INFLUENCE OF COARSE AGGREGATE CHARACTERISTICS ON CONCRETE PROPERTIES

MD RABIUL ALAM
(BSc Engg., RUET)

A THESIS SUBMITTED FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING
MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY

2019

The thesis titled "**Influence of Coarse Aggregate Characteristics on Concrete Properties"** submitted by Md Rabiul Alam Roll No: 1012110022, Session: October 2012, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Transportation) on 26 May 2019.

BOARD OF EXAMINERS

1. ______________________________________ : Chairman (Supervisor)
Lt Col Mohammed Russedul Islam, PhD
Associate Professor
Department of Civil Engineering, MIST, Dhaka

2. ______________________________________ : Member (Co-Supervisor)
Lt Col Md Jahidul Islam, PhD
Associate Professor
Department of Civil Engineering, MIST, Dhaka

3. ______________________________________ : Member (Ex-Officio)
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Department of Civil Engineering, MIST, Dhaka

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Department of Civil Engineering, MIST, Dhaka

5. ______________________________________ : Member (External)
Dr Mohammad Al Amin Siddique
Associate Professor
Department of Civil Engineering, BUET, Dhaka

6. ______________________________________ : Member (External)
Dr Muhammad Hasanuzzaman
Assistant Professor
Department of Glass and Ceramic Engineering, BUET, Dhaka

DECLARATION

I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

Md Rabiul Alam

26 May 2019

ACKNOWLEDGEMENT

I express my utmost gratitude to the Almighty Allah for the successful completion of the research work as planned.

I also express my deepest gratitude and sincere appreciation to my thesis supervisor Lt Col Mohammed Russedul Islam, PhD and Co-supervisor Lt Col Md Jahidul Islam, PhD Department of Civil Engineering MIST, Dhaka for their constant guidance, invaluable suggestions and affectionate encouragement which were extremely helpful on accomplishment this thesis.

I pay my deepest honor to Major General Abu Syeed Md Masud, BSP Chief Coordinator Padma Multipurpose Bridge Project for selecting me to undergo MSc Engineering Degree in one of the most prestigious Institute of Bangladesh. My Deep appreciation and thanks to Brigadier General Wahidul Islam, SUP, NDC, psc Head of the Department of Civil Engineering, MIST, Senior Material Engineer Moazzem Hossain and Material Engineer Gobindo Kumar from N-8 Highway Project, Material Enginner Kutub Uddin from Spetra Construction Ltd, and Tushar Kanti Kait from Max Construction ltd. I need to convey my special thanks to Abdul Monem Limited and his laboratory team lead by Material Engineer Kazi Abu Borhan for their whole hearted support for doing all maximum laboratory tests. I convey my heartiest satisfactions to the Army team who were with me all time to support my thesis works are Sgt Md Anwor Faruq, Lcpl Md Monirul Islam, Snk Md Nurul Islam, Lcpl Md Kaushikur Rahman and civil staff Lab technician Shahjahan, office staff Kamruzzaman and Aman. I remember with due respect the assistance from Nag Traders for supporting me to collect local stones from the original sources.

I recompense my respect to Professor Syed Humayun Akhter, department of Geology, Dhaka University and Dr Muhammad Hasanuzzaman, Department of Glass and ceramic, BUET for their laboratory support which has enhanced my thesis work.

I also pay deepest homage to those who helped directly and indirectly in performing the work in connection with the thesis, specially laboratory of MIST, Dhaka and Laboratory SA-3, Padma Bridge Project Area.

Finally I would like to express my profound gratitude to my respected parents, my beloved wife Ahsana Sayeed, son Mahdi Mohtasim and daughter Ma As Sama for their continuous support, encouragement and sacrifice for my thesis. Their prayers and support helped me to complete my postgraduate degree in time. May Almighty help us always and enlighten us with knowledge.

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ABSTRACT

A good number of infrastructure projects are implemented in Bangladesh during the last decade and many more are still in pipeline. In the financial year 2017-18 approximately 12.7 million tons of aggregate are used by the construction industries. Local sources could supply only 11% of those aggregate and rest 89% are collected from foreign sources. Due to the wide variation of aggregate sources performance of concrete become unpredictable in some cases. Therefore, in the present study influence of coarse aggregate characteristics on concrete properties are investigated in the context of Bangladesh. To evaluate the performance of aggregate and corresponding concrete, six widely used coarse aggregate sources are selected for this study. A series of laboratory test are conducted to evaluate the ACV, TFV, LAA, EI, and FI, specific gravity, water absorption and unit weight for all six aggregates. Additionally, chemical composition and petrographic properties are also explored. Keeping the gradation of aggregate constant, two type of concrete mix (w/c ratio 0.3 and 0.4) were prepared to cast concrete cylinders and beams by using six sources of coarse aggregate. Admixture is used in concrete mix to achieve similar workability for all concrete, especially for low w/c ratio concrete. Concrete properties including compressive, tensile and flexural strengths are determined. The study finds that physical properties of aggregate generally influence the properties of concrete, especially for concrete with 50 MPa compressive strength. The outcomes of the study will help the engineers to select appropriate sources of aggregate depending on concrete strength requirement.

DEDICATED TO

MY PARENTS AND FAMILY

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LIST OF ABBREVIATIONS

Symbols	Description
ASSHTO	American Association of State Highway Transportation Officials
ASTM	American Society for Testing and Materials
ACI	American Concrete Institute
ADB	Asian Development Bank
BS	British Standard
DEEW	Dhaka Elevated Expressway
ECNEC	Executive Committee of National Economic Council
GDP	Gross Domestic Product
GSB	Geological Survey of Bangladesh
HMA	Hot Mix Asphalt
LGED	Local Government Engineering Department
MRT	Mass Rapid Transit
NBR	National Board of Revenue
OPEC	Organization of Petroleum Exporting Countries
PMBP	Padma Multipurpose Bridge Project
PBRLP	Padma Bridge Rail Link Project
QA	Quality Assurance
RHD	Roads and Highway Department
RMSS	Road Materials and Standard Study
RQD	Rock Quality Designation
RMP	Road Material Plan
SASEC	South Asia Sub-regional Economic Corporation
STP	Standard Test Procedures
WDXRF	Wavelength Dispersive X-Ray Fluorescence
XRF	X-ray Fluorescence
PCC	Pozzolanic Portland Cement

OPC	Ordinary Portland Cement
ACV	Aggregate Crushing Value
TFV	Ten Percent Fine Value
LAA	Los Angeles Abrasion
FI	Flakiness Index
EI	Elongation Index
MoR	Modulus of Rupture
PI	Pakur (India)
KV	Khuong (Vietnam)
SM	Seremban (Malaysia)
Mo	Moddhapara
Bh	Bholagang
Ja	Jaflong

CHAPTER 1
INTRODUCTION

1.1 Background

Bangladesh, our beloved mother land, emerged as an independent country in 1971 after breaking away and achieving independence from Pakistan. It is enriched as the glorious historic background. Bangladesh with its millions of united active hands heading towards progressive world being pregnant with modern thoughts and ideologies as a result of that Bangladesh has put his steps into the zone of developing countries. For the development of a country one of the foremost important issues is communication network. Keeping this in view, Bangladesh government has put due importance on this sector. With a view to achieving desired economic development road networking at every corner of the country is highly required. Both the government and non-government development organization are trying hard to implement total network plan throughout at the country. Besides these, the revised "Strategic Transport Plan of Dhaka" (2015 to 2035) has got outmost priority under implementation program [1].

It is mention worthy with complacence that mega project like Padma Multipurpose Bridge Project (PMBP), Padma Bridge Rail Link Project (PBRLP), Dhaka Elevated Expressway (DEEW), Mass Rapid Transit (MRT), Bus Rapid Transit (BRT), Dhaka-Mawa-Bhanga National Highway N8 road, Karnafuly Tunnel and many other mega projects are on progress which will lead our total communication sector toward a new horizon.

At present the total length of highways, constructed under RHD and LGED, is 21,642 and 10,311 km respectively. Our total road communication network includes 20.74 km bridge and 6122 culverts [2,3]. Milestone projects like Hatirzheel, Jatrabari Flyover, Kuril Flyover, Mirpur Flyover have already been implemented in the recent past. Implementation of all these have been foremost leading milestone for the future prospect of our construction sector [4].

In fact, development of road communication network is one of the foremost key factors for boosting up the economy as well as reducing the poverty of our nation on its way forward. Jamuna Bridge has linked the northern part with the capital city Dhaka and thereby it has contributed a lot to the overall prospect of the whole country. In the same way Padma Bridge will increase 2.6% GDP of south-west region and 1.26% GDP of total economy of the nation [5]. Government is planning to increase all two lane highway into 4-lane highway with service roads which with a view to providing advantage to the communication sector as well to our economy. Huge involvement of construction works will engage major part of the finance. To meet up large quantity of construction materials like coarse aggregates engineers need to be very economical in design and construction, especially for low-quality aggregates which are characterized as porous and weak. The properties of concrete are found to be significantly affected by the types of aggregates [6]. Wu et al. in their study on the mechanical properties of high performance concrete, have found that the strength, stiffness, and fracture energy of concrete for a given water/cement ratio depend on the type of aggregate, especially for high-strength concrete [7]. They suggested that for producing high-strength concrete with low brittleness, high-strength aggregate with low brittleness should be used. Few studies have also been conducted on the effect of aggregates on the properties of concrete [8, 9]. These studies have revealed that all the major properties of concrete including compressive strength, tensile strength, water absorption, chloride permeability, coefficient of chloride diffusion, and rate of reinforcement corrosion are significantly affected by the type of aggregates.

With widespread use of concrete as a structural material, there is a continuous effort to develop high performance concrete with increased strength and durability for reducing the consumption of materials and increasing the service life of the structure. However, it is very difficult to produce a high-performance concrete mixture using low quality of aggregates. Durability problems (mainly reinforcement corrosion) are often encountered in concrete structures subjected to aggressive exposure conditions, such as marine environments [10, 11]. This eventually results in economic loss due to high cost of maintenance, durability incompetence, structural and service failures [12-15].

Besides new construction work, it is very important to maintain the previously constructed thousands kilometer of roads and bridges. Without maintenance the whole construction network will collapse and the aim of the communication sector will not be fulfilled. The weather of our country specially the rainy season is very harmful for our asphalt roads. Water logged areas are highly vulnerable to damage and design engineers suggest for concrete road instead of asphalt road. Maintenance of roads requires high cost and gets less priority Form the road agencies. To have an effective road network all over the year we need to give emphasis for maintenance work. In recent days some foreign aided projects are considering 4 to 6 years maintenance cost with the project cost. For example project like South Asia Sub regional Economic Cooperation (SASEC) which is funded by ADB and OPEC are providing project fund with 1 year defect liability and 4 years maintenance cost. SASEC-2 is providing 1 year defect liability and 6 years maintenance fund with total project cost.

To build road infrastructure we need to build many bridges in Bangladesh. It is because our country runs through by many rivers which require numbers of bridge and culvert construction. In case of long lasting road, reinforced cement concrete may incase high initial investment but will require less maintenance cost. Here project cost can be minimized using high strength concrete. Using good quality aggregate and go for high strength concrete in road construction will save large amount of materials. In this study main focus will be to suggest good quality aggregate and analysis on aggregate properties to identify its influence on concrete work.

1.2 Present State of Problem

Government of Bangladesh has given due priority on road construction works in last one decade. In every Executive Committee of National Economic Council meeting, numbers of new projects are approved for implementation. It is good to state that economy of Bangladesh has reached in a comfortable state and government is able to provide required fund to almost all implemented projects. One of the main requirements of construction works is huge amount of coarse aggregates. In concrete works coarse aggregates occupies almost 70-80% of the concrete by weight [16]. So aggregate plays a very important role in concrete strength specially, in high strength concrete.

From NBR report in the year 2016-17 total 9.4 million tons and in 2017-18 total 12.7 million tons of aggregates were used in overall construction works in Bangladesh [17]. Out of total consumption only 11% of coarse aggregates were supplied from our own local source and 89% coarse aggregates were imported from different countries [17]. At present mostly used coarse aggregates are imported from India (Pakur, Meghaloy, Gujrat), Vietnam (Khuong), Malaysia (Seremban), Dubai, Indonesia and other countries. Our local sources of coarse aggregate are limited and those are mostly located in Moddhapara, Bholagong, Jaflong, Sherpur and some other small sources. Coarse aggregate from Moddhapara provides largest share of local demand but the amount is not more than 1.2 million tons per year.

Most importantly, there is a lacking of detailed research on locally available and imparted coarse aggregate. Few researches are available but those are not the same aggregate that are presently used to build infrastructure. It is important to know detail aggregate properties and their impacts on concrete. That’s why this study is done to know the different properties of aggregates and to correlate the properties with concrete strength.

1.3 Objectives of the Study

The main objective of this research work is to conduct a study to identify the properties of commonly used coarse aggregates and to know at what extent they influence concrete strength. The specific objectives are as follows:

(a) To determine the physical and chemical characteristics of aggregates.
(b) To evaluate properties of concrete.
(c) To correlate concrete properties with that of aggregates.

1.4 **Scope of the Study**

This study is based on series of experiment based on laboratory test. The scope of the study was limited to the following:

(a) To select widely used aggregates in mega projects (03 foreign and 03 of local sources) for this study.

(b) To find out physical properties of aggregate like ACV, TFV, LAA, FI, EI, specific gravity and unit weight following standards, like AASHTO, ASTM and BS.

(c) To perform tests, like chemical composition of aggregate, soundness and Alkali-Silica reactivity in order to identify chemical properties of aggregate.

(d) To identify the mineralogical natures of aggregate through petrography test.

(e) To prepare four types of concrete mix with two different cement types (OPC and PCC) and two different w/c ratios (0.3 and 0.4). The aggregate gradation was kept fixed for all four combinations in order to achieve consistent results.

(f) To conduct tests of concrete, like compressive strength, tensile strength, flexural strength, Young's modulus and chloride ion penetration for concrete cylinders and beams at the age of 07, 28 and 90 days.

1.5 Organization

This study has been presented in five distinct chapters where the key aspects of entire research are being reflected separately:

Chapter 1: Background, Statement of the problem, objectives and scope of the study.

Chapter 2: A review of the literature on the subject matter and findings from previous studies on road materials and concrete properties.

Chapter 3: Research methodology of the study.

Chapter 4: Test results, analysis, evaluation and discussion.

Chapter 5: Final remarks as conclusion of the study and recommendations for further study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In essence, a literature review identifies, evaluates and synthesized the relevant literature within a particular field of research. Considering these aspects the present chapter deals with the brief description of the previous research conducted on areas that are relevant to aggregate characteristics, concrete properties and the relation between aggregate and concrete. This chapter also discusses about various relevant materials those are available in different parts of our country.

2.2 Economical Use of Construction Materials, its Availability and Effects on Concrete

A variety of modernized construction material options have recently become available due to ongoing research and support in innovative technologies. An ideal and modern construction material will aim to maintain structural strength while reducing its impact on the environment. In addition, modern construction materials must be able to adapt to various weather and site conditions [18]. Implementation of solutions is needed, both from the utilization of locally available materials and well supervised constructional practices on one hand, and well-packaged design that takes into consideration the strength and durability of the intended structures on the other [19, 20]. Economy will be achieved if the integrity of locally available materials is probed with a view to determining their performance with respect to improved strength and resistance to migration of corrosive substances, such as chloride concentration at rebar level. These requirements include the use of high-performance concrete (with low water/cementitious materials ratio, optimum fine to total aggregate ratio, adequate cementitious materials content, and use of admixtures) and increased concrete cover [21-23]. Several studies have been reported on optimal design of concrete mixtures [24-27]. Crack control measures and implementation of measures designed specifically for corrosion protection are some of the factors that can help to control the onset and rate of corrosion [28].

The invention of concrete, which was essential to architecture utilizing arches, created an immediate, permanent demand for construction aggregates. Economy denotes the proper management of materials and of site, as well as economical balancing of cost and common sense in the construction of works. The advent of modern blasting methods enabled the development of quarries, which are now used throughout the world, wherever competent bedrock deposits of aggregate quality exist. In many places, good quality stone bedrock deposits do not exist. In these areas, natural sand and gravel are mined for use as aggregate. Where neither stone, nor sand and gravel, are available, construction demand is usually satisfied by shipping in aggregate by rail, barge or truck.

In the field of road construction material Bangladesh lacks in readily available adequate quantities of road construction materials such as hard rocks. Hard rocks are often sought for use in pavement structures to provide the necessary strength to carry traffic loads. Instead, a useful traditional substitute is the brick which is produced abundantly throughout Bangladesh. The excessive dependence on bricks alone, however, poses a serious threat to the environment through increasing desertification. While the country is striving hard to develop its road communication infrastructure, the paucity of quality road materials proves to be a serious impediment towards attaining the desired goal. In this backdrop, necessity demands an inventory of road making coarse aggregate to economize the construction job maintaining the quality in work.

Geologically, Bangladesh occupies a greater part of the Bengal Basin and the country is covered by Tertiary folded sedimentary rocks (12%) in the north, north eastern and eastern parts; uplifted Pleistocene residuum (8%) in the north western, mid northern and eastern parts; and Holocene deposits (80%) consisting of unconsolidated sand, silt and clay. The oldest exposed rock is the Tura Sandstone of Paleocene age but older rocks like Mesozoic, Paleozoic amid Precambrian basement have been encountered in the drill holes in the north western part of the country [29].

Figure 2.1 shows that mineral deposits suitable for road construction and are available in Bangladesh. These minerals are hard rock, gravel, boulder, construction sand, brick clay and limestone. Gravel and construction sand are found in the small hills, mainly in the northern part of the country (Moddhapara, Dinajpur; Sherpur; Bholaganj, Sylhet). Exploitation of the deposits of limestone, construction sand and gravel are done through small scale quarrying. Development of subsurface hard rock mine at Moddhapara is now in operation.

2.3 **Description of Construction Materials**

2.3.1 **Construction aggregate**

Construction aggregate, or simply "aggregate", is a broad category of coarse particulate material used in construction, including sand, gravel, crushed stone, slag, recycled concrete and geo synthetic aggregates. Aggregates are the most mined materials in the world. Aggregates are a component of composite materials such as cement concrete and asphalt concrete; the aggregate serves as reinforcement to add strength to the overall composite material. Due to the relatively high hydraulic conductivity value as compared to most soils, aggregates are widely used in drainage applications such as foundation and

French drains, septic drain fields, retaining wall drains, and road side edge drains. Aggregates are also used as base material under foundations, roads, and railroads.

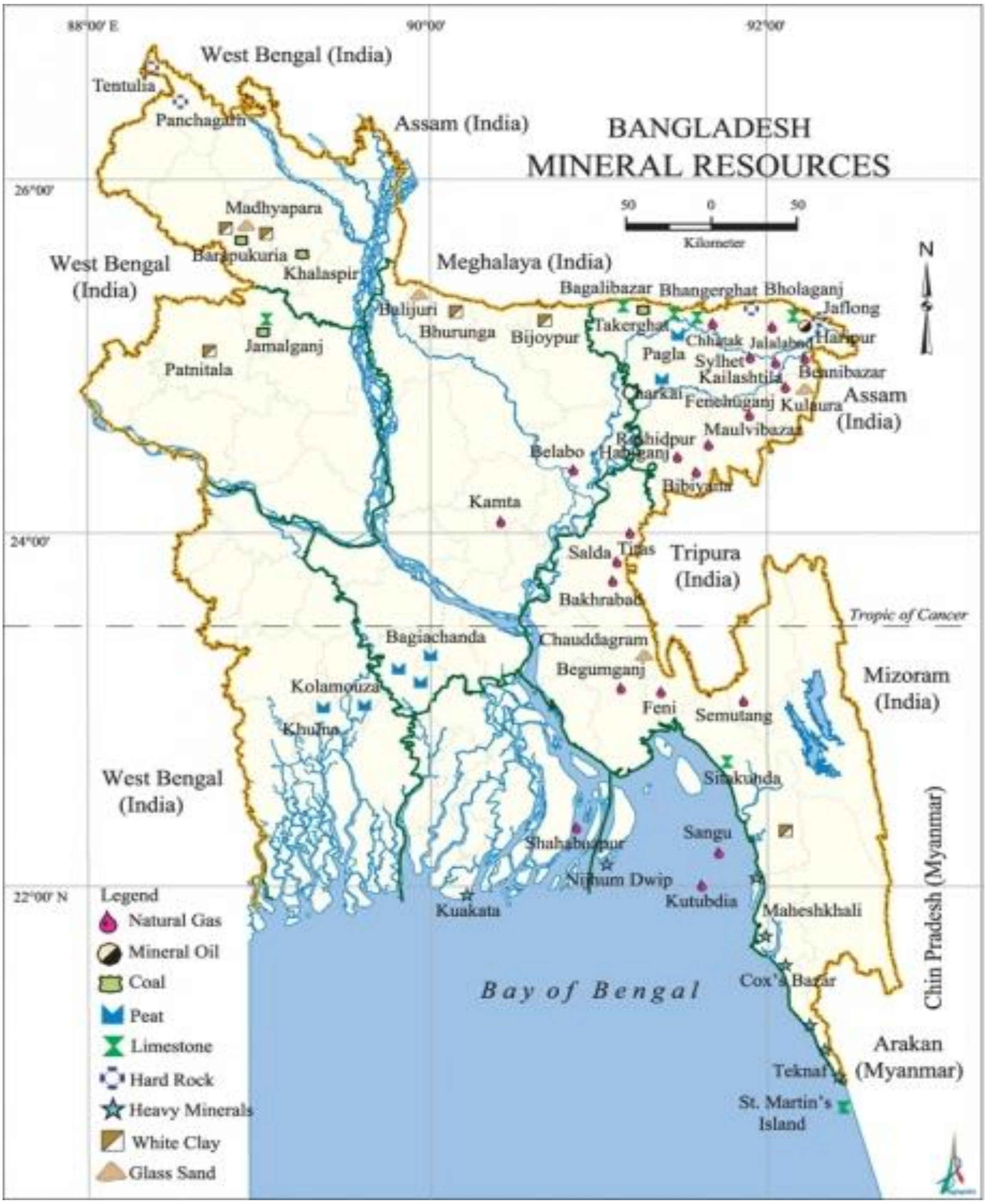


Figure 2.1: Mineral resources of Bangladesh.
(http://en.banglapedia.org/index.php?title=Mineral_Resources)

Aggregate characteristics have a significant effect on the behavior of fresh and hardened concrete. Although these effects of aggregate characteristics change continuously as a function of particle size, the following classification will be made according to common practice: material retained in the No 4 sieve will be considered coarse aggregate, material passing No. 4 sieve and retained in the No. 200 sieve (75 μm) will be considered fine aggregate, and material passing No. 200 sieve will be called herein after micro fines [30].

