\ sand}{V\ sand}}$$

$$1640\ kg/m^3 = \frac{M\ sand}{8.95\ x\ 10^{-2}}\ m^3$$

$$M_{sand} = 1640\ \frac{kg}{m^3} \times 8.95 \times 10^{-2}\ m^3$$

$$= 146.7\ kg$$

$$V_{Sand}\ 80\% = 80\% \times 1.1182 \times 10^{-1}\ m^3$$

$$= 8.95 \times 10^{-2}\ m^3$$

For 1 cement part value equals the initial calculation value

M_{Cement} = 56.72, W/C ratio = 0.5

V_{Water} = 56.72kg x 0.5

= 28.36 kg

$\rho\ water = 1000$ kg/m³

$$\boldsymbol{\rho = \frac{M}{V}}$$

1000 kg/m³ = $\frac{28.36\ kg}{V}$

V = $\frac{28.36\ kg}{1000\ kg/m^3}$

= 2.836 x 10^{-2} m³

Example 10.6.3

Example of concrete cube mixture calculation 1:3:6

Cement Sand Aggregate

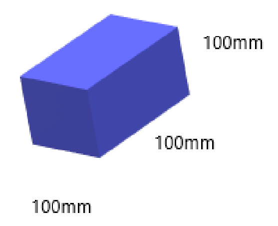
<u>Calculation for cube quantity</u>

Number of days of testing = 3,7,14,28 (4 Different duration of testing)

Density test (3 Cubes at each testing) = 3 x 4 No. of days = 12 Cubes

Curing test (3 Cubes at each testing) = 3 x 4 No. of days = 12 Cubes

12 Cubes + 12 Cubes + 1 (Sample for exhibition) = 25 Cubes



<u>Volume of cube</u>

$V = 1x\ 10^{6}\ mm^3$

$= 1\ x\ 10^{-3}\ mm^3$

$V25 = 1\ x\ 10^{-3}\ x\ 25$

$= 2.5\ x\ 10^{-2}\ m^3$

$V25 + 10\%\ Balance = 2.75\ x\ 10^{-2}\ m^3$

Volume / Portions = $\frac{\mathbf{2.75\ x\ 10^{-2}}}{\mathbf{10}}$ **m^3 = 2.75 x 10^{-3} m^3**

$\rho\ cement = 1440$ kg/m³

$\rho\ sand = 1640$ kg/m³

$\rho\ aggregate = 1390$ kg/m³

Ratio 1:3:6 → 10 Portions (1 + 3 + 6)

- **Cement (1 Portion)**

$$\boldsymbol{\rho = \frac{M}{V}}$$

$$1440\ \text{kg/m}^3 = \frac{M}{2.75\ x\ 10^{-3}}\ \text{m}^3$$

$$M_{Cement} = 1440\ \text{kg/m}^3 \text{ x } 2.75 \text{ x } 10^{-3}\ \text{m}^3$$
$$= 3.96\ \text{kg}$$

- **Sand (3 Portion)**

$$V_{Sand} = 3 \text{ x } 2.75 \text{ x } 10^{-3}\ \text{m}^3$$
$$= 8.25 \text{ x } 10^{-3}\ \text{m}^3$$

$$\rho = \frac{M}{V}$$

$$1640\ \text{kg/m}^3 = \frac{M}{8.25} \text{ x } 10^{-3}\ \text{m}^3$$

$$M_{Sand} = 1640\ \frac{kg}{m^3} \text{ x } 8.25 \text{ x } 10^{-3}\ \text{m}^3$$
$$= 13.5\text{kg}$$

- **Aggregate (6 Portion)**

$$V_{Aggregate} = 6 \text{ x } 2.75 \text{ x } 10^{-3}\ \text{m}^3$$
$$= 1.65 \text{ x } 10^{-2}\ \text{m}^3$$

$$\rho = \frac{M}{V}$$

$$1390\ \text{kg/m}^3 = \frac{M}{1.65\ x\ 10^{-2}}\ \text{m}^3$$

$M_{Aggregate} = 1390 \frac{kg}{m^3}$ x 1.65 x 10^{-2} m^3

= 22.94 kg

- **Water**

W/C ratio = 0.5

Cement = 3.96 kg

Water = 3.96 x 0.5

= 1.98 kg @ 1.98 ℓ

Example 10.6.4

Example of calculation of concrete cube mixture with coconut shell admixture and mixing ration of 1:3:6 with 20% coconut shell (TK) replacing the volume of sand.

1 , 3 , 6

Cement 20% TK 80% Sand Aggregate

***The calculation of cement, aggregate, and water has no changes.**

- <u>TK & Sand</u>

V_{Sand} portion = 8.25 x 10^{-3} m^3

V20% TK = 20% x 8.25 x 10^{-3} m^3

= 1.65 x 10^{-3} m^3

$\rho = \frac{M}{V}$, $\rho\, TK$ = **700 kg/m³**

$700\ kg/m^3 = \frac{m}{1.65\ x\ 10^{-3}}\ m^3$

$M = 700\ kg/m^3 \times 1.65 \times 10^{-3}\ m^3$

$= 1.155\ kg$

$V80\%_{Sand} = 80\% \times 8.25 \times 10^{-3}\ m^3$

$= 6.6 \times 10^{-3}\ m^3$

$\boldsymbol{\rho = \frac{M}{V}}$ **,** $\boldsymbol{\rho\ sand = 1640}$ **kg/m³**

$1640\ \frac{kg}{m^3} = \frac{m}{6.6\ x\ 10^{-3}}\ m^3$

$M = 1640\ \frac{kg}{m^3} \times 6.6 \times 10^{-3}\ m^3$

$M80\%_{Sand} = 10.824\ kg$

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