The American Society for Testing and Materials (ASTM) publishes an exhaustive listing of specifications for various construction aggregate products, which, by their individual design, are suitable for specific construction purposes. These products include specific types of coarse and fine aggregate designed for such uses as additives to asphalt and concrete mixes, as well as other construction uses."

Sources for these basic materials can be grouped into three main areas: Mining of mineral aggregate deposits, including sand, gravel, and stone; use of waste slag from the manufacture of iron and steel; and recycling of concrete, which is itself chiefly manufactured from mineral aggregates. In addition, there are some (minor) materials that are used as special lightweight aggregates: clay, pumice, polite, and vermiculite.

2.3.2. **Hard rock**

It is a term used loosely for igneous and metamorphic rocks, as distinguished from sedimentary rock. The hard rock of Bangladesh is mainly available at Moddhapara, Bholaganj, Jaflong, Tetulia, Patgram, and Panchagarh. Some sedimentary rocks are available at parts of Chittagong and Chittagong Hill Tracts also [31]. Among all Moddhapara Subsurface Hard Rock is considered as one of the best quality and it contains a huge deposit. In 1974-75 the Geological Survey of Bangladesh (GSB) drilled six wells in and around Moddhapara, Dinajpur and confirmed the existence of Precambrian hard rock at very shallow depth (128m and 154m). The Rock Quality Designation (RQD) of fresh rock varies from 60% to 100%. The Government of

Bangladesh approved the project in 1978. However, the project started working formally from early 1994.The Moddhapara underground project is extended over an area of 1.44 sq km (approximately). The Hard rocks are to be extracted from a depth of 170m to 230m below the surface. The total reserves are estimated at 172 million metric tonnes and the mineable reserves are 72 million metric tonnes. At Mo these rocks consist commonly of gneiss and schist together with granite/granodiorite and quartz/diorite. Development of this underground hard rock mine is going on. Its annual production has been estimated to be 1.65 million metric tons [31]. Figure 2.2 shows the location of Mo hard rock.

Figure 2.2: Moddhapar hard rock, Dinajpur.

(http://en.banglapedia.org/index.php?title=Mineral_Resources)

2.3.3 **Gravel**

Deposits of gravel are found along the piedmont areas of the Himalayas in the northern boundaries of Bangladesh. These river borne gravels come from the upstream during the rainy season. Total reserve of the gravel deposits is about 10 million cum. Gravel deposits are being exploited and used in the country.

(a) Wide areas of northern and northeastern parts of Bangladesh are covered with gravel beds. In the north - west, the gravels are well exposed at Dahagram-Angorpota, Patgram, Dalia, Chapani, Kaliganj in greater Rangpur and Tetulia, Vazanpur, Boalmari, etc in greater Dinajpur. These gravels are quite large (maximum recorded elongation is 30 cm) [31] and are alternated with very coarse to medium sand. They are quite fresh and well rounded, with a smooth surface. The sphericity and roundness of these gravels are high and they have quartz, quartzite, granite, gneiss and schist as their dominant lithologies.

(b) The gravels of the north eastern part of Bangladesh are well exposed in the Jaintiapur-Bholaganj area in greater Sylhet district. Here the gravel beds are divided into two lithostrati graphic sub-units: older sub-unit (high terrace) and younger sub-unit (low terrace) [31]. The older sub-unit in the Jaintiapur area and Binda Tila that caps the hill tops has been named the 'Sona Tila Gravel Bed'. Similarly, the younger sub-unit of the Bholaganj area and the river bed deposits of the present river system have been named the 'Bholaganj Gravel Bed'. Both the sub-units belong to the Dihing Formation.

(c) The Sona Tila Gravel Bed is equivalent to the Lower Pleistocene series and belongs to the Moddhupur Clay formation while the Bholaganj Gravel Bed is equivalent to the Upper Pleistocene to Holocene series. Similarly, the former is weathered and the latter is fresh, hard and high quality derived from the Khasi-Jaintia Hill Ranges. The gravels of both the beds are of igneous and metamorphic origin. They have high sphericity and roundness values and as such suggest long transportation and longtime abrasion of the gravel sediments. They are made up of river borne deposits.

(d) Apart from these, numerous hill streams also deposit gravels on the streambeds of the hill ranges and in the plains close to these ranges. These hill ranges are mostly located in the Sylhet, Chittagong and Chittagong Hill Tracts region. Also in the Teknaf-Cox's Bazar Sea beach seven separate occurrences of gravels are present between Moderbunia chhara and Rajarchhara. These gravels are of sedimentary origin and mostly belong to the Surma and Tipam Group of sediments (Source: http://www.ebanglapedia.com/en/article.php). Proper excavation of hard rock may partially fulfill the country's demand for constructing roads, bridges, dams and embankments. A probable estimated quantity of Gravel deposit in Table 2.1 and pictures in Figure 2.3 are given below.

Table 2.1: Construction related materials deposits of Bangladesh.

Name of the Mineral	**Place**	**Estimated Reserve (million metric ton)**	**District**	**Remarks**
Limestone	Joypurhat Bagalibazar #Takerghat Lalghat Naogaon	100 17 12.9 12.9 --	Joypurhat Sunamganj Sunamganj Sunamganj Naogaon	# 6,12,371 tons of limestone from Takerghat have been exploited During 1972-93
Hard Rock	Mo	115 (Exploited)	Dinajpur	Mine development activities is going on
*Gravel Deposit	Bholaganj Tetulia Patgram Chittagong Hill Tract	4 2.5 2.5 1.0	Sunamganj Panchagar Lalmonirhat Chittagong	Gravel deposits are being exploited from different places of the country

* Reserve is in million tons except that of gravel which is in million m^3

Figure 2.3: Gravel

(https://www.google.com.bd/search?q=Mineral+resources+of+Bangladesh&source613)

2.3.4 **Limestone**

In the early 1960's, a quarry of limestone of Eocene age with a small reserve at Takerghat in the north eastern part of the country started supplying raw materials to a cement factory. This was the first mine in the country which was actually a quarry. In the 1960s GSB discovered another limestone deposit in Joypurhat at a depth of about 515-541m below the surface with a total reserve of 100 million ton [31]. GSB continued its effort to find out limestone deposits at shallow depth. In the mid 1990s GSB discovered limestone deposit at a depth of 493-508 m and 531-548 m below the surface at Jahanpur and Paranagar of Naogaon respectively (Figure2.4). Thickness of these deposits is 16.76m and 14.32 m respectively.

Figure 2.4: Limestone in Bangladesh.

(http://en.banglapedia.org/index.php?title=Mineral_Resources)

2.3.5 **Construction sand**

It is very much available in the riverbeds throughout the country. Of all the sources, the Sylhet sand is considered best for construction works. Sand consists mostly of quartz of medium to coarse grains. It is extensively used as construction material for buildings, bridges, roads etc all over the country. The Figures 2.5, 2.6, 2.7 and 2.8 are showing location of sand collection points, stockpiles of sand and few sources of Sylhet sand like Kanaighat Upazilla.

Figure 2.5:Collection site of Sylhet sand.

(https://www.google.com.bd/search?q=Collection+site+of+Sylhet+sand&source=lnms&tbm=isch&sa=X&ved=0ahUKEwi5p7SC7uDjAhXSSH0KHdYxCOcQ_AUIEigB&biw=1366&bih=613)

Figure 2.6: Sources of sand in Kanaighat Upazilla, Sylhet.

(http://en.banglapedia.org/index.php?title=Kanaighat_Upazila)

Figure 2.7: Stockpile of Sylhet sand.

(https://www.google.com.bd/search?q=Collection+site+of+Sylhet+sand&source=lnms&tbm=isch&sa=X&ved=0ahUKEwi5p7SC7uDjAhXSSH0KHdYxCOcQ_AUIEigB&biw=1366&bih=613)

Figure 2.8: Sand collection point in Sylhet.

(https://www.google.com.bd/search?q=Collection+site+of+Sylhet+sand&source=lnms&tbm=isch&sa=X&ved=0ahUKEwi5p7SC7uDjAhXSSH0KHdYxCOcQ_AUIEigB&biw=1366&bih=613)

2.3.6 **Portland cement**

Portland cement is the most common type of Cement use around the world. This Cement is made by heating lime stone (Calcium Carbonate) with other materials (Clay) to 1450°C in a kiln, in a process known as Calcinations. A molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix to form calcium silicates and other cementations compounds. Table 2.2 shows the percent of components of Portland cement.

Table: 2.2: Components of Portland cement

	Components						
	SiO_2 content (%)	AlOs content (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Specific gravity (%)
Percent (%)	21.9	6.9	3	63	2.5	1.7	3.15

2.4 Sources of Materials and Collection Points in Bangladesh from Different Geographical Areas

2.4.1 General

The RMSS Materials Engineers team undertook a comprehensive field survey throughout the country during the dry seasons of 1991 [31]. The Road Materials and Standard Study Bangladesh was published on June 1994. The aim of this survey was to complete the investigation made by the others and particularly by the Road Material Project (RMP) team and to collect representative samples for geotechnical tests in the laboratory. The field survey was conducted successively in the 6 regions delineated by the mission and called RMSS area 1 to RMSS area 6 [Figure 2.9]. This area wise inventory described the type of soils and materials encountered in each zone. Each of these areas includes one or more number of zones. The RMSS team divided Bangladesh into 6 areas namely:

Area 1. Faridpur, Barisal, Patuakhali, Kushtia, Jessore and Khulna Districts.

Area 2. Rangpur, Bogra and Rajshahi Regions.

Area 3. Dhaka and Mymensingh Region.

Area 4. Sylhet Region.

Area 5. Comilla, Feni and Noakhali.

Area 6. Chittagong, Cox's Bazar and Teknaf.

Figure 2.9: RMSS Area 1 to RMSS Area 6

In this thesis, only Area 2, 3 and 4 will be discussed. In Bangladesh all major as well as minor projects basically depend on these three areas for construction material. Among these areas, Bh, Mo and Sherpur zones are most focused zones. In this study, little important information was highlighted. These information were taken as inputs later.

2.4.2 **Area 2. Rangpur, Bogra and Rajshahi regions**

The main focus of this Area is Mo Hard Rock which is widely used in construction work. Few important aspects of Mo hard rock is discussed below.

Mo Hard Rock.

Mo hard rock mine is located in Mo, Dinajpur, Bangladesh. Its geographical coordinates are 25° 33’ 15’’ N to 25°34’ 15’ N latitude and 89° 3° 30°E to 89° 4’ 53’ E longitude Mo hard rock Mine is 330km away from Dhaka, the capital of Bangladesh and 14km away from phulbari, Dinajpur [Figure 2.10]

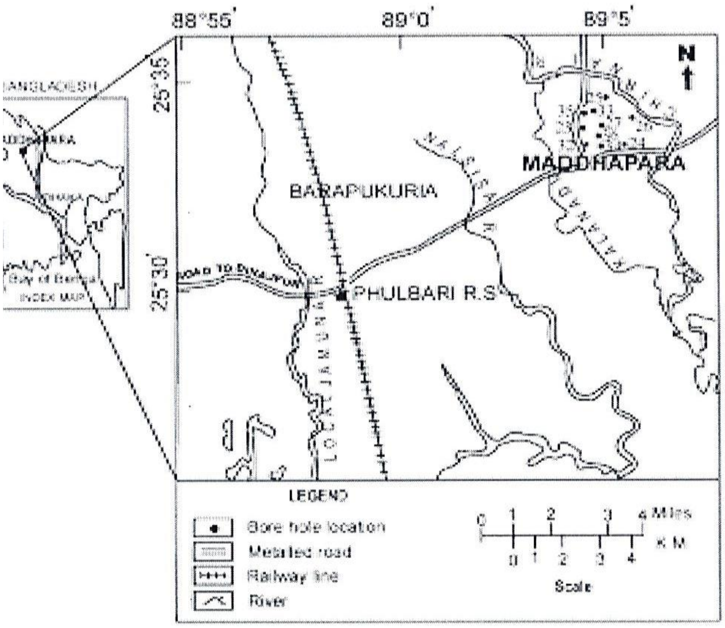


Figure 2.10: Location of Mo hard rock mine 18

Mo hard rock mining area and its environs are formed by the deposition of three different materials, e.g. Piedmont Alluvium, Tista Alluvium and Barind Tract. The Piedmont plains occur throughout most of Dinajpur District and of Rangpur District.

The old Himalayan Piedmont plain is a part of a gigantic alluvial formed by the Tista River, before it abandoned the landscape. The Tista Alluvium is underlain by Recent to

Sub-Recent and older Flood plain. Barindra Tract presents somewhat alluvium termed the Madhupur Clay.

2.4.3. **Area 3. Dhaka and Mymensingh region**

The area is dominated by the extensive Pleistocene residual deposits of the Modhupur Tract which covers the central region. Recent alluvium of the Old Brahmaputra and the Jamuna surround the tract and make up the majority of the remaining soil types found in this area. Along the northern border with India, numerous small sources of pebbles, gravels and coarse sands occur.

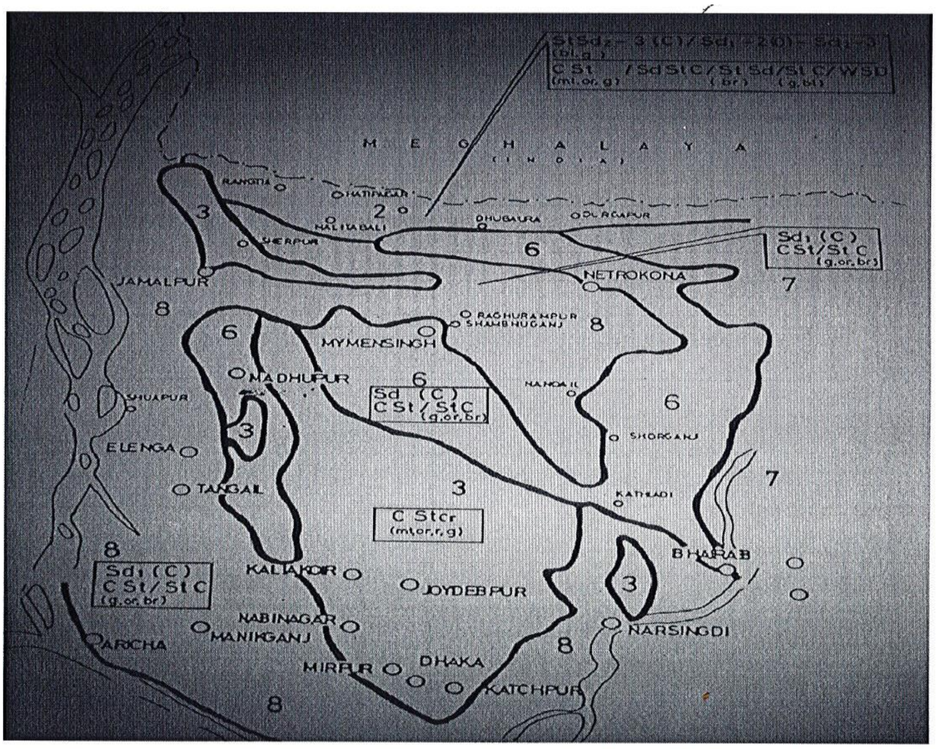


Figure 2.11: RMSS area 3 - zones

(Road Material and Standard Study Bangladesh, project no. ALA/88/08, Final Report, Volume II A, Inventory of Materials, June1994).

Zones. Figure 2.11 shows the area 3 which is composed of RMP (Road Master Plan) Zones 2(Nalitabari), 3(Dhaka, Narsingdi), 6(Mymensingh) and 8(Aricha, Katchpur). Main materials found here are shown in the Table 2.3 below.

Table 2.3: Aggregate deposits in zones of area 3

RMP Zone	Name of Site	Materials	Remarks
2 (Hatipagar, Nalitabali, Durgapur)	Gazaria	Sd2(Medium Sand), (Coarse Sand)	Can be use in bitumen or sand Asphalt
	Garaighat	Sd1(Fine Sand), sd2(Medium Sand	Exploitable only during 2 months
	Kaliganga	Sd1(Fine Sand), sd2(Medium Sand	Can be use in bitumen or sand Asphalt
	Tawahkhura	G(Gravels), (Coarse Sand)sd3	
	Gorv Charan Dudnai	G(Gravels)	
	Gazni	G(Gravels), (Coarse Sand)sd3	
	Fahamari Mayakhshi	G(Gravels)	
	Jamagara Jawval	Sd2, (Coarse Sand), sd3, G(Gravels)	Can be use in bitumen or sand Asphalt
	Menning River	Sd2, (Coarse Sand), sd3, G(Gravels)	
	Ailatoli	(Coarse Sand) sd3, G(Gravels)	Small deposits, local use
	Tengramari	G(Gravels)	Small deposits, local use
	Ghoshgaon	Sd2(Medium Sand), (Coarse Sand), sd3	Small deposits
3 (Sherpur, Joydebpur, Kaliakor, Nabinagar)	Madhupur Clay	G(Gravels), St(Sandy Silt)	Good materials for bricks

Figure 2.12: Sand collection at Gazaria.

(https://www.google.com/search?q=Sand+collection+at+Gazaria&safe=active&client=firefox-b-d&channel=trow&source=lnms&tbm=isch&sa=X&ved=0ahUKEwjdu6207-DjAhVLp48KHTEtCqYQ_AUIEigB&biw=1366&bih=613)

Table 2.3 shows various types of aggregate deposits like Fine sand (sd1), medium sand(sd2), coarse sand(sd3),Gravels(G), sandy silt (st) and clay, which are available in various zones/sites. These deposits are basically locally used for construction works or other purposes. Figure 2.12 shows a sand collection point of Gazaria site in zone 2(Nalitabari, North of Mymensingh). This sand also used locally, not vary significant amount to meet the requirement of other areas construction work.

2.4.4 **Area 4: Sylhet region**

Figure 2.13 shows the area 4 which is situated in the north-east of Bangladesh. Area 4 encompasses the area north of Brahmanbaria to Takerghat and all the area to the east of this line to the Indian border near to Zakiganj.

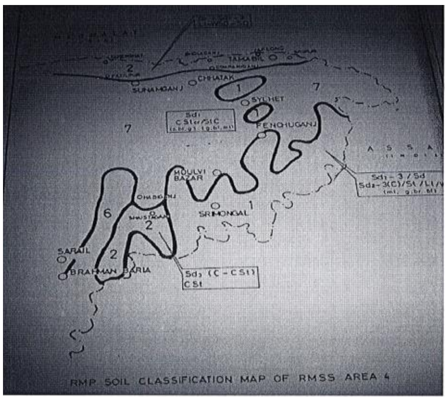


Figure 2.13: Sand collection at Sylhet region.

Zones. This area is the most important source of road materials found in Bangladesh. It is within the area that the majority of hard rock for surface dressings and aggregates along with coarse sands and gravels are found. RMP Zones 1(Sylhet, Fenchuganj), 2(Brahmanbaria) and 7(Sunamganj, Chatak) are represented within area.

The main materials and the locations available in this area are shown in Table 2.4. Table 2.4 shows various types of aggregate deposits like Fine sand (sd1), medium sand (sd2), coarse sand (sd3), and Gravels- Shingle's boulders (G), which are available in various zones/sites. These deposits are basically used for construction works or other purposes. Figure 2.13 shows a sand collection point of Sylhet Region. From these sites, aggregate deposits cover all over the country demand and the quality of sand is very good.

Table 2.4: Aggregate deposits in zones of area 4.

RMP Zone	Name of Site	Material	Remarks
2	Srimongol	Sd1(Fine Sand), sd2(Medium Sand), sd3(Coarse Sand), G(Gravels-Shingles boulders)	Local Use
	Bholaganj Quarry	Sd1(Fine Sand), sd2(Medium Sand), G(Gravels-Shingles boulders)	
	Bholaganj deposit		
	Jaflong	sd2(Medium Sand), sd3(Coarse Sand), G(Gravels-Shingles boulders)	
	Sreepur	Sd1(Fine Sand), G(Gravels-Shingles boulders)	

2.4.5 **Aggregate collection points / ports and quantity**

In Bangladesh there are numbers of land, rail and see ports from where aggregates are being imported in our country. In Table 2.5 shows the lists and approximate amount that are imported in every year.

Table 2.5: Land, rail and see ports for coarse aggregate collection.

Ports		Sources of Aggregates	Remarks
Land	Burimari (Lalmonirhat)	Jalpaiguri, Bhutan	Aggregate received per year (250x40x 20 x 12) x 8= 1.92 cr ton
	Bangla-bondha (Ponchogor)	Japaiguri	
	Hilly (Denajpur)	PI	
	Sona-mosjeed (Chapinababgonj)	PI	
	Vhomra (Satkhira)	PI	
	Dhenoa Kamalpur (Jamalpur)	Meghalay (Garo Hill)	
	Tamabil (Sylhet)	Meghalay (Garo Hill)	
	Nakugau (Shearpur)	Meghalay (Garo Hill)	
Rail	Dorshona (Chuwadanga)	PI	(1500x 8x 12)x2=0.29 cr ton
	Rohonpur (Rajshahi)	PI	
Sea	Chittagong, Mongla	Gujrat, KV, Indonesia, Thailand, Dubai, SM , Oman	(25,000x 4x x10x12) x1.5 = 1.8 cr ton
In land	Sylhet and Ponchogo	Mo, Bh, Ja	(300x35x25)x12= 0.32 cr ton

In Table 2.6 the amount of aggregate that are imported inside Bangladesh are mentioned. This is the record of NBR. The digital system of record started from 2013-14 financial years. But this system yet to be reliable and informative.

Table 2.6: NBR aggregate data

Description	Quantity (Million Ton)		
	2015-16	2016-17	2017-18
Broken or Crushed Stone	1.3	7.3	9.2
Boulder Stone	1.2	2.1	3.5
Other than Boulder Stone	0.1	0.001	0.0001
Total	2.6	9.4	12.7
(Local and Foreign)	(0.29 and 2.31)	(1.1 and 8.3)	(1.4 and 11.3)

2.5 Aggregate Properties

A majority of the volume of concrete (60 – 80 %) is occupied by aggregate. In fact, for most conventional concretes, more than 75% of the volume is aggregate. Aggregates are essential in concrete from the point of view of economy (since cement is expensive), dimensional stability (aggregates do not easily creep or shrink), stiffness, and abrasion resistance.

2.5.1 Classification of aggregates

Typically, coarse aggregate sizes are larger than 4.75 mm (5 mm in British code), while fine aggregates form the portion below 4.75 mm. A maximum size up to 40 mm is used for coarse aggregate in most structural applications, while for mass concreting purposes such as dams, sizes up to 150 mm may be used. Fine aggregates, on the other hand, have particles up to a minimum size of 0.075 mm [31].

The grading of the aggregate can be distinguished based on the sieve analysis. Aggregates that predominantly show size fractions in a limited range of sizes are called ‘uniformly’ graded, while aggregates that show a continuous gradation of size are called ‘well’ graded or continuously graded. When an aggregate shows size fractions in two or more well defined and well separated ranges, it is called ‘gap’ graded. The overall objective is to use a combination of coarse and fine aggregate in concrete in such as way as to get a continuous gradation of sizes, to ascertain the best packing of the aggregate.

Based on the source, aggregates may be classified as natural and manufactured. Natural aggregates may again be classified into those that may be used as is (such as river gravel), and those which are obtained from crushing of rock. On the other hand, manufactured aggregates are those prepared artificially, such as slag, glass, fly ash.

Aggregates can also be classified based upon their density as: lightweight, normal weight and heavyweight. Figure 2.14 shows lightweight aggregates such as pumice and tuff (natural pyroclastic igneous) or vermiculite and perlite (synthetic) have densities in the range of 800 – 1000 kg/m3, compared to normal weight aggregates such as limestone or granite that range from 2500 – 2900 kg/m3 and heavyweight aggregates such as hematite and barite, which have densities as high as 5400 kg/m3 [31]

Figure 2.14: Pelletized and sintered fly ash makes a good lightweight aggregate.
(https://pdfs.semanticscholar.org/fc12/69c238628645a0711e027597b742918d615f.pdf)

2.5.2 **Gradation**

Coarse aggregates used in concrete making contain aggregates of various sizes. This particle size distribution of the coarse aggregates is termed as "Gradation". The sieve analysis is conducted to determine this particle size distribution.

Grading pattern is assessed by sieving a sample successively through all the sieves mounted one over the other in order of size, with larger sieve on the top. The material retained on each sieve after shaking represents the fraction of aggregate coarser than the sieve in question and finer than the sieve above.

Proper gradation of coarse aggregates is one of the most important factors in producing workable concrete. Proper gradation ensures that a sample of aggregates contains all standard fractions of aggregate in required proportion such that the sample contains minimum voids. Figure 2.15 shows different graded aggregate. A sample of the well graded aggregate containing minimum voids will require minimum paste to fill up the voids in the aggregates. Minimum paste means less quantity of cement and less quantity of water; leading to increased economy, higher strength, lower shrinkage and greater durability. The workability is improved when there is an excess of paste above that required to fill the voids in the sand, and also an excess of mortar (sand plus cement) above that required to fill the voids in the coarse aggregate because the fine material lubricates the larger particles.

Cement-paste or the "Matrix" that links together the coarse aggregates is weaker than the aggregates. It is this matrix that is vulnerable to all ills of concrete. It is more permeable and is susceptible to deterioration by the attack of aggressive chemicals. Therefore lesser the quantity of such weak link in concrete, the better will be the concrete. This objective can be achieved by having well graded aggregates [31].

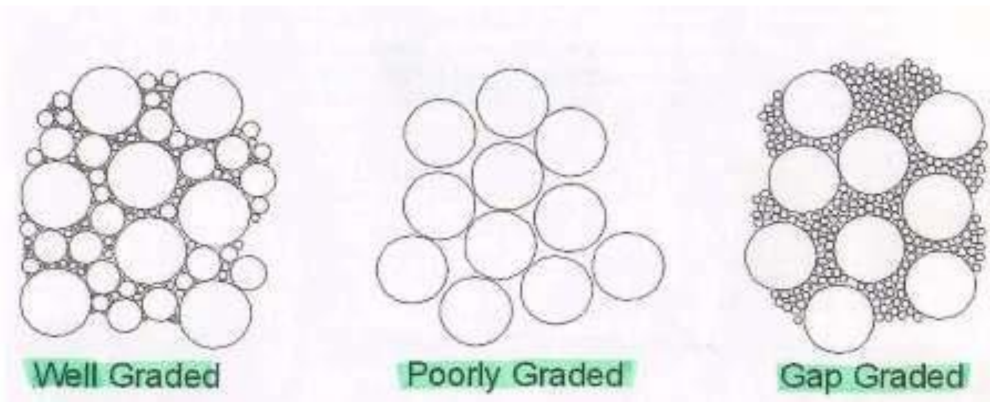


Figure 2.15: Gradation of aggregates, showing, well-graded, poorly graded and gap graded.

(https://pdfs.semanticscholar.org/fc12/69c238628645a0711e027597b742918d615f.pdf)

2.5.3 **Particle shape and texture**

The roundness of the aggregate will affect its packing properties as well as the interlock obtained between aggregates. Angular aggregates result in better packing and interlock. On the other hand, rounder aggregates typically need less water for the same workability. Roundness may be defined by the sphericity of aggregate, or, from the other viewpoint, as the angularity of the aggregate. Because of weathering, river gravel (or sand) gives rounded aggregate, while angular aggregates are obtained using crushed stone.

Flakiness or elongation of the aggregate can result in anisotropic packing, poor compaction, and lowered concrete strengths. As discussed earlier, flakiness and elongation could result from the geological nature of the aggregate (aggregates from rocks showing directional properties would tend to be flaky and elongated).

Texture of the aggregate is rough or smooth, and dictates the strength of the paste-aggregate bond. Rougher aggregates show better bond with paste, but also cause an increase in the water demand. Weathered aggregates are smooth, while crushed aggregates are rough.

2.5.4 **Aggregate strength, modulus and toughness**

The strength of aggregate tested independently is generally always higher than that of concrete. However, aggregate in concrete is stronger than the concrete for conventional concrete, while the aggregate strength is lower than concrete strength for high strength concrete, where the cementitious matrix is extremely strong. Aggregate strength depends on its parent rock composition, texture and structure [31]. The modulus of elasticity is related to strength of the aggregate. It is very important for a number of reasons:

E values of aggregate very different from paste will cause a mismatch at the interface, and this region can thus get prone to cracking. Figure 2.16 shows a typical pattern of crack development in concrete subjected to compressive loading. The interface cracks form first, and then grow outwards into the mortar. Thus the best concrete aggregates are those with E values in the range of the paste. Stiffness of the aggregate will affect the deformation of concrete due to creep and shrinkage. Stiffer the aggregate, lesser is the overall deformation.

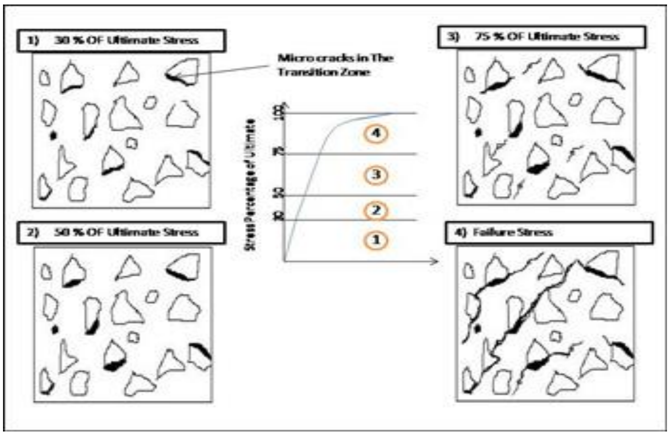


Figure 2.16: Crack development pattern of concrete in compression

Other aggregate qualities related to its strength are its hardness (which will affect abrasion resistance), impact resistance (related to toughness), and crushing value, or resistance to pulverization.

2.5.5 **Specific gravity and bulking**

Aggregates are porous, and posses a number of voids, some of which are penetrable and some impenetrable. This nature of aggregate makes it difficult to describe one value for its specific gravity. Based on the test methods used, three types of specific gravity are calculated – Bulk, Saturated surface dry, and Apparent. Determination of the true specific gravity of the aggregate is not possible (unless it is crushed to the smallest possible dimension) because the true volume of the aggregate can never be determined (as some pores are totally inaccessible).

Fine aggregate is susceptible to increases in volume due to the presence of moisture. This phenomenon is called bulking. Bulking can lead to problems during volume batching of the aggregates and causes harsh mixes with compaction problems. Crushed sand is more susceptible to this problem compared to natural sand [31].

2.6 Concrete Properties and Related Formula

Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but start decreasing at higher stress levels as matrix cracking develops. Concrete has a very low coefficient of thermal expansion, and as it matures concrete shrinks. All concrete structures will crack to some extent, due to shrinkage and tension. Concrete which is subjected to long-duration forces is prone to creep [32]. Figure 2.17 shows the nature compressive strength of concrete at different ages.

Typical properties of normal strength Portland cement concrete [33]:

Density: 2240 - 2400 kg/m^3 (140 - 150 lb/ft^3)

Compressive strength: 20 - 40 MPa (3000 - 6000 psi = 432 - 864 ksf)

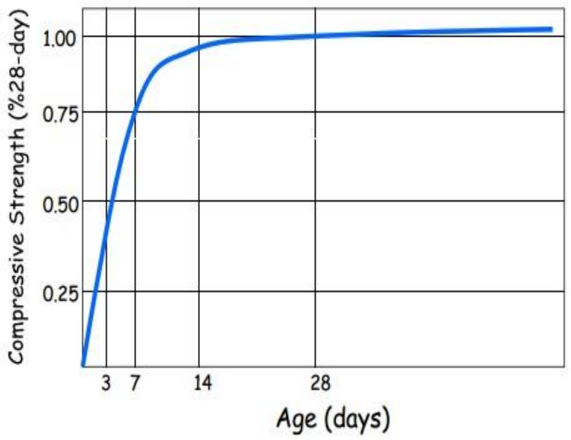


Figure 2.17: Compressive strength of concrete (% of 28-day strength) vs age (days)

Flexural strength: 3 - 5 MPa (400 - 700 psi = 57.6 - 100.8 ksf)

Tensile strength: 2 - 5 MPa (300 - 700 psi = 43.2 - 100.8 ksf)

Modulus of elasticity: 14000 - 41000 MPa (2 x 10^6 - 6 x 10^6 psi = 288000 - 864000 ksf)

The American Concrete Institute (ACI) suggests the following equation for the modulus of elasticity:

$E_c = 33\omega_c^{1.5}\sqrt{f_c'}\,(psi)$ ________________ 2.1

where

w_c = weight of concrete (pounds per cubic foot)

f'_c = compressive strength of concrete at 28 days (psi)

AASHTO Load and Resistance Factor Design Manual, or "LRFD" suggests the following equation:

$E_c = 33000K_1\omega_c^{1.5}\sqrt{f_c'}\,(ksi)$ _________________ 2.2

where

K_1 = correction factor for aggregate source (taken as 1.0 unless determined otherwise)

w_c = weight of concrete (pounds per cubic foot (pcf))

f'_c = compressive strength of concrete at 28 days (psi)

A handy approximate equation:

$E_c = 1820\sqrt{f_c'}\,(ksi)$ _________________ 2.3

Permeability: 1 x 10^{-10} cm/sec (2.8346 x 10^{-7} ft/day)

Coefficient of thermal expansion: 10^{-5} $^oC^{-1}$ (5.5 x 10^{-6} $^oF^{-1}$)

Drying shrinkage: 4 - 8 x 10^{-4}

Drying shrinkage of reinforced concrete: 2 - 3 x 10^{-4}

Poisson's ratio: 0.20 - 0.21

Shear strength: 6 - 17 MPa (870 - 2465 psi)

Specific heat: 0.75 kJ/kg K (0.18 Btu/lbm oF (kcal/kg oC))

2.7 Relation of Aggregate and Concrete Properties

2.7.1 Effect of absorption

Aggregate porosity may affect durability as freezing of water in pores in aggregate particles can cause surface popouts. However, Forster [38] states “that relationship between absorption and freeze-thaw behavior has not proven to be reliable.” Nevertheless, absorption can be used as an initial indicator of soundness. Furthermore, aggregates with low absorption tend to reduce shrinkage and creep.

2.7.2 Effect of mineralogy and coatings

Aggregates with varying mineralogical composition produce concretes of diverse characteristics. According to Alexander [40], the type of aggregate affects the strength and the stiffness and long-term deformations of hardened concrete. For example, some 24 aggregates may react negatively with cement or, on the contrary, they may interact beneficially with paste, enhancing strength or stiffness. As a result, elastic modulus, creep, or shrinkage can vary as much as 100 percent depending on aggregate type. The type of aggregate also affects the interfacial transition zone, ITZ, which has an effect on strength and stiffness of concrete. Finally, the type of aggregate influences the abrasion resistance of concrete, particularly of high-strength concrete. Coatings, the layers of material covering the surface of aggregate, can increase the demand for water and can impair the bond between paste and particles. Sometimes these coatings are formed by materials that can interact chemically with cement, negatively affecting concrete [41].

2.7.3 **Effect of strength and stiffness**

The strength and the stiffness of coarse aggregate directly influence the behavior of hardened concrete: Although in normal concrete, strength is controlled by the paste or by the transition zone between paste and aggregate, the strength of high-performance concrete depends not only on the strength but on the mineralogy of coarse aggregate as well. At the same time, according to aside from texture and shape the modulus of elasticity is the aggregate property that most affects compressive and flexural strengths of concrete. According to Popovics [42] “within limits, the higher the elastic modulus of aggregate, the lower the flexural strength.” In addition, the elastic modulus of aggregate, as well as its volume concentration, affects the elastic modulus of concrete and the long-term effects, shrinkage and creep.

2.7.4 **Effect of maximum size**

Maximum size of aggregate (MSA) influences workability, strength, shrinkage, and permeability. Mixtures with large maximum size of coarse aggregate tend to produce concrete with better workability, probably because of the decrease in specific surface [39]. There is an optimal maximum size of coarse aggregate that produces the highest strength for a given consistency and cement content [39]. For example, in high-performance concrete (HPC) with low water-cement ratio and high cement content, a high value of MSA tends to reduce strength. This can be explained by the observation that bond with large particles tends to be weaker than with small particles due to smaller surface area-to-volume ratios. Mixtures with coarse aggregate with large maximum size tend to have reduced shrinkage and creep [39]. Finally, for a given water-cement ratio, the permeability increases as the maximum size of the aggregate increases [43].

2.7.5 **Effect of relative density (specific gravity)**

Relative density is not necessarily related to aggregate behavior. However, it has been found that some aggregates compounds of shale, sandstone, and chert that have somewhat low specific gravity may display poor performance, particularly in exposed concrete in northern climates(i.e., low permeability is an indicator of poor durability)[44].

2.7.6 **Effect of soundness and toughness**

Soundness, according to, is the aggregate resistance to weathering that primarily includes resistance to freezing and thawing, and to a lesser extent, resistance to wetting and drying; and heating and cooling. A sound aggregate has a satisfactory durability factor when used in properly mature concrete with enough air void content [41]. Durability problems such as pop-outs" and D-cracking I pavements in some regions have been reported associated with unsound aggregates. There is a critical aggregate size below which freeze-thaw problems generally do not occur. Unfortunately, for most aggregates this is greater than sizes used in practice, except for some poorly consolidated sedimentary rocks [19]. Soundness of aggregate may be estimated by ASTM C 88 "Soundness of Aggregate by Sodium Sulfate or Magnesium Sulfate", by AASHTO T 103 "Soundness of Aggregates by Freezing and Thawing" or by petrographic examination.

Toughness of aggregate affects abrasion resistance of concrete. Hard aggregates should be used in pavements and elements subject to abrasion or erosion. The Los Angeles abrasion test is commonly used to assess toughness and resistance to abrasion of aggregate. However, as the Los Angeles test does not correlate well with concrete wear in the field, the resistance to abrasion of concrete should also be tested [19].

Toughness can also be evaluated by the Micro-Deval abrasion test. This test is used in some countries. The Micro-Deval test has also been suggested for aggregates to be used in hot-mix asphalt, HMA, mixtures in the United States, based on correlation between test results and field performance [45].

2.8 **Conclusion**

This chapter with different forms of literature relates the relationship between aggregate and concrete different nature of the literatures. Some definite relationship existing in between is mentioned in some literatures. Elaborate information on our local aggregate by RMSS under RHD, is mentioned in this chapter. Characteristic of aggregate related to strength and shapes have direct effect on concrete strength. Some characters have no effect on concrete strength. In next chapters, these facts are discussed in logical frame.

CHAPTER 3

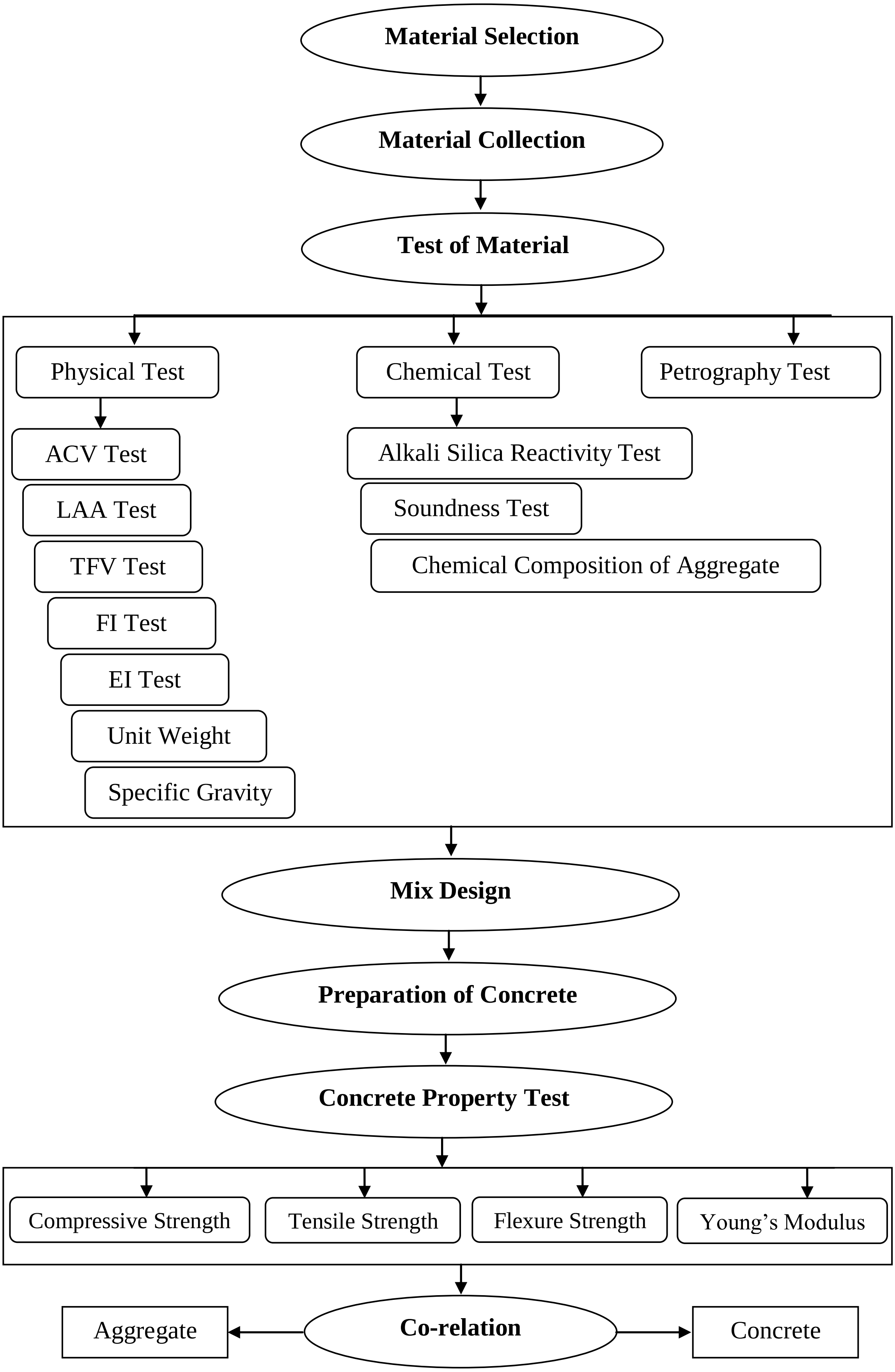
RESEARCH METHODOLOGY AND TEST PROCEDURE

3.1 Introduction

Concrete contains aggregates of various types, with ever increasing complexity as concrete science and technology advances. Last one decade construction sector in Bangladesh has initiated huge numbers of national development works which involve million tons of aggregates. Natural aggregates are being used in these construction projects; however, no significant study has been conducted on aggregate in recent days. In the present study steps has been taken to analyze the characteristics of aggregates and to establish a relation with concrete strength.

Six aggregates which are mostly used in the construction industry were selected first for this research work. Three of them are from local and three of them were from foreign sources. Local aggregates named Mo, Bh and Ja were collated from original sources. Foreign aggregates named PI, KV and Malaysia (Seremban) were collected from Dhaka – Bhanga N8 Highway project stockyards. Gradations of both coarse and fine aggregates were kept similar in order to compare various aggregate properties. Besides coarse aggregate and concrete tests, fine aggregate and cement tests were also performed. All the test of aggregates, concrete and cement were implemented following AASHTO, ASTM, BS methods and ACI codes. Roads and Highways (RHD) and Padma Multipurpose Bridge Project (PMBP) specifications were also followed in some special cases.

3.2 Sequence of Study (Flow Chart)



3.3 Materials

3.3.1 Coarse aggregate

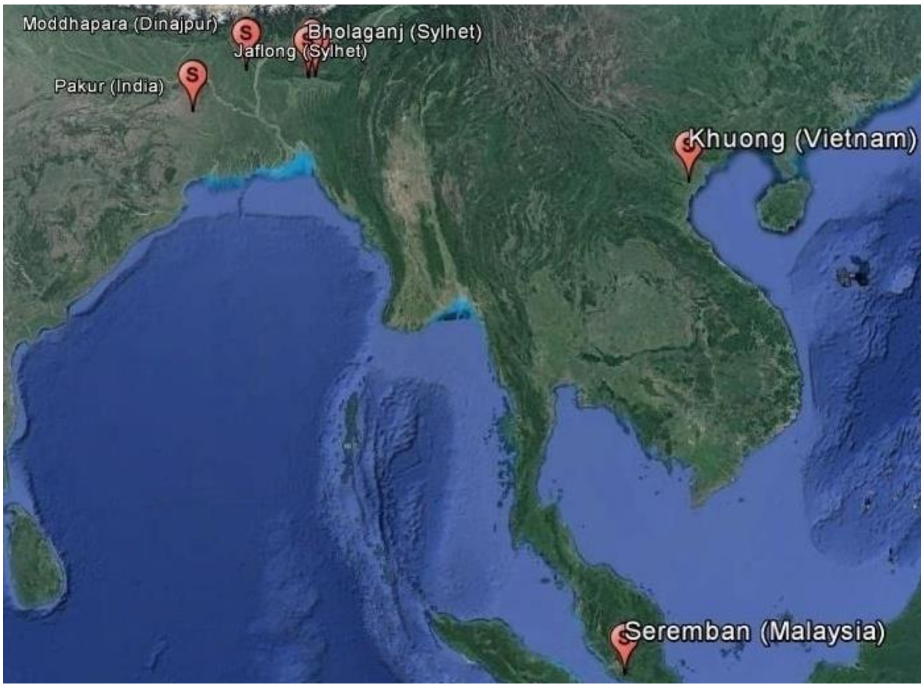
3.3.1.1 Selection of materials

From local sources widely used aggregate i.e Modhapara (Mo), Bholagong (Bh) and Ja (Jaflong) are selected for this research work. On the other hand coarse aggregates of foreign sources are coming from more than 10 sources. Among them mostly used aggregates i.e. Pakur, India (PI), Seremban, Malaysia (SM) and Khuong, Vietnam (KV) aggregates are selected for this work. Picture of all six aggregates are shown in Figure 3.1.

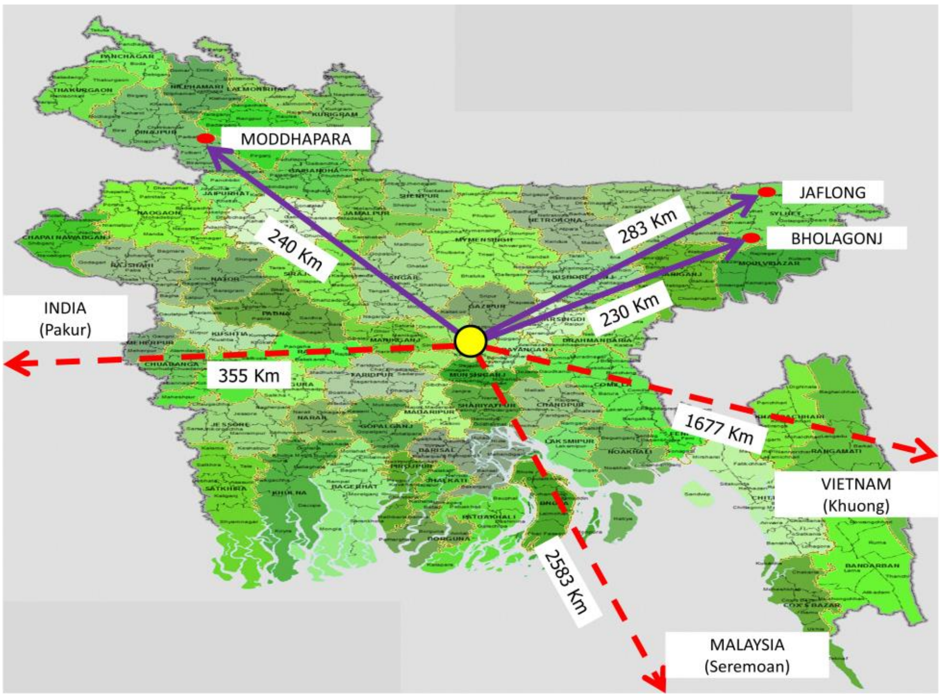
Figure 3.1: Aggregates selected for this study

3.3.1.2 Collection of materials

Collections of representative material samples are very significant issue while performing experimental works. Therefore, for aggregates from local sources, such as Mo, Bh and Ja, were collected from the actual site. In case of foreign aggregate collection was done from Dhaka- Mawa- Bhanga (N-8) project. Main sources are PI, KV, SM. Sources and distances of aggregate locations are located in the map as shown in Figure 3.2.



(a)



(b)

Figure 3.2: Location of aggregate source

3.3.2 **Fine aggregate**

Those particles passing the 9.5 mm (3/8 in.) sieve, almost entirely passing the 4.75 mm (No. 4) sieve, and predominantly retained on the 75 µm (No. 200) sieve are called fine aggregate. For increased workability and for better economy, the fine aggregate should have a rounded shape. The purpose of the fine aggregate is to fill the voids in the concrete. Fine aggregate for this work has been collected from Sylhet area. Table 3.1 provides the information on properties of fine aggregate.

Table 3.1: Properties of fine aggregate

Item / Ser	Fineness Modulus (FM)	Maximum Dry Density (MDD)	California Bearing Ratio (CBR)	Optimum Moisture Content (OMC)	Loose Unit Weight
1.	2.775	1784 kg/m^3	21.5% at 98% of	10.66%	1466 kg/m^3

3.3.3 **Cement**

Cement as binding material, used in construction and engineering projects. It is typically made by heating a mixture of limestone and clay until it almost fuses and then grinding it to a fine powder. When mixed with water, the silicates and aluminates in the cement undergo a chemical reaction and the resulting hardened mass become impervious to water. It may also be mixed with aggregates (crushed stone and sand) to form concrete [47].

For the present work cement has been collected from Bosundhara. Two types of cement including ordinary Portland cement (OPC/CEM I-52.5N) and Portland composites cement (PCC/CEM II/B-M (S-V-L) -42.5N) were used. Both physical and chemical tests for cement were performed and described in Table 3.2. As observed from the test results, OPC has higher CaO content and higher compressive strength compare to PCC.

Table 3.2: Chemical and physical properties of cement (PCC and OPC)

Chemical Compositions				
Ser	Name of Properties	Ref. Standard	Test Results PCC (%)	Test Results OPC (%)
1	Silicon di-Oxide (SiO_2)	ASTM C 114	23.60	19.74
2	Aluminum Oxide (Al_2O_3)		5.25	5.06
3	Ferric Oxide (Fe_2O_3)		3.89	3.21
4	Calcium Oxide (CaO)		55.58	64.67
5	Magnesium Oxide (MgO)		2.27	2.11
6	Insoluble Residue (IR)		5.75	0.7
7	Sulfur tri-Oxide (SO_3)		1.70	2.43
8	Trlcalcium Acuminate (C_3A)		7.33	9.7
9	Loss on Ignition (LOI)		2.81	1.63
10	Chloride Content (CC)		0.023	-
11	Total Alkalis(Na_2O+0658K_2O)		0.50	0.29
Physical Compositions				
Ser	Name of Properties	Ref. Standard	Test Results	Test Results
1	Fineness: Blaine (m²/kg)	ASTM C 204	386	414
2	Specific Gravity	ASTM C 188	2.93	3.15
3	Soundness (Autoclave)%	ASTM C 151	0.01	-
4	Initial Setting Time (IST), min	ASTM C 191	180	45
5	Final Setting Time (FST), min		365	190
6	Strength, 3 days (MPa)	ASTM C 109	18.14	30.21
7	Strength, 7days (MPa)		29.44	36.28
8	Strength, 28days (Mpa)		39.52	46.55

3.3.4 **Admixture**

Admixtures are primarily used to modify the properties of fresh and hardened properties of concrete and to ensure the quality of concrete during mixing, transporting, placing, curing and to overcome certain emergencies during concrete operations. For the present study Sika Plast 2004 NS was used as an admixer. SikaPlast 2004 NS is a powerful super plasticiser which gives strong water reduction with extended workability and improved flow, placing and compaction characteristics.

3.4 Test of Coarse Aggregate

Aggregate physical properties are the essential elements to select aggregate for concrete work. After collection of aggregate major physical components were tested in laboratories. Some procedures of determining aggregate properties are explained bellow.

3.4.1 Aggregate gradation

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are an essential ingredient in concrete [48]. Table 3.3 and Figure 3.3 shows the gradation of aggregate.

Table 3.3: Gradation chart of aggregates

Sieve Size (mm)	Mass Retained (gm)	Percent Retained (%)	Cumulative Percent Retained (%)	Cumulative Percent Passing (%)
75	0	0.00	0.00	100.00
37.5	0	0.00	0.00	100.00
19	275	5.00	5.00	95.00
9.50E+00	4125	75.00	80.00	20.00
4.75E+00	825	15.00	95.00	5.00
2.36E+00	275	5.00	100.00	0.00
1.18		0.00	100.00	0.00
6.00E-01		0.00	100.00	0.00
3.00E-01		0.00	100.00	0.00
1.50E-01		0.00	100.00	0.00
Pan				
	5500	100.00	680.00	
FM			6.8	

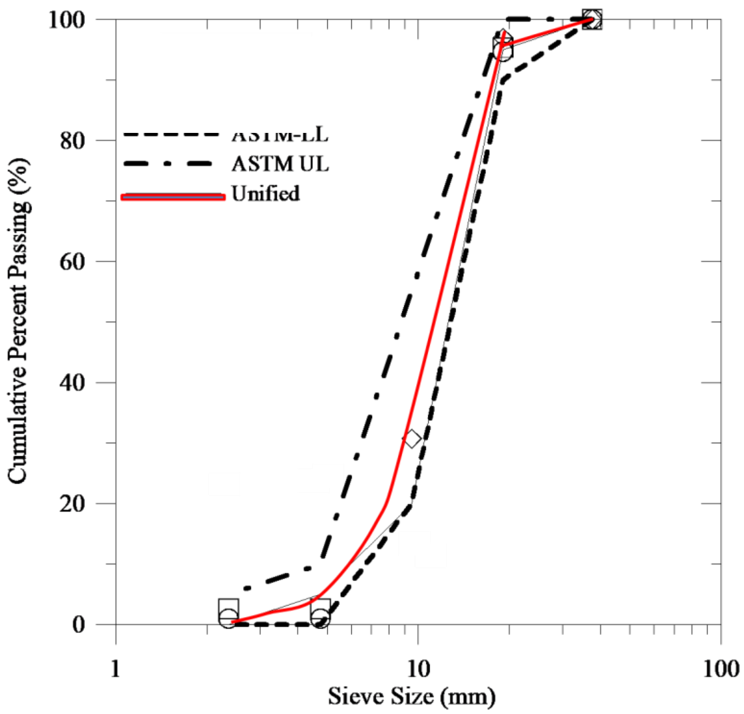


Figure 3.3: Gradation of aggregate

3.4.2 **Aggregate crushing value (ACV) test**

BS 812 part 110 describes a method to determine the aggregate crushing value (ACV) which gives a relative measure of the crushing resistance of aggregate under an increasing compressive load. The method is applicable to aggregates passing a 14.0 mm test sieve and retained on a 10.0 mm test sieve [49].The accuracy of the applied load has a strong influence on the test result. The standard states that the required force of 400 kN has to be reached in 10 min ± 30 s. At the very beginning of the test there is significant sample deformation, which affects the loading rate. According to the standard, the compression machine control system shall automatically compensate these instabilities and complete the test in an overall time of 10 min ± 30 s. Dividing the whole test duration of 600 seconds into 10 intervals of 60 seconds each, each 40 kN load step should be reached in 60 ± 3 seconds. The Figure 3.4 shows the 10 load steps and corresponding times.

Time (s)	Load (kN)
60.30	40.68
120.20	80.43
181.10	120.64
240.21	160.61
300.21	200.00
360.21	240.46
420.22	280.21
480.22	320.36
540.32	360.36
600.30	400.54

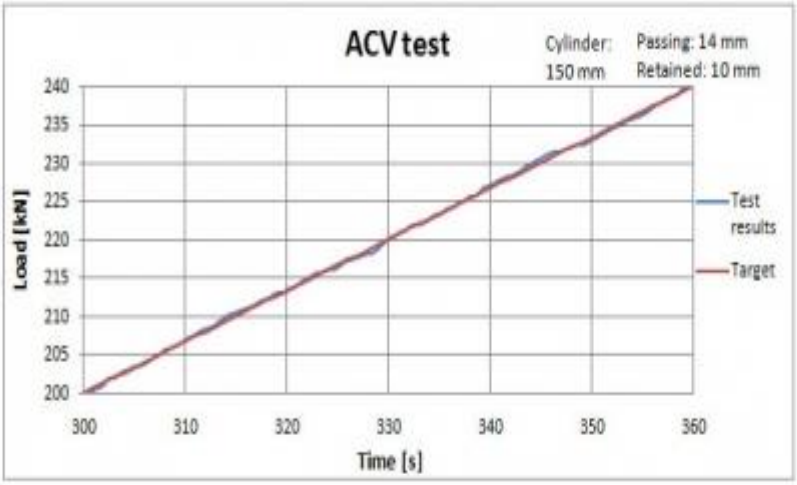


Figure 3.4: 10 load steps and corresponding times

3.4.3 **Los Angeles abrasion (LAA) test**

The standard LA abrasion test subjects a coarse aggregate sample (retained on the No. 12 (1.70 mm) sieve) to abrasion, impact, and grinding in a rotating steel drum containing a specified number of steel spheres.

Aggregates undergo substantial wear and tear throughout their life. In general, they should be hard and tough enough to resist crushing, degradation and disintegration from any associated activities including manufacturing, stockpiling, production, placing and compaction. Furthermore, they must be able to adequately transmit loads from the pavement surface to the underlying layers and eventually the subgrade. Aggregates not adequately resistant to abrasion and polishing may cause premature structural failure and/or a loss of skid resistance. Figure 3.5 shows the steel spheres that are used in Los Angeles abrasion test.

Figure 3.5: Steel spheres

3.4.4 **Ten percent fines value (TFV) test**

The particular purpose which an aggregate is meant to serve requires the aggregate to have a particular strength. This strength is usually stated in the specification. TFV test provides a method for measuring this strength. This method is suitable for testing both strong and weak aggregate passing a 14.0 mm test sieve and retained on a 10.0 mm test sieve.

Calculation and expression of result

a) Calculate the force F (in kN), to the nearest whole number, required to produce 10% fines for each test specimen, with the percentage of material passing in the range of 7.5% to 12.5%, from the following expression:

$F = 14 f / (m + 4)$ ________________ 3.1

Where, *f* is the maximum force in kN and *m* is the percentage of material passing the 2.36 mm test sieve at the maximum force.

b) Calculate the mean of the two results to the nearest 10 kN or more or to the nearest 5 kN for forces of less than 100 kN. Report the mean as the aggregate 10% fines value, unless the individual results differ by more than 10 kN or by more than 0.1 times the mean value. In this case repeat the test on two further specimens, calculate the median of the four results to the nearest whole number and report the median as the aggregate 10% fines value [50].

3.4.5 **Flakiness index (FI) test**

Flakiness Index test method is based on the classification of aggregate particles as flaky when they have a thickness (smallest dimension) of less than 0.6 of their nominal size, this size being taken as the mean of the limiting sieve apertures used for determining the size fraction in which the particle occurs. The flakiness Index of an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested. The test is not applicable to material passing a 6.30 mm BS test sieve or retained on a 63.0 mm BS test sieve [51]. Figure 3.6 shows the thickness gauge used to determine flakiness index.

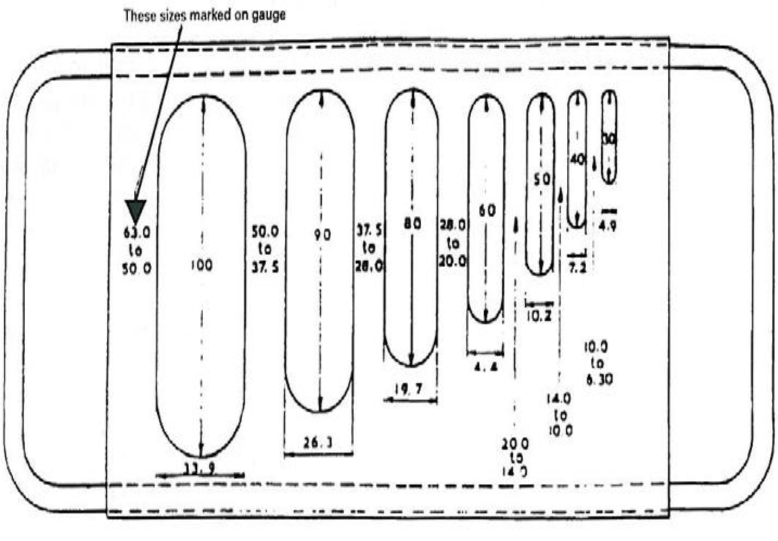


Figure 3.6: Thickness gauge (flakiness index) indicating sizes of openings.

Calculating and Reporting (Flakiness Index): The Flakiness Index shall be reported to the nearest whole number. The sieve analysis obtained in the test shall also be reported.

Flakiness = M2/M3 x 100________________ 3.2

3.4.6 **Elongation index (EI) test**

The particle is considered as elongated if its length is more than 1.8 times the mean sieve size of the size fraction to which the particle belongs. Similarly, the particle is considered as flaky if its thickness is less than 0.6 times the mean sieve size of the size fraction. Elongated and flaky particles have a large surface area relative to its small volume, hence it decreases the workability of concrete mix. The flaky particles can affect the durability of concrete as they tend to be oriented in one plane, with water and voids forming underneath. The presence of flaky or elongated particles in excess of 10-15% of the weight of coarse aggregate is undesirable. The test is carried on aggregate sizes between 63 mm and 6.3 mm. Figure 3.7 shows the Elongation scale and Flakiness scale.

Calculations: Elongation Index = M3/M2 × 100________________3.3

Figure 3.7: Elongation scale and flakiness scale

3.5 **Mix Design**

The objective of this study is to correlate concrete strength with the coarse aggregate properties. Furthermore, it is expected that the ordinary Portland cement (OPC) will provide higher strength compare to Portland composite cement (PCC). Moreover, high range water reducing admixture is used to achieve acceptable workability for freshly mixed concrete. Therefore, in the present study following condition has been considered: (a) variation in cement types, (b) variation in water-cement ratios, and variation in admixture quantity. Considering these facts, two water-cement ratios, such as 0.3 and 0.4, and two admixtures content, such as 1% and 0.75% by weight of cement was selected. To prepare the concrete mix ratios ACI 211.1-91 was adopted. Table 3.4 shows amount of different components of concrete for 1 cum of volume.

Table 3.4: Concrete mix design for 1 m^3 of concrete

Designation	Water (kg)	Cement (kg)	CA (kg)	FA (kg)	Admixture (ml)
PI-03	205	683	1037	501	683
PI-04	205	513	1037	650	385
KV-03	205	683	1040	470	683
KV-04	205	513	1040	618	385
SM-03	205	683	1008	449	683
SM-04	205	513	1008	597	385
Mo-03	205	683	1043	455	683
Mo-04	205	513	1043	603	385
Bh-03	205	683	972	480	683
Bh-04	205	513	972	629	385
Ja-03	205	683	1035	427	683
Ja-04	205	513	1035	575	385

3.6 Concrete Preparation for Tests

According to the gradation chart concrete mixture was prepared and casted around 720 cylinders and 72 beams for concrete test. All cylinders and beams were processed under water that is curing was done for 20 days. Casting was done in Abdul Monem

Laboratory at Panchchar, Madaripur. Initial preparation of aggregate, curing and 7 days concrete tests were done at CSC-1, PMBP laboratory. All concrete cylinders and beams were carried to MIST laboratory for 28 days and 90 days concrete tests. Finally concrete and aggregate test results are analyzed to have a relation between aggregate characteristics and concrete properties. Table 3.5 shows total volume of work that has been executed to complete the whole thesis work.

Table: 3.5: Summary of concrete works used for this thesis works.

Ser	Test	7 Days	28 Days	90 Days	Total	Remarks
1.	Compressive Strength	03	06	03	12	12*24=288
2.	Tensile Strength	-	03	03	06	06*24=144
3.	Young's Modulus	-	03	03	06	06*24=144
4.	Flexural Strength	-	03	-	03	03*24=72
5.	Chloride Ion Penetration	-	03	03	06	06*24=144
Each aggregate had four different concrete mix (OPC-0.3 and 0.4 w/c: PCC-0.3 and 0.4 w/c). For six aggregates total 720 Cylinder and 72 Beam were casted for concrete test mentioned above.						

The whole works were performed in different places to ease the work. Initial works that is concrete castings were done in Padma project area in 2 different laboratories. All concrete cylinders and beams kept under water for 20 days to get sufficient curing. After curing all concrete items were carried to MIST laboratories of further necessary tests.

Figure 3.8 shows the aggregate separation process according to their gradation. In Figure 3.9 preparatory works of concrete in progress. Coarse aggregate and fine aggregate are mixed in proportion. In Figure 3.10 preparatory works of concrete in progress.

Admixture is measured and mixed with concrete mix. In Figure 3.11 concrete mixture is compiled. Slump is measured as per the prescribed in code. In Figure 3.12 after slump measurement molds of cylinder are placed for concrete casting. All necessary precautions are taken to have a good concrete. In Figure 3.13 after slump measurement molds of beams are placed for concrete casting. All necessary precautions are taken to have a good concrete. Figure 3.14 shows curing process of concrete cylinder and beam. After one day of concrete casting the cylinder and beams are opened from the molds and all are kept under water for curing. Total days of curing are 20 days.

Figure 3.8: Preparation of aggregate for concrete casting

Figure 3.9: Aggregate mixing in proportion

Figure 3.10: Concrete mixing

Figure 3.11: Slump measurement

Figure 3.12: Cylinder casting

Figure 3.13: Beam casting

Figure 3.14: Curing of concrete cylinder and beam

CHAPTER 4
RESULTS AND DISCUSSION

4.1 General

In the present study tests of coarse aggregate was first conducted to characterize the aggregate properties. Both physical and chemical tests of aggregate were performed. Physical tests include aggregate crushing value (ACV), ten percent fines value (TFV), Los Angeles abrasion value, elongation index, flakiness index, fractured face, unit weight, specific gravity and absorption capacity. On the other hand chemical tests include chemical composition analysis, soundness test and alkali-silica reactivity test. Besides these, petrographic test of coarse aggregate was conducted. Using these aggregates, in total 720 concrete cylinders and 72 concrete beams were prepared for compressive strength, tensile strength, Young's modulus, chloride ion penetrability at 7, 28 and 90 days. Two different water-cement ratios, namely 0.30 and 0.40 with admixture were chosen for the current study. Finally, test results of concrete were plotted against aggregate properties to find correlation between concrete strength and aggregate properties.

4.2 Test of Aggregates

For this study aggregates were collected from three local sources, namely Modhapara (Mo), Bholagong (Bh) and Jaflong (Ja) as well as three foreign sources, such as Pakur, India (PI), Seremban, Malaysia (SM) and Khuong, Vietnam (KV).The various tests of aggregates were done following AASHTO, ASTM, BS and EN standards. Physical, chemical and petrography tests were done in five laboratories: (a) Abdul Monem Ltd laboratory of Padma Project Area at Pachchar, Madaripur (b) Service Area 3 laboratory of Padma project area at Kutubpur, Madaripur(c) Transportation and Concrete laboratory of MIST at Mirpur, Dhaka (d) Glass and Ceramic laboratory of BUET at Palashi, Dhaka and (e) Geology Department laboratory of Dhaka University.

4.3 Physical Properties of Coarse Aggregate

Physical properties of aggregates are those that refer to the physical structure of the particle that make up the aggregate. There are numbers of physical properties that indicate the strength, durability, toughness and suitability of an aggregate. In the present study aggregate crushing value (ACV), ten percent fines value (TFV), Los Angeles abrasion value, elongation index, flakiness index, fractured face, unit weight, specific gravity and absorption capacity tests were conducted and discussed.

4.3.1 Aggregate crashing value (ACV) test

The aggregate crushing value provides a relative measure of resistance to crushing under a gradually applied compressive load. To achieve a high quality of concrete, aggregate possessing low aggregate crushing value is preferred [52]. Aggregate Crashing Value test results are made known in Table 4.1.

Table 4.1: Result of aggregate crashing value (ACV) test

Result	Aggregate					
	PI	KV	SM	Mo	Bh	Ja
ACV	12.0	17.0	17.0	19.0	20.0	21.0

As shown in Table 4.1 Pakur, India (PI)aggregate provides maximum resistance against gradually applied compressive load among all six aggregates. Whereas, aggregate from both Bholagong (Bh) and Jaflong (Ja) showed higher crushing value meaning lower resistance against compressive load.

4.3.2 **Ten percent fine value (TFV) test**

Ten percent fine value is a measure of the resistance of aggregate crushing subjected to gradually applying compressive loading and it is applicable to both weak and strong aggregate. Fine aggregates are defined as those passing through 2.36mm sieve. The test aims at looking for the forces required to produce 10% of fine values (i.e. weight of fines aggregates/weight of all aggregates = 10%). This test is very similar to ACV Test in which a standard force 400kN is applied and fine materials expressed as a percentage of the original mass is the aggregate crushing value [52].

Table 4.2: Result of ten percent fine value (TFV) test

Result	Aggregate					
	PI	KV	SM	Mo	Bh	Ja
TFV (kN)	290	220	240	190	210	170

Table 4.2 represents the result of TFV of all six aggregates. The result shows that Pakur, India (PI) aggregate offers maximum resistance against the applied compressive load to produce 10% fine aggregate by crushing the coarse aggregate. On other hand, aggregate from Jaflong (Ja) shows the lowest resistance.

4.3.3 **Los Angeles Abrasion (LAA) test**

The Los Angeles abrasion test is a measure of degradation of mineral aggregates of standard grading resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres. The Los Angeles (L.A.) abrasion test is a common test method used to indicate aggregate’s toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate in concrete must resist crushing, degradation and disintegration in order to produce a high quality concrete [53].

Table 4.3: Result of Los Angeles Abrasion (LAA) test

Result	Aggregate					
	PI	KV	SM	Mo	Bh	Ja
LAA (%)	12	21	17	26	29	32

Table 4.3 shows LAA test results of all six aggregates. Laboratory test result shows that PI aggregate provides maximum resistance against abrasion and impact load to produce fine aggregate among all six aggregates; whereas, Ja aggregate shows minimum resistance against abrasion.

4.3.4 **Elongation index**

For determining elongation index, Particle is elongated when its length (longest dimension) is more than 1.8 of the mid-size of the sieve fraction. Aggregate to be classified is separated into seven sieve fractions from 63 to 6.3mm, and each fraction is examined separately. Six labeled openings between pairs of metal pins measure particle from each of the six sieve cuts below 50mm. The mass of all elongated particles (failing to pass between pins) as percent of the sample is the elongation index [54].

Table 4.4: Result of elongation index test

Result	Aggregate					
	PI	KV	SM	Mo	Bh	Ja
EI (%)	23.0	23.0	16.0	21.0	24.0	13.0

Table 4.4 representing results of Elongation Index for all six aggregates. In this case Pakur aggregate doesn’t show the best result. Here Ja aggregate provides best result among all six aggregates. Then on SM, Mo, KV, PI and Bhoagang.

4.3.5 **Flakiness index**

An aggregate is termed flaky when its least dimension (thickness) is less than three-fifth of its mean dimension. The mean dimension of aggregate is the average of the sieve sizes through which the particles pass and are required, respectively.

Table 4.5: Result of Flakiness Index Test

Result	Aggregate					
	PI	KV	SM	Mo	Bh	Ja
FI (%)	17.0	15.0	12.0	22.0	19.0	20.0

Table 4.5 represents the results of flakiness index of all six aggregates considered for this study. Serenbam, Malaysia (SM) aggregates provide best result among all six aggregates. Then on KV, PI, Bh, Ja and Mo.

4.3.6 **Specific gravity**

Specific gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. Specific gravity is important for several reasons. Some deleterious particles are lighter than the good aggregates. Tracking specific gravity can sometimes indicate a change of material or possible contamination. Differences in specific gravity may be used during production to separate the deleterious particles from the good using a heavy media liquid.

Table 4.6: Result of specific gravity test

Ser	Aggregate	Specific Gravity		
		Oven Dry	SSD	Apparent
1.	PI	2.88	2.88	2.95
2.	KV	2.78	2.80	2.82
3.	SM	2.63	2.65	2.69
4.	Mo	2.74	2.76	2.80
5.	Bh	2.62	2.64	2.68
6.	Ja	2.65	2.66	2.70

Table 4.6 shows the specific gravity of all six aggregates. Specific gravity varies between 2.62 to 2.88 (in oven dry condition) with aggregate from PI showing the highest while Bh showing the lowest values.

4.3.7 **Unit weight**

The specific weight (also known as the unit weight) is the weight of per unit volume of a material. The symbol of specific weight is γ (Gamma) [56]. A commonly used value is the specific weight of water on Earth at 5°C which is 9.807 kN/m^3 or 62.43 lbf/ft^3.

Table 4.7: Result of unit weight test

Result	Aggregate					
	PI	KV	SM	Mo	Bh	Ja
Unit Weight (kg/cum)	1673	1677	1626	1682	1567	1669

Table 4.7 represents the unit weight of all six aggregates. The unit weight of all aggregates varies between 1567 to 1677 kg/m^3 with aggregate from KV showing the highest while Bh showing the lowest values.

4.3.8 **Percent water absorption**

Water absorption is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include: type of aggregate, additives used, temperature and length of exposure. The data sheds light on the performance of the in materials in water or humid environments [57].

Table 4.8: Result of percent water absorption test

Result	Aggregate					
	PI	KV	SM	Mo	Bh	Ja
Percent Water Absorption (%)	1.2	0.6	0.7	0.8	0.9	0.7

Table 4.8 represents the water absorption of all six aggregates. The water absorption of PI aggregate is remarkably high among all six aggregate. Then of Bh, Mo, SM, Ja and KV.

4.3.9 **Fractured face**

A fractured face is defined as being caused either by mechanical means or by nature and should have sharp or slightly blunted edges. A gravel which was previously fractured by hand or by machine and then weathered by water or time is not accepted as fractured. Natural fractures, to be accepted, must be similar to fractures produced by a crusher. A broken surface constituting an area equal to at least 25% of the projected area of the particle, as viewed perpendicular to (looking directly at) the fractured face, is considered an acceptable fractured face [58].

Table 4.9: Fractured face of aggregate (PMBP, ASTM: D 5821)

Ser	Stone	Sample (19 mm-12.5 mm)										Avg	Remarks
		01	02	03	04	05	06	07	08	09	10		
1.	PI	04	05	04	05	05	05	05	04	04	04	4.5	100% of aggregates have 3 or more fractured faces.
2.	KV	05	05	05	04	04	04	04	04	04	05	4.4	
3.	SM	05	04	04	04	**03**	04	04	05	04	04	4.1	
4.	Mo	04	04	04	04	05	05	04	04	04	04	4.2	
5.	Bh	**03**	04	04	04	04	04	05	05	04	04	4.1	
6.	Ja	04	04	04	05	04	04	04	05	05	04	4.3	

Table 4.9 views the fractured face of all six aggregates. The more fractured faces provide more compacted and strong aggregates, where as rounded face provide less bonding and provide weak concrete.

4.3.10 **Summary**

All the physical properties of aggregates are summarized in Table 4.10 along with the test standards. Limiting values found in various codes or standards are also included for ACV, LAA, TFV, FI and EI. Here, ACV, TFV and LAA results focus on strength of aggregates; whereas EI and FI focus on shape of the aggregates.

Table 4.10: Summary of physical properties

Source of Aggregate	ACV (%)	Los Angeles (%)	TFV (KN)	Elongation Index (%)	Flakiness Index (%)	Specific Gravity			Water Absorption (%)	Unit wt (kg/cum)
						Oven Dry	SSD	Apparent		
PI	12.0	12.0	290.0	23.0	17.0	2.85	2.88	2.94	1.2	1673
KV	17.0	21.0	220.0	23.0	15.0	2.78	2.80	2.82	0.6	1677
SM	17.0	17.0	240.0	16.0	12.0	2.63	2.65	2.69	0.7	1626
Mo	19.0	26.0	190.0	21.0	22.0	2.74	2.76	2.80	0.8	1682
Bh	20.0	29.0	210.0	24.0	19.0	2.62	2.64	2.68	0.9	1567
Ja	21.0	32.0	170.0	13.0	20.0	2.65	2.66	2.70	0.7	1669
Standard Code	BS 812-110	AASHTO T-96	BS 812-111	BS 812	BS 812	ASTM C-128-97			ASTM C-128-97	AASHTO T-19
Limiting Value	30%	30%	150 kN	30%	30%	-	-	-	-	-

Considering physical properties of course aggregates following comments can be made:

(a) Aggregate crushing value test result represents that PI aggregate is the best aggregate among all others. It provides crushing value 12% against 30% accepted vale in road construction work according to RHD specifications. Crushing value of other aggregates are KV 17%, SM 17%, Mo 19 %, Bh 20.0%, Ja 21 %.

(b) Ten percent Fine value test result shows that PI aggregate provide best result among others and it is 290kN. The accepted value in road construction is 150 kN as per RHD specifications. TFV of other aggregates are KV 220kN, SM 240kN, Mo 190kN, Bh 210kN, Ja 170kN

(c) Los Angeles Abrasion test results represent that PI aggregate have best resistance against the abrasion and impact load. It provides LAA 12% against 30% accepted value in road construction works according to RHD specifications. Abrasion values of other aggregates are KV 21%, SM 17%, Mo 26%, Bh 19%, Ja 32%.

(d) Crushing, abrasion and fine value represent the strength of aggregates. Considering these three characters of aggregate it can be mentioned that PI (India) is the most strong and desirable aggregate for high strength concrete. Then of SM, KV, Mo, Bh and Ja.

(e) Flakiness Index test results shows that SM aggregate provide lowest value 12 % and indicate the best result. The accepted value of FI is 30% as per RHS specification. Flakiness Index of other aggregates are KV 15%, PI 17%, Mo 19%, Bh 19%, Ja 20%.

(f) Elongation Index test results represent that SM aggregate provide lowest value 16 % and indicate the best result. The accepted value of EI is 30% as per RHS specification. Elongation Index of other aggregates are KV 15%, PI 17%, Mo 19%, Bh 19%, Ja 20%.

(g) Considering the shape it can be mentioned that SM is the most suitable and desirable aggregate for high strength concrete. Then on Ja, KV, Mo, PI and Bh.

(h) Considering strength and shape of aggregate SM is the best aggregate for high strength concrete. Then of PI, KV, Mo, Ja, and Bh.

4.3.11 **Valuation marking on physical properties**

To have the priority aggregate list, base on its category and performance, the results have been marked as per their values. In Table 4.11 for every individual property highest value is marked as 100 and the lowest value is marked as 50. Other values are marked proportionately.

Table 4.11: Valuation marking on physical properties

Source of Aggregate	ACV	Los Angeles	TFV		Elongation Index	Flakiness Index		Total Pts
	(1)	(2)	(3)	(1+2+3)	(4)	(5)	(4+5)	Total
PI	12.0 (100)	12 (100)	290 (100)	300	23 (50)	17 (69)	119	419
KV	17 (72)	21 (78)	220 (71)	221	23 (50)	15 (81)	131	352
SM	17 (72)	17 (88)	240 (79)	239	16.0 (100)	12.0 (100)	200	439
Mo	19 (61)	26 (65)	190 (58)	184	21 (64)	19 (56)	120	304
Bh	20.0 (56)	29 (58)	210 (67)	181	23 (50)	19 (56)	106	287
Ja	21 (50)	32 (50)	170 (50)	150	16 (100)	20 (50)	150	300

According to the marking system basing on strength PI is the best and then SM, KV, Mo, Bh and Ja. And Basing on shape SM is the best and then KV, Mo, PI, Ja and Bh. Considering total value SM is the best aggregate among all six and then on PI, KV, Mo, Ja, Bh.

4.4 Chemical Test of Coarse Aggregate

Besides physical properties of aggregate it is also vital to know the chemical properties of aggregate. While mixing concrete there may exist some elements of aggregates that occur internal reactions and make poor concrete. So it is always suggested to have some chemical test of aggregate to confirm that aggregates are free of chemical hazard.

4.4.1 Chemical composition

X-ray fluorescence (XRF) provides one of the simplest, most accurate and most economic analytical methods for the determination of elemental composition of many types of materials. Indispensable to both Rand and quality assurance (QA) functions, advanced and unique wavelength dispersive X-ray fluorescence (WD-XRF) products are routinely used to analyze products from cement to plastics and from metals to food to semiconductor wafers. Elementary compositions of all six aggregates are determined by WD-XRF and shown in Table 4.12.

Table 4.12: Chemical ingredient

Chemical Element	Aggregate					
	PI (%)	KV(%)	SM (%)	Mo (%)	Bh (%)	Ja (%)
SiO_2	56.194	4.587	67.185	57.331	83.264	81.993
Fe_2O_3	11.912	1.707	4.801	9.689	3.187	3.204
Al_2O_3	10.676	1.024	10.352	9.243	4.649	5.426
CaO	10.394	78.720	5.101	11.614	2.773	2.676
MgO	3.620	12.639	0.985	4.204	0.940	0.818
K_2O	3.161	0.364	8.141	3.463	3.220	3.932
TiO_2	1.799	0.223	0.622	1.029	0.595	0.607
Na_2O	1.543	0.173	1.937	2.255	0.825	0.905
P_2O_5	0.350	0.046	0.348	0.564	0.182	0.174
SO_3	0.224	0.244	0.174	0.085	0.096	0.117

SrO	0.064	0.191	0.018	0.119	0.016	0.017
Cr_2O_3	-	0.031	0.060	0.068	0.047	-
MnO	-	0.028	0.088	0.147	0.048	0.038
ZrO_2	0.019	-	0.030	-	0.136	0.070
ZnO	0.022	0.016	0.064	-	-	-
Rb_2O	0.015	-	0.080	0.014	0.015	0.017

Legend: Top Elmn 2nd Elmn 3rd Elmn 4th Elmn

Table 4.12 shows that KV aggregate is governed by Calcium and other five aggregates (PI, SM, Mo, Ja and Bh) are governed by Silica. Other major elements of aggregate are Iron, Aluminum, Magnesium, Potassium etc.

4.4.2 **Soundness test of coarse aggregate**

The soundness test on aggregate is carried out to learn the resistance of aggregates to weathering actions like thawing, freezing, alternate wetting and drying in normal conditions and in salt water, variation in temperature. When subjected to above stated conditions, aggregates which are weak, porous, and contains any irrelevant matters, can drastically undergo volume change (ASTM C-88). If the resistance against weathering action is good for aggregate, then it will have high durability [59].

Table 4.13: Result of magnesium sulphate soundness test

Result	Aggregate					
	PI	KV	SM	Mo	Bh	Ja
Weighted Loss in $MgSO_4$(%)	1	1	0	2	3	4

Table 4.13 shows results of Soundness test of all six aggregates. The maximum tested value is 4.% and minimum is0 % weight loss. The allowable limit is maximum 12% weight loss. So all six aggregates are well protected from weathering actions.

4.4.3 **Alkali – silica reactivity test of coarse aggregate**

Alkali-silica reactivity is an expansive reaction between reactive forms of silica in aggregates and potassium and sodium alkalis, mostly from cement, but also from aggregates, pozzolans, admixtures and mixing water. External sources of alkali from soil, deicers and industrial processes can also contribute to reactivity. The reaction forms an alkali-silica gel that swells as it draws water from the surrounding cement paste, thereby inducing pressure, expansion and cracking of the aggregate and surrounding paste. This often results in map-pattern cracks, sometimes referred to as alligator pattern cracking. ASR can be avoided through 1) proper aggregate selection, 2) use of blended cements, 3) use of proper pozzolanic materials and 4) contaminant-free mixing water [60].ASTM (C-289) Test activities of Alkali – Silica reactivity are shown in Figure 4.1.

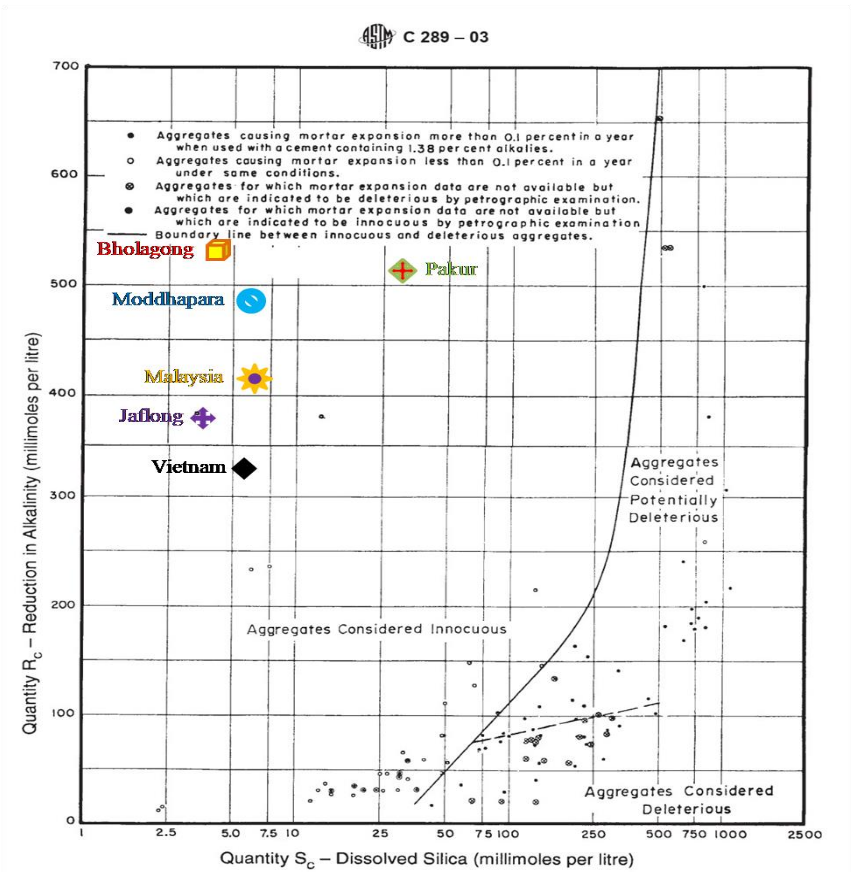


Figure 4.1: Illustration of division between innocuous and deleterious aggregates on basis of reduction in alkalinity test [61].

Table 4.14: Result of alkali-silica reactivity test

Properties	Unit	Results					
		PI	SM	KV	Mo	Bh	Ja
Dissolved Silica, SiO_2	mmol/l	31.7	7.1	5.2	5.56	4.6	4.5
Reduction in Alkalinity	mmol/l	518.5	420	333.5	485	530	366.5
Remark: The sample is considered innocuous (Harmless)							

Table 4.14 shows the results of Alkali-Silica reactivity test. Test result indicates that all aggregates are safe from alkali reactivity and can be safely used in concrete mix.

4.4.4 **Summary on chemical properties**

Comments on Chemical Ingredient of Coarse Aggregate:

(a) Chemical Ingredient of coarse aggregate analysis shows that KV is based on Calcium other five aggregates are based on Silica. The ingredient amounts are KV CaO 78.7%, SiO_2 at PI 56.2%, SM 67.2%, Mo 57.3%, Bh 83.3% and Ja 82.0%. Other remarkable amount of ingredient are Fe, Mg, Al and K which are present at different amount ranging from 1 -11%. There are some other elements which are in very low amount i.e. less than 1%.

(b) Soundness test result represent that weight loss in $MgSO_4$ for PI 1%, KV 1%, SM 0 %, Moddopar 2%. Bh 3%, Ja 4%. The permissible loss in $MgSO_4$ is 12%. So all aggregates are strong enough against weathering actions.

(c) Alkalinity test result shows that all six aggregates are well resistant from Alkali – Silica reactivity and all aggregates are considered as Innocuous.

4.5 Petrography Test of Coarse Aggregate

Petrography analysis apprises the quality of course aggregate and provide a numerical means of expressing and comparing quality of sample from the same and different sources. In petrography analysis aggregate particles are initially subjected to geological classification. Analysis is done following ASTM C-295 and finally following results have been sketched out.

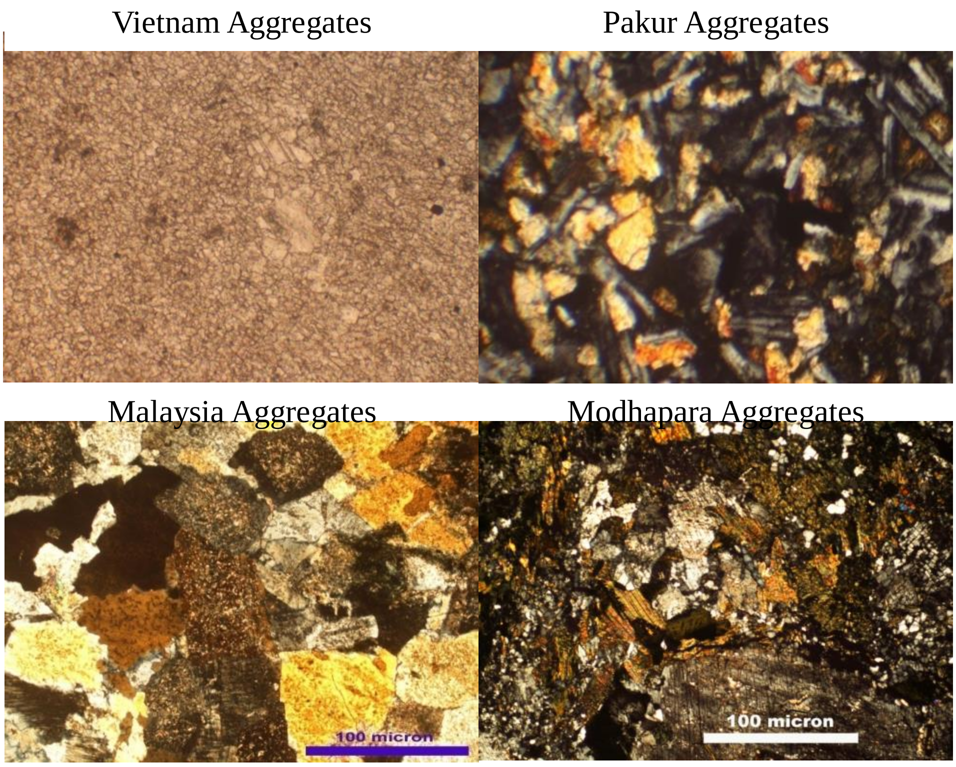


Figure 4.2: Photomicrographs of aggregates under cross polarized light

Table 4.15: Aggregates groups

Stone	Origin	Rock Type
PI	Igneous	Basalt
KV	Sedimentary	Lime Stone
SM	Igneous	Granite
Mo	Igneous	Granodiorite
Bh	Sedimentary	Granite
Ja	Sedimentary	Granite

Table 4.15 shows the geological classifications of course aggregates. PI goes under Basalt, SM goes under Lime stone and all other like SM, Mo, Bholagang and Jaflog aggregate goes under Granite.

4.6 **Concrete Properties**

Concrete has relatively high compressive strength, but significantly lower tensile strength. As a result without compensating, concrete would almost always fail from tension – even when loaded in compression. The practical implication of this is that concrete elements subjected to tensile stresses must be reinforced with materials that are strong in tension. The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develop. Concrete has a very low coefficient of thermal expansion, and as it matures concrete shrinks. All concrete structures will crack to some extent, due to shrinkage and tension. The density of concrete varies, but is around 2,400 kilograms per cubic metre (150 lb/cu ft). In this study various tests have been done to evaluate the important properties of aggregate and then to relate with the aggregate properties.

4.6.1 **Workability**

Concrete workability is a broad and subjective term describing how easily freshly mixed concrete can be mixed, placed, consolidated and finished with minimal loss of homogeneity. Workability is a property that directly impacts strength, quality, appearance, and even the cost of labor for placement and finishing operations. The slump value of concrete mix that has been used in this study is mentioned bellow in Table 4.16. As observed from the slump values for all the concrete have almost similar slump values and more than 200 mm. This ensure that the workability of concrete remain same for different combination of concrete and does not influence strength properties of concrete.

Table 4.16: Slump value of various concrete mix

Ser	Aggregate	Cement	w/c	Slump (mm)
1.	PI	OPC	0.3	215
			0.4	210
		PCC	0.3	210
			0.4	205
2.	KV	OPC	0.3	215
			0.4	210
		PCC	0.3	220
			0.4	210
3	SM	OPC	0.3	215
			0.4	210
		PCC	0.3	220
			0.4	210
4.	Mo	OPC	0.3	215
			0.4	210
		PCC	0.3	220
			0.4	215
5.	Bh	OPC	0.3	215
			0.4	210
		PCC	0.3	220
			0.4	215
6.	Ja	OPC	0.3	215
			0.4	210
		PCC	0.3	220
			0.4	210

4.6.2 **Compressive strength**

Compressive strength of concrete cylinder test provides an idea about the characteristics of concrete. By this single test one can judge whether the concreting has been done properly or not. Strength of concrete depends on several factors, especially strength of cement mortar, strength of coarse aggregate and the bond between the cement mortar and coarse aggregate. Therefore, for the present study, strength of cement mortar is varied by using two different types of cements, such as ordinary Portland cement (OPC) and Portland composite cement (PCC). Strength of aggregate is varied by adopting aggregate from various sources. Finally, the bond between the cement mortar and coarse aggregate is checked by considering two different w/c ratios. At lower w/c ratio bond between the mortar and aggregate is higher due to a stronger interfacial transition zone (ITZ) compare to the higher w/c ratio. American Society for Testing Materials (ASTM C39/C39M) provides standard test method for compressive strength of cylindrical concrete specimens [62] which is follower here.

Table 4.17 represents compressive strength of four concrete mixes. From the result it is obvious that w/c = 0.3 provides more strength than that of w/c = 0.4 concrete mix. Furthermore, concrete with OPC shows higher strength compare to concrete with PCC. It is very significant that with controlled concrete mix design, concrete strength of 85 MPa and more can be achieved. For w/c ratio of 0.3, concrete compressive strength ranges between 46.5 to 85.9 MPa depending on the type of aggregate and cement. On the other hand, for w/c ratio of 0.4, concrete strength varies between 38.4 to 65.8 MPa.

Concrete mix with OPC and w/c = 0.3 provide very high strength concrete and their strength varies with the aggregate types. Figure 4.3 and Table 4.17 shows that SM provide highest compressive strength of 85.9 MPa concrete; and then on KV, Bh, Mo, PI and finally Ja with 52.6 MPa concrete.

Table 4.17: Result of compressive strength at 28 days

Aggregate	Concrete with OPC (MPa)		Concrete with PCC (MPa)	
	W/C = 0.3	W/C = 0.4	W/C = 0.3	W/C = 0.4
PI	69.6	58.6	54.2	45.5
KV	74.3	58.2	59.0	41.8
SM	85.9	65.8	57.3	45.9
Mo	70.7	61.5	55.9	38.4
Bh	71.6	49.8	53.9	46.3
Ja	52.6	50.3	46.5	45.1

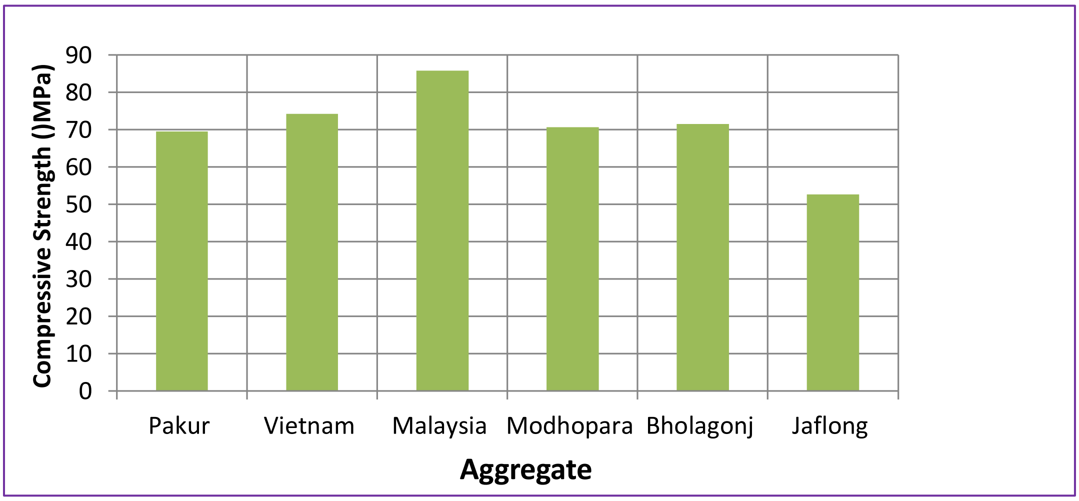


Figure 4.3: Compressive strength of concrete with OPC and w/c = 0.3

Concrete mix with OPC and w/c = 0.4 provides relatively higher strength concrete. Figure 4.4 and Table 4.17 shows that concrete with SM provides 65.8 MPa compressive strength and then on PI 58.6 MPa, KV 58.2 MPa, Mo 61.5 MPa, Bh 49.8 MPa and Ja 50.3 MPa.

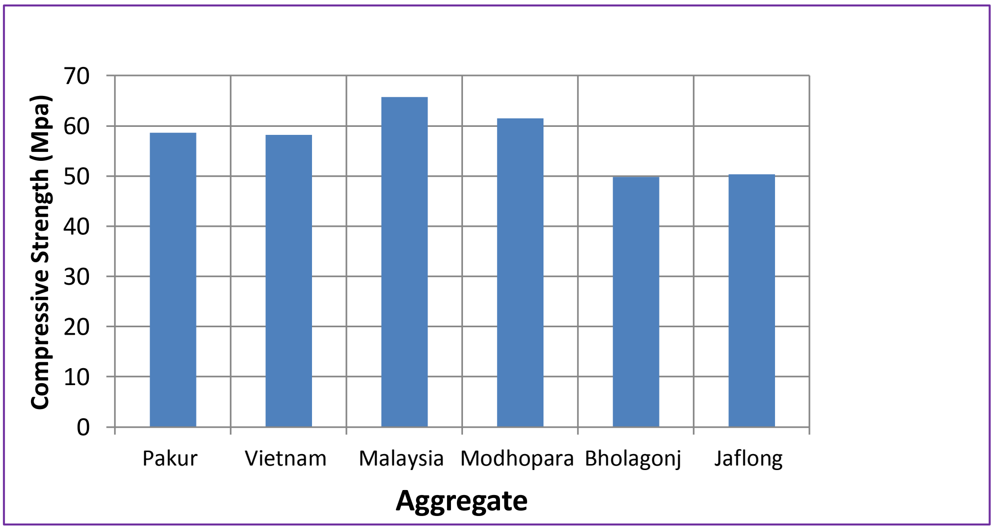


Figure 4.4: Concrete compressive strength with OPC and w/c = 0.4.

Concrete mix with PCC and w/c = 0.3 provides moderate strength concrete. Figure 4.5 and Table 4.17 shows that SM provides 57.3 MPa concrete and then on PI 54.2 MPa, KV 57.3 MPa, Mo 55.9 MPa, Bh 53.9 MPa and Ja 46.5 MPa concrete.

Concrete mix with PCC and w/c = 0.4 provides moderate strength concrete. Figure 4.5 and Table 4.17 shows that SM provides 45.5 Mpa concrete and then on PI 45.5 MPa, KV 45.9 MPa , Mo 38.4 MPa, Bh 46.3 MPa and Ja 45.1 MPa concrete.

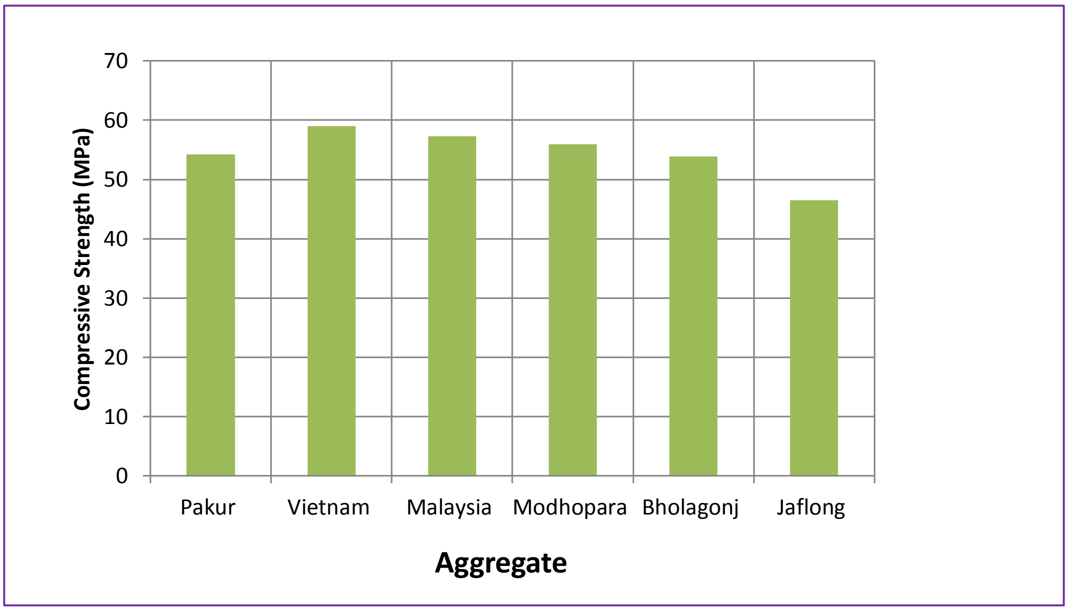


Figure 4.5: Concrete compressive strength with PPC and w/c = 0.3.

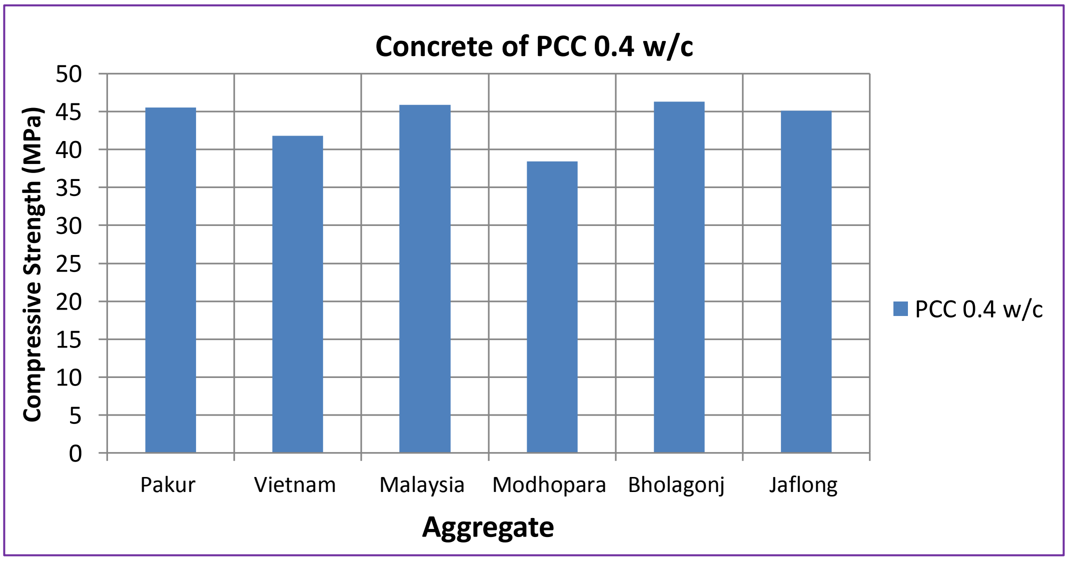


Figure 4.6: Concrete compressive strength with PPC and w/c = 0.4

To observe the increase rate of concrete strength in respect of days, tests are done on 7 days, 28 days and 90 days. The results of compressive strength of different durations are shown in following Figures.

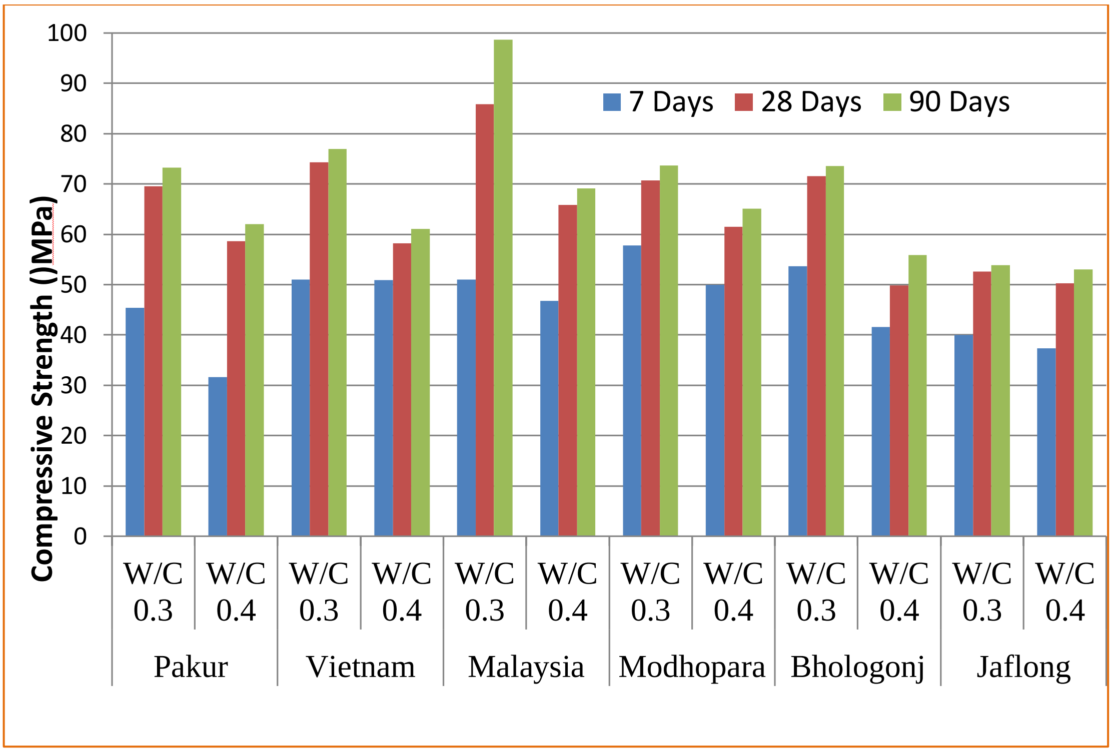


Figure 4.7: OPC (w/c 0.3 and 0.4) vs compressive strength

In Figure 4.7 compressive strength of 28 days is considered as full strength. In that case OPC cement concrete of 0.3 and 0.4 w/c ratio gain 75% strength at 07 days. And at 90 days the strength increased by 6%.

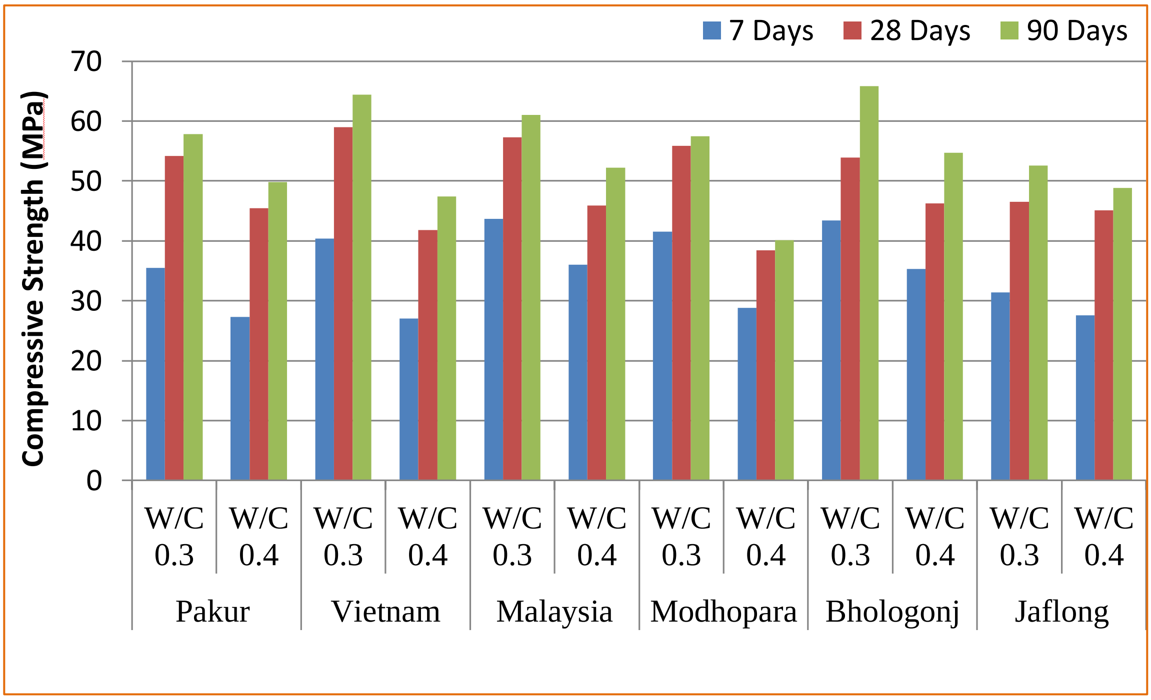


Figure 4.8: PCC (w/c 0.3 & 0.4) vs compressive strength

In Figure 4.8 compressive strength of 28 days is considered as full strength. In that case PCC cement concrete of 0.3 & 0.4 w/c ratio gain 70% strength at 07 days. And at 90 days the strength increased by 10%.

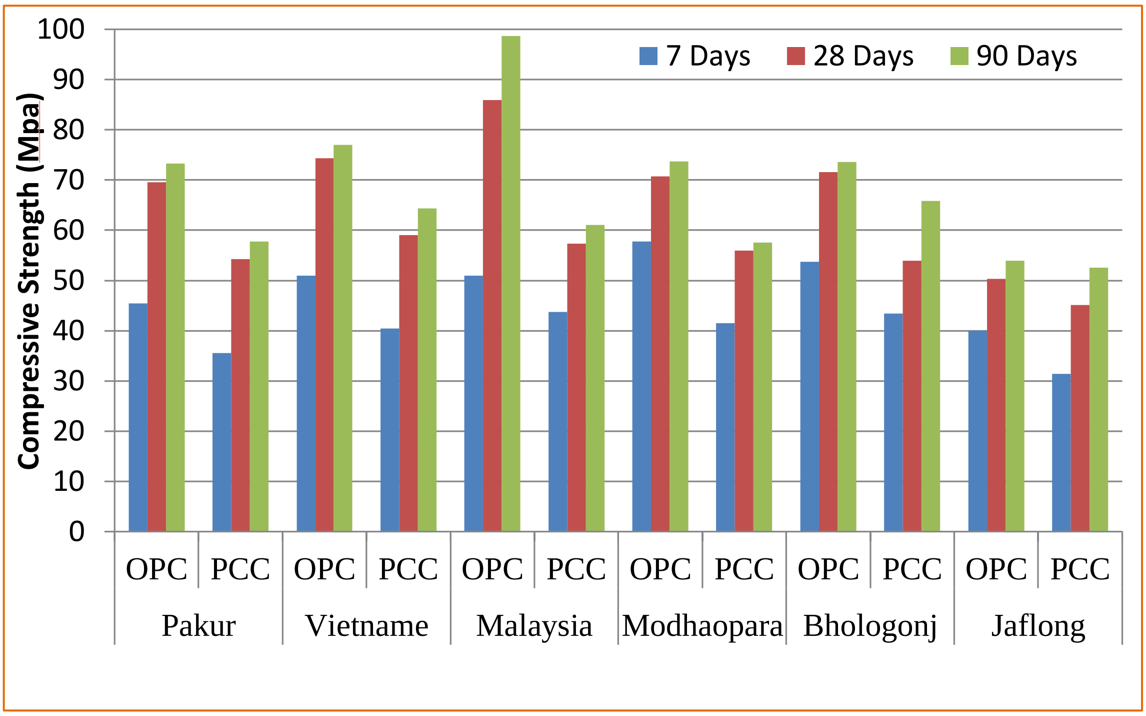


Figure 4.9: w/c 0.3 (OPC & PCC) vs compressive strength

In Figure 4.9 compressive strength of 28 days is considered as full strength. In that case at 0.3 w/c ratio OPC& PCC cement concrete gain 71% strength at 07 days. And at 90 days the strength increased by 6%.

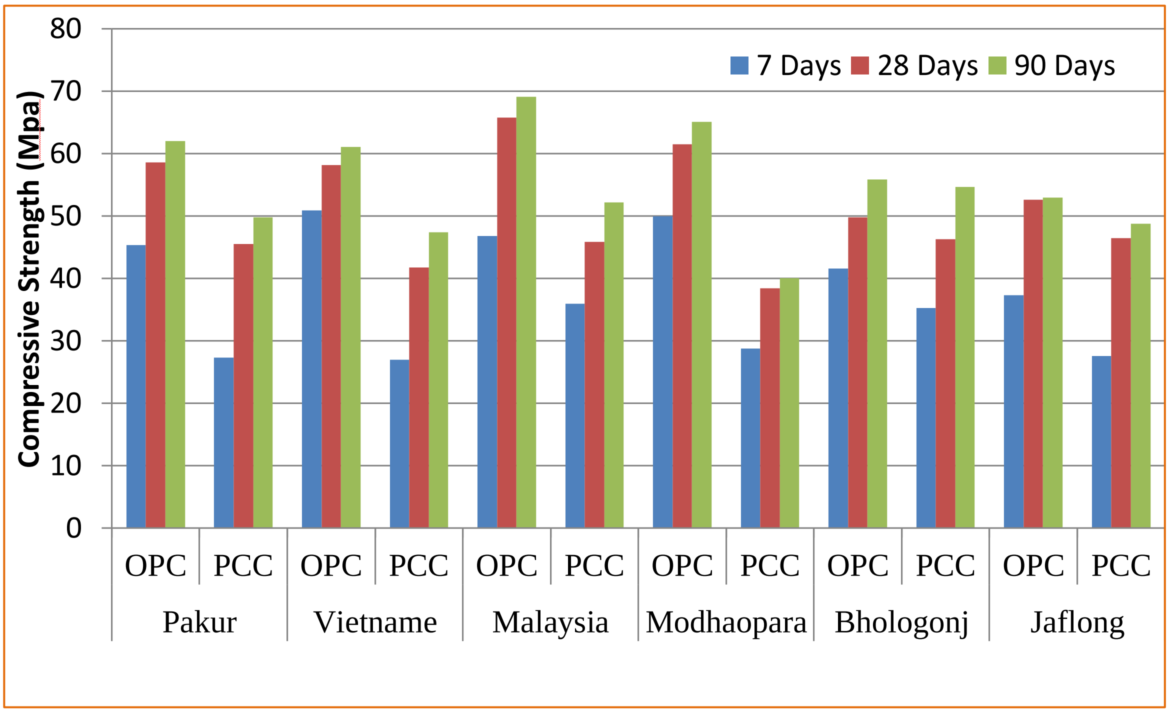


Figure 4.10: w/c 0.4 (OPC & PCC) vs compressive strength

In Figure 4.10 compressive strength of 28 days is considered as full strength. In that case at 0.4 w/c ratio OPC& PCC cement concrete gain 72% strength at 07 days. And at 90 days the strength increased by 9%.

4.6.3 **Tensile strength**

The ability of the concrete withstand in pulling force (Tensile Stress) without broke is called Tensile Strength of concrete. The tensile strength of concrete is measured by the units of Force per Cross Sectional area (N/Sq mm or Mpa).The concrete is superior in compression force and weak in tension force. So the reinforcement has been provided in concrete to prevent the crack formation.

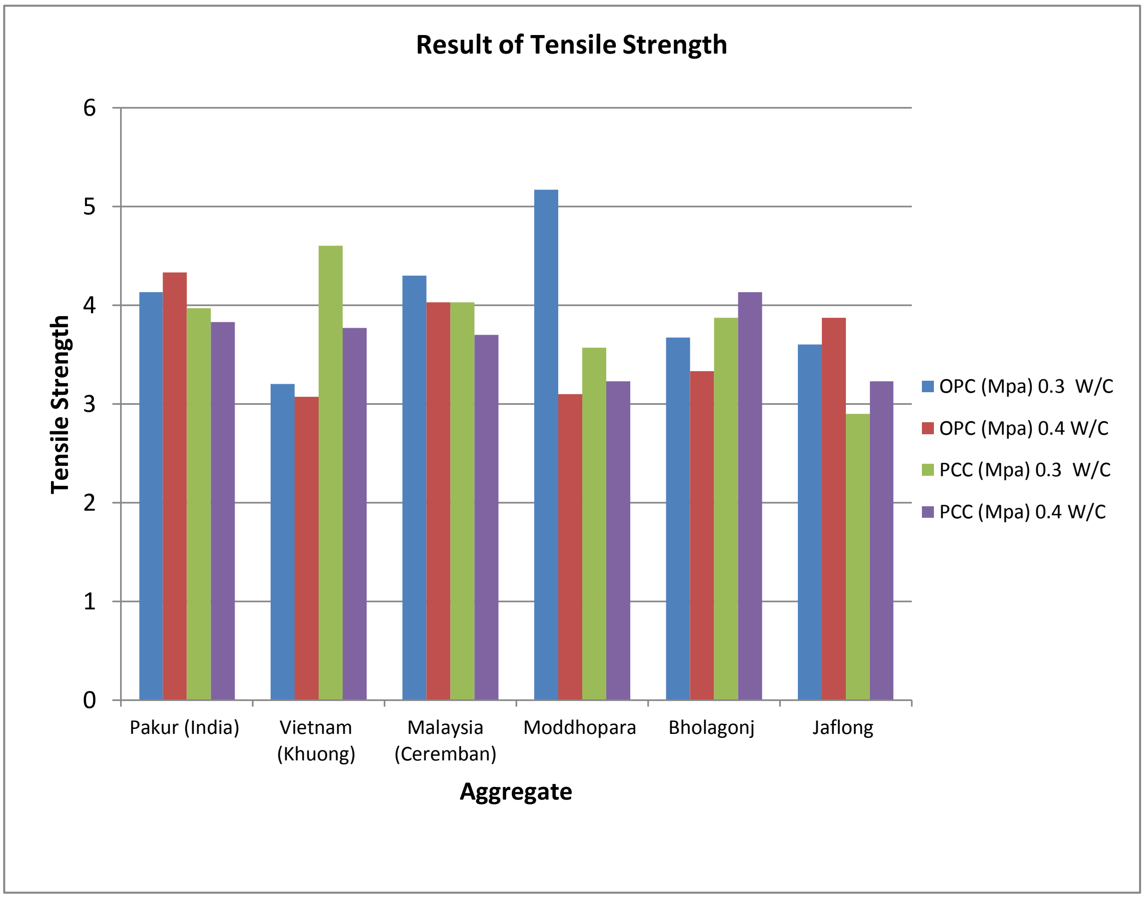


Figure 4.11: Tensile strength of six aggregates

Figure 4.11 shows the tensile strength of aggregates. Tensile strength of concrete is very low with respect to its compressive strength. It is taken as 1/10 of its compressive strength but in calculation tensile strength is generally ignored.

4.6.4 **Flexural strength**

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. The flexural strength is expressed as Modulus of Rupture (MoR) in psi (MPa) and in determined by standard test methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading) [63].Flexural MoR is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used. However, the best correlation for specific materials is obtained by laboratory tests for given materials and mix design. The MoR determined by third-point loading is lower than the MoR determined by center-point loading, sometimes by as much as 15% [64].

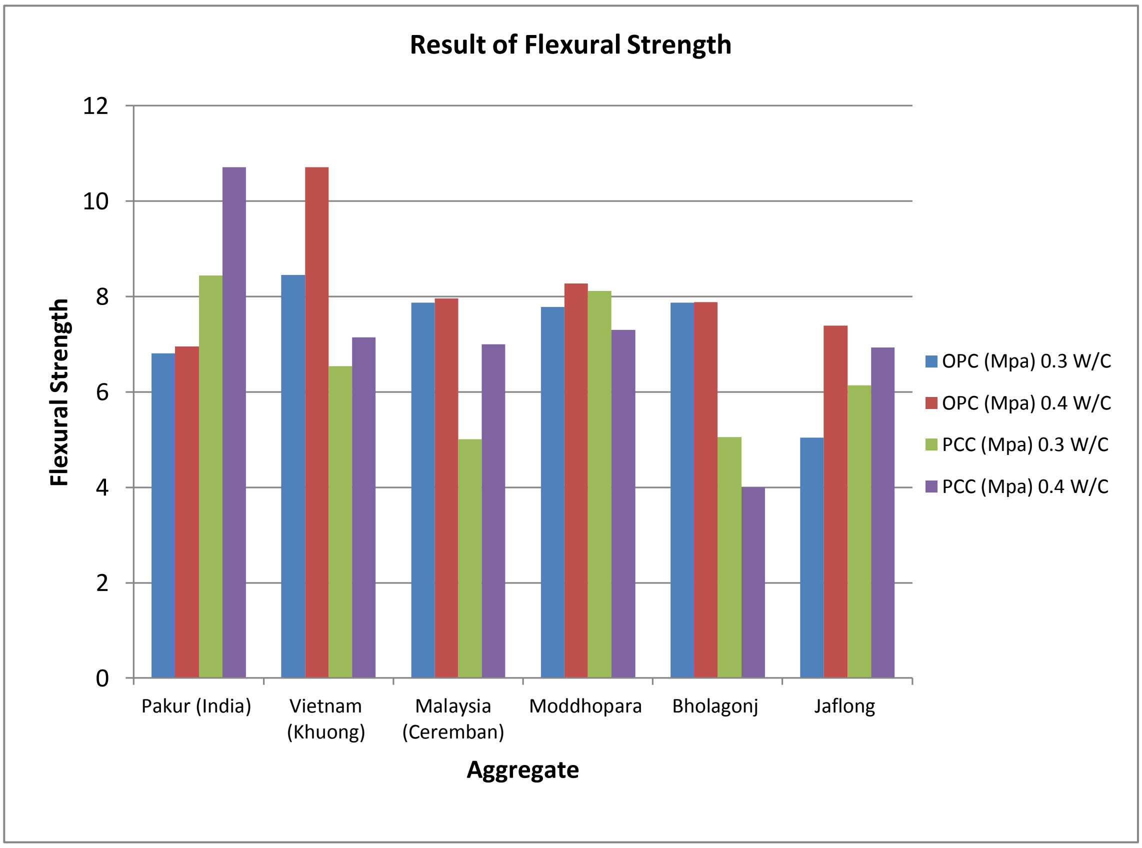


Figure 4.12: Flexural strength of six aggregates

Figure 4.12 shows the flexural strength of aggregates. Flexural strength of concrete is very low with respect to its compressive strength.

4.6.5 Relation between Compressive Strength vs Tensile and Flexural Strength

Relationship between the tensile and compressive strength is not straight forward. Tensile strength properties of concrete depend heavily on the bond between the aggregate and cement mortar and aggregate properties. For many years modulus of rupture determined from the flexure test has been used to identify the tensile strength concrete. The splitting tensile test gives an indication of tensile strength; but it is not a true representation of true axial tensile strength. Therefore, the results of various tensile strength do not provide a uniform relationship with the compressive strength. However, a somewhat good relationship achieved between the tensile strength and square root of compressive strength. In the present study two equations (Eqn. 4.1 & 4.2) have been proposed to correlate compressive and tensile strengths. Figure 4.13 and 4.14 shows the graphical representation between the tensile and compressive strengths for splitting tensile strength and modulus of rupture, respectively. In both cases, the relationships show good correlation.

Tensile strength, $f_t = 0.52\sqrt{f_c'}$ (4.1)

Flexural strength, $f_r = 0.66\sqrt{f_c'}$ (4.2)

Graphical representation:

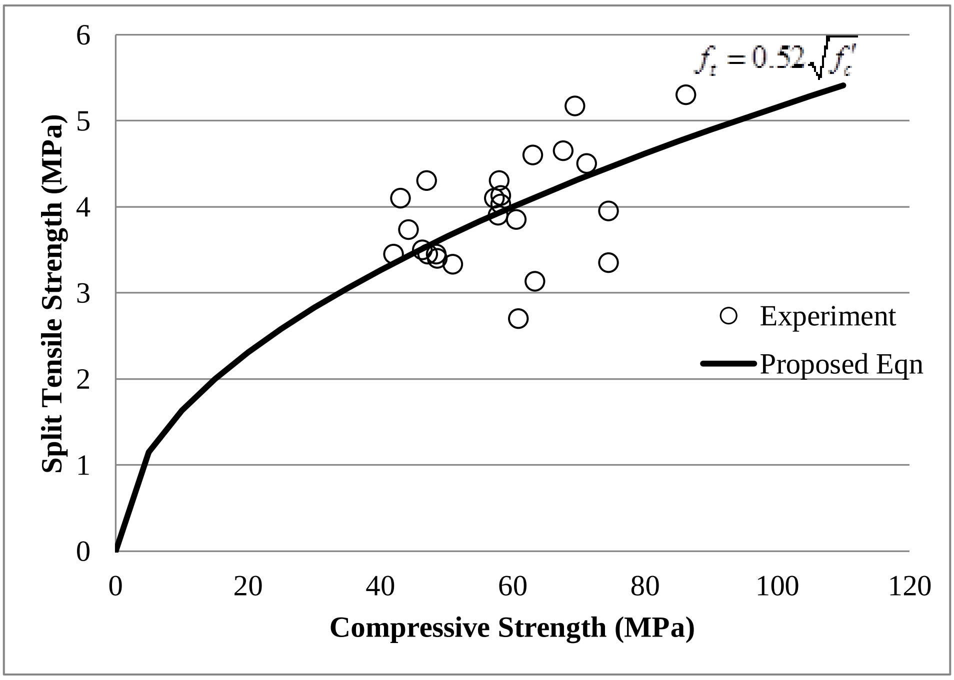


Figure 4.13: Relationship between the split tensile strength and compressive strength for concrete at 28 days of age.

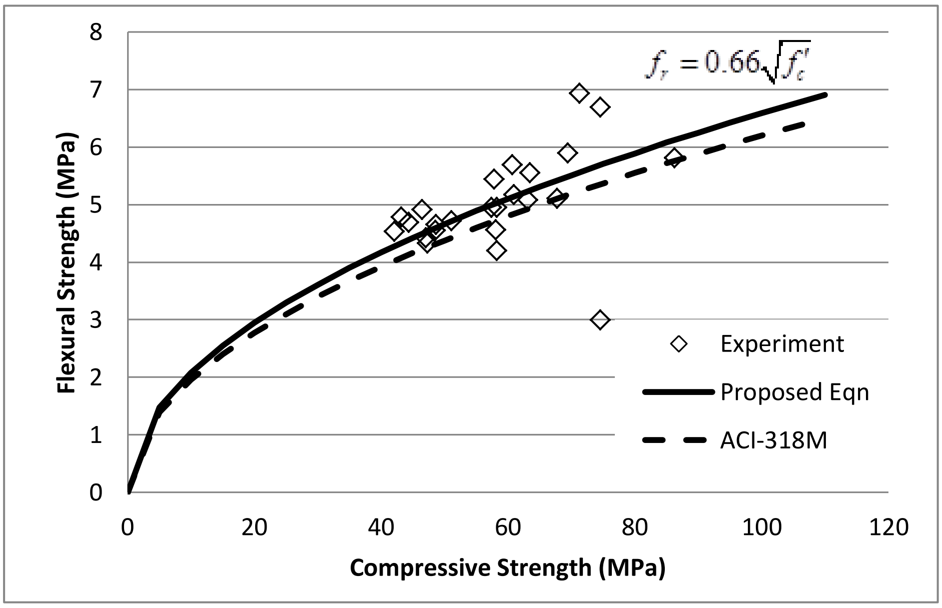


Figure 4.14: Relationship between the flexural strength and compressive strength for concrete at 28 days of age.

4.6.6 **Young's Modulus**

Modulus of elasticity (also known as elastic modulus, the coefficient of elasticity) of a material is a number which is defined by the ratio of the applied stress to the corresponding strain within the elastic limit. Physically it indicates a material's resistance to being deformed when a stress is applied to it. Modulus of elasticity also indicates the stiffness of a material.

Figure 4.15 shows the results of modulus of elasticity of all four type of concrete. Modulus of Elasticity of Concrete can be defined as the slope of the line drawn from a stress of zero to a compressive stress of 0.45f'c. As concrete is a heterogeneous material. The strength of concrete is dependent on the relative proportion and modulus of elasticity of the aggregate. Here concrete with SM aggregate have provided best result then of KV, Mo, PI, Ja and Bh.

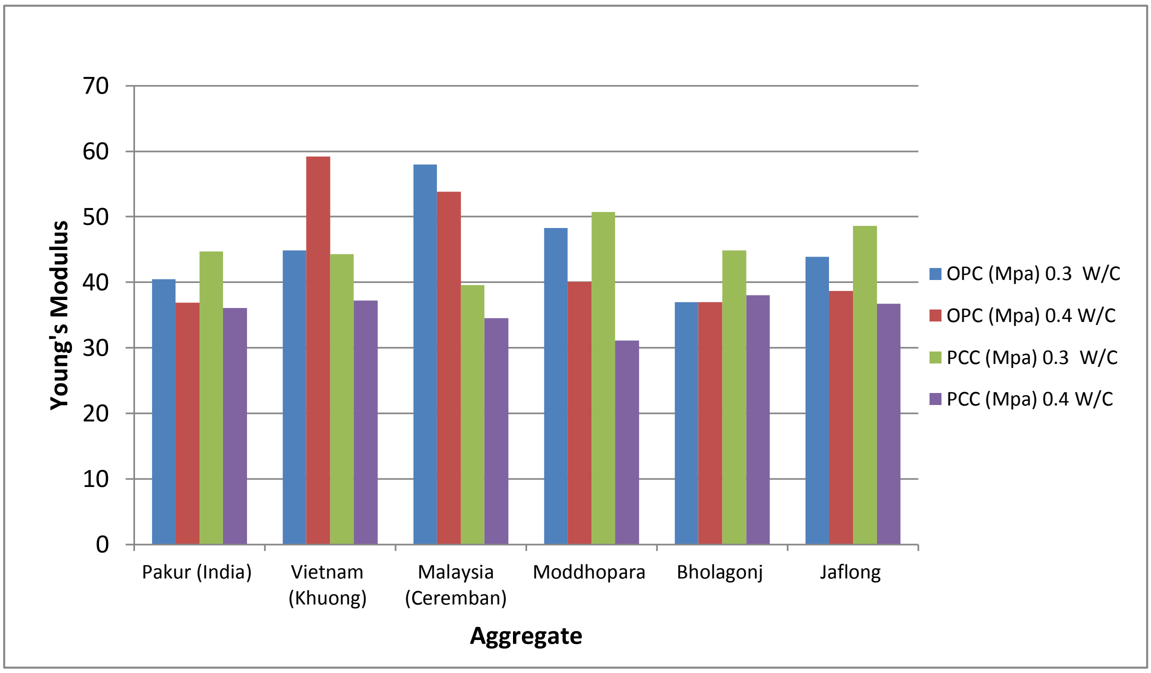


Figure 4.15: Young's modulus of six aggregates

4.6.7 Chloride ion penetrability

For reinforced concrete bridges, one of the major forms of environmental attack is chloride ingress, which leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability, and aesthetics of the structure. This may lead to early repair or premature replacement of the structure. A common method of preventing such deterioration is to prevent chlorides from penetrating the structure to the level of the reinforcing steel bar by using relatively impenetrable concrete. The ability of chloride ions to penetrate the concrete must then be known for design as well as quality control purposes. The penetration of the concrete by chloride ions, however, is a slow process. It cannot be determined directly in a time frame that would be useful as a quality control measure. Therefore, in order to assess chloride penetration, a test method that accelerates the process is needed, to allow the determination of diffusion values in a reasonable time. AASHTO T 358 test method covers the determination of the electrical resistivity of water-saturated concrete through surface resistivity to provide a rapid indication of its resistance to the penetration of chloride ions [65]. This method is alternative method of more popular but exhaustive rapid chloride penetration test.

Table 4.18 and 4.19 provide the test results of Chloride Ion Penetrability for all four types concrete. Test result shows that concrete with OPC provide low to high chloride Ion Penetrability. And concrete with PCC provides low to very low Chloride Ion Penetrability.

Table 4.18: Result of chloride ion penetrability (OPC)

Stone	W/C 0.3		W/C 0.4	
	Surface Resistivity Test (kohm-cm)	Chloride Ion Penetrability (as per AASHTO T358)	Surface Resistivity (kohm-cm)	Chloride Ion Penetrability (as per AASHTO T358)
SM	11.7	High (<12)	11	High (<12)
KV	11.3	High (<12)	18.9	Moderate (12-21)
Bh	22.3	Low (21-37)	17.9	Low (21-37)
PI	18.4	Moderate (12-21)	10.2	High (<12)
Mo	19.3	Moderate (12-21)	19	Moderate (12-21)
Ja	17.7	Moderate (12-21)	21.97	Low (21-37)

Table 4.19: Result of chloride ion penetrability (PCC)

Stone	W/C 0.3		W/C 0.4	
	Surface Resistivity Test (kohm-cm)	Chloride Ion Penetrability (as per AASHTO T358)	Surface Resistivity Test (kohm-cm)	Chloride Ion Penetrability (as per AASHTO T358)
SM	55.2	Very Low (37-254)	43.97	Very Low (37-254)
KV	42.45	Very Low (37-254)	46.05	Very Low (37-254)
Bh	59.66	Very Low (37-254)	43.96	Very Low (37-254)
PI	39.72	Very Low (37-254)	35.19	Low (21-37)
Mo	48.55	Very Low (37-254)	39.68	Very Low (37-254)
Ja	41.17	Very Low (37-254)	36.13	Very Low (37-254)

4.7 Correlation between Aggregate Properties and Concrete Strength

Concrete may be distinct as mixture of water, cement or binder, sand and aggregate, where the water and cement form the paste and the aggregates form the inert filler. In absolute volume terms the aggregate amounts to 60- 80% of the volume of concrete and is, therefore, the major constituent. The aggregate type and volume influences the properties of concrete, its mix proportion and its economy.

In practice, difficulties are frequently encountered in translating these properties into specification requirements for aggregates, or in assessing aggregate test results to determine compliance or otherwise with already specified parameters.

The essential requirement for an aggregate for concrete is that it remains stable within the concrete and in the particular environment throughout the design life of the concrete. The characteristics of aggregate must not affect adversely the performance or cost of the concrete in either the fresh or hardened state. In following paragraphs effects of particular properties of aggregates on concrete are discussed.

4.7.1 ACV vs compressive strength

ACV is one of the vital properties of aggregate. ACV value represents the strength of aggregate. The tested vales of aggregate and compressive strength are shown in Table 4.20 and 4.21 bellows. Trend line of ACV and compressive strength are drawn to see the actual effect of ACV on concrete strength.

Table 4.20: Correlation between ACV vs compressive strength (OPC)

Aggregate	ACV	Variation (%)	Compressive Strength			
			OPC			
			w/c 0.3	Variation (%)	w/c 0.4	Variation (%)
PI	12.0	0.0	69.6	0.00	58.6	0.00
KV	17	-38.9	74.3	6.8	58.2	-0.7
SM	17	-45.0	85.9	23.4	65.8	12.3
Mo	19	-60.0	70.7	1.6	61.5	5.0
Bh	20.0	-66.5	71.6	2.9	49.8	-15.0
Ja	21	-72.7	52.6	-24.4	49.8	-15.0

Table 4.21: Correlation between ACV vs compressive strength (PCC)

Aggregate	ACV	Variation (%)	Compressive Strength			
			PCC			
			w/c 0.3	Variation (%)	w/c 0.4	Variation (%)
PI	12	0.0	54.2	0.00	45.5	0.00
KV	17	-38.9	59	8.9	41.8	-8.1
SM	17	-45.0	57.3	5.7	45.9	0.9
Mo	19	-60.0	55.9	3.2	38.4	-15.6
Bh	20	-66.5	53.9	-0.6	46.3	1.8
Ja	21	-72.7	46.5	-14.2	45.1	-0.9

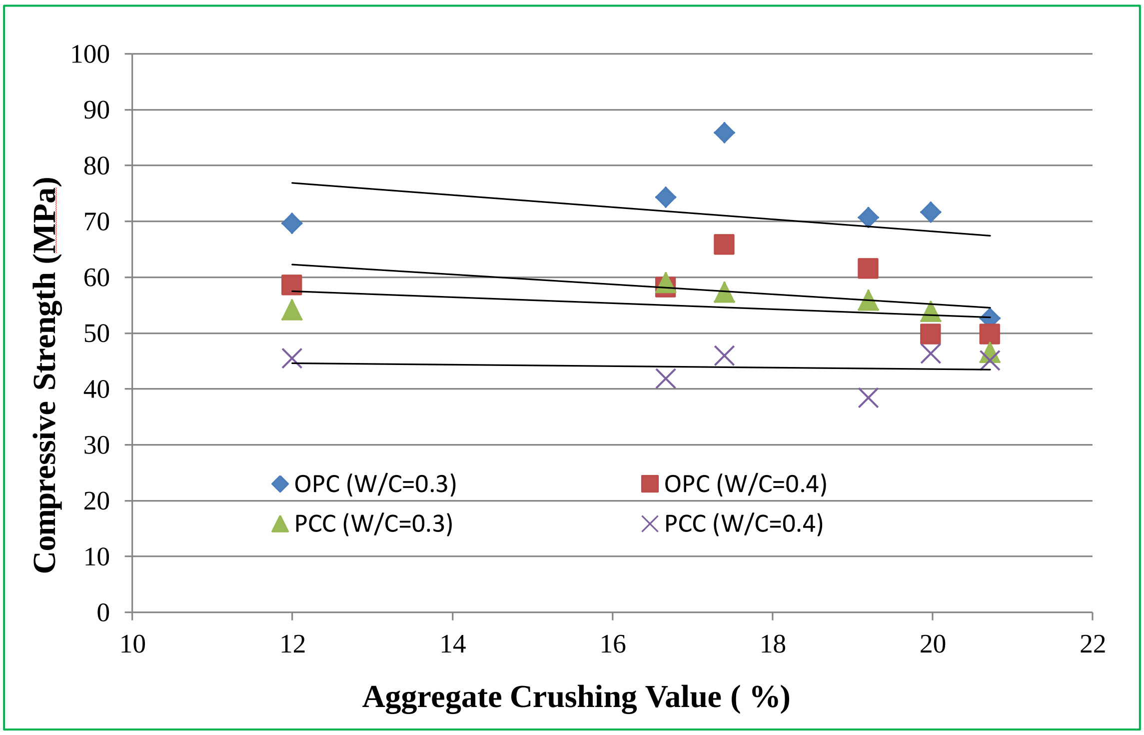


Figure 4.16: ACV vs compressive strength

Table 4.20 and 4.21, the Figure 4.16 represent that aggregate having less ACV provide more compressive strength. It is very clear from above Figure that this trend is much effective for high strength concrete that is over 50 MPa.

4.7.2 **TFV vs compressive strength**

Ten percent fine value is another vital property of aggregate. It also represents the strength of concrete. TFV values of all six aggregates are shown below. Trend line of TFV and compressive strength are drawn to see the actual effect of TFV on concrete strength.

Table 4.22: Correlation between TFV vs compressive strength (OPC)

Aggregate	TFV	Variation (%)	Compressive Strength			
			OPC			
			w/c 0.3	Variation (%)	w/c 0.4	Variation (%)
PI	290	0.0	69.6	0.0	58.6	0.0
SM	240	-15.8	85.9	23.4	65.8	12.3
KV	220	-21.7	74.3	6.8	58.2	-0.7
Bh	210	-26.4	71.6	2.9	49.8	-15.0
Mo	190	-34.9	70.7	1.6	61.5	4.9
Ja	170	-41.2	52.6	-24.4	49.8	-15.0

Table 4.23: Correlation between TFV vs compressive strength (PCC)

Aggregate	TFV	Variation (%)	Compressive Strength			
			PCC			
			w/c 0.3	Variation (%)	w/c 0.4	Variation (%)
PI	290	0.0	54.2	0.0	45.5	0.0
SM	240	-15.8	57.3	5.7	45.9	0.9
KV	220	-21.7	59	8.9	41.8	-8.1
Bh	210	-26.4	53.9	-0.6	46.3	1.8
Mo	190	-34.9	55.9	3.1	38.4	-15.6
Ja	170	-41.2	46.5	-14.2	45.1	-0.9

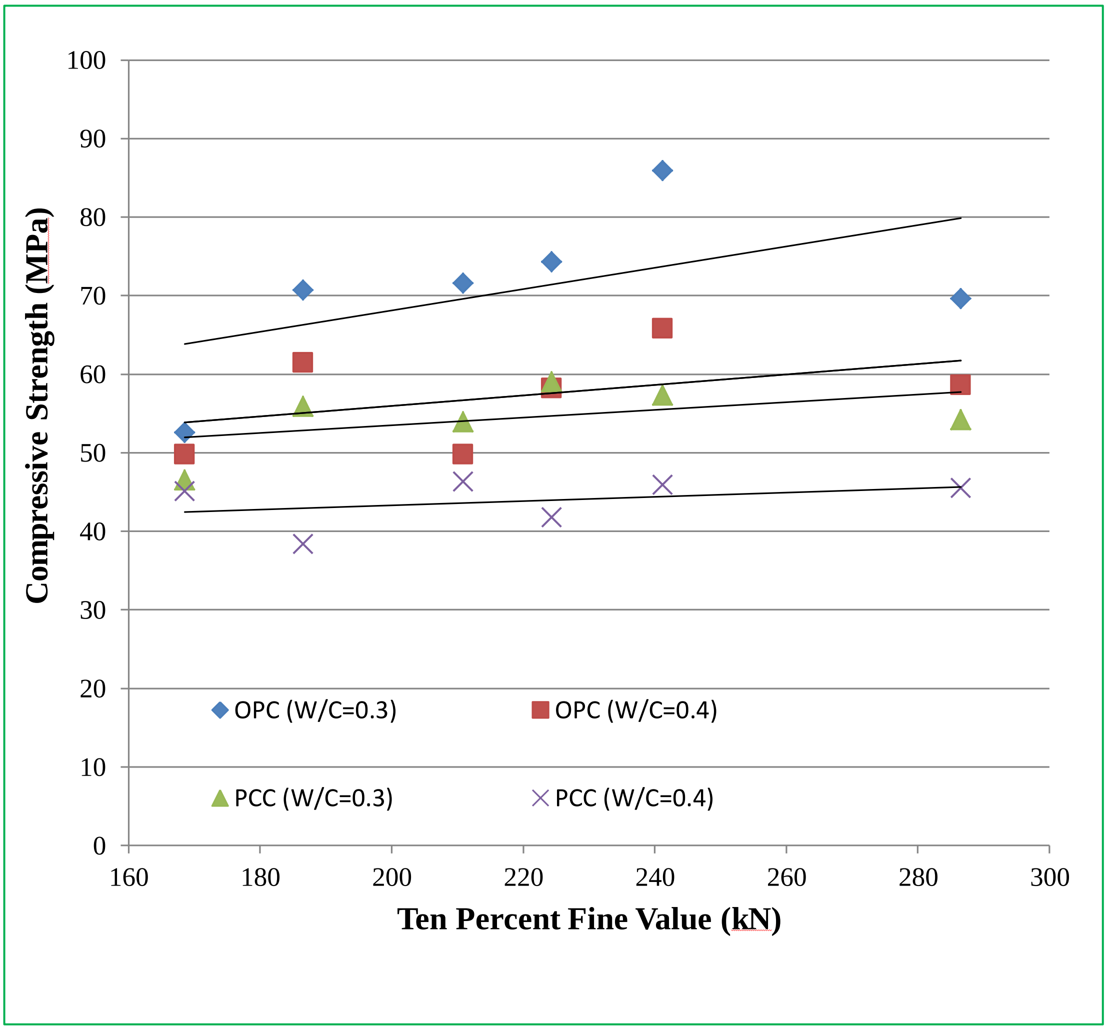


Figure 4.17: TFV vs compressive strength

Table 4.22 and 4.23, the Figure 4.17 represent that aggregate having more TFV provide more compressive strength. It is very clear from above Figure that this trend is much effective for high strength concrete and it is above 50 MPa.

4.7.3 **LAA vs compressive strength**

LAA is also a vital property of aggregate. It also represents the strength of concrete. LAA values of all six aggregates are shown below. Trend line of LAA and compressive strength are drawn to see the actual effect of LAA on concrete strength.

Table 4.24: Correlation between LAA vs compressive strength (OPC)

Aggregate	LAA	Variation (%)	Compressive Strength			
			OPC			
			w/c 0.3	Variation (%)	w/c 0.4	Variation (%)
PI	12	0.0	69.6	0.0	58.6	0.0
SM	16	-35.6	85.9	23.4	65.8	12.3
KV	21	-70.2	74.3	6.8	58.2	-0.7
Mo	26	-116.5	70.7	1.6	61.5	4.9
Bh	28	-134.2	71.6	2.9	49.8	-15.0
Ja	32	-164.2	52.6	-24.4	49.8	-15.0

Table 4.25: Correlation between LAA vs compressive strength (PCC)

Aggregate	LAA	Variation (%)	Compressive Strength			
			PCC			
			w/c 0.3	Variation (%)	w/c 0.4	Variation (%)
PI	12	0.0	54.2	0.0	45.5	0.0
SM	16	-35.6	57.3	5.7	45.9	0.9
KV	21	-70.2	59	8.9	41.8	-8.1
Mo	26	-116.5	55.9	3.1	38.4	-15.6
Bh	28	-134.2	53.9	-0.6	46.3	1.8
Ja	32	-164.2	46.5	-14.2	45.1	-0.9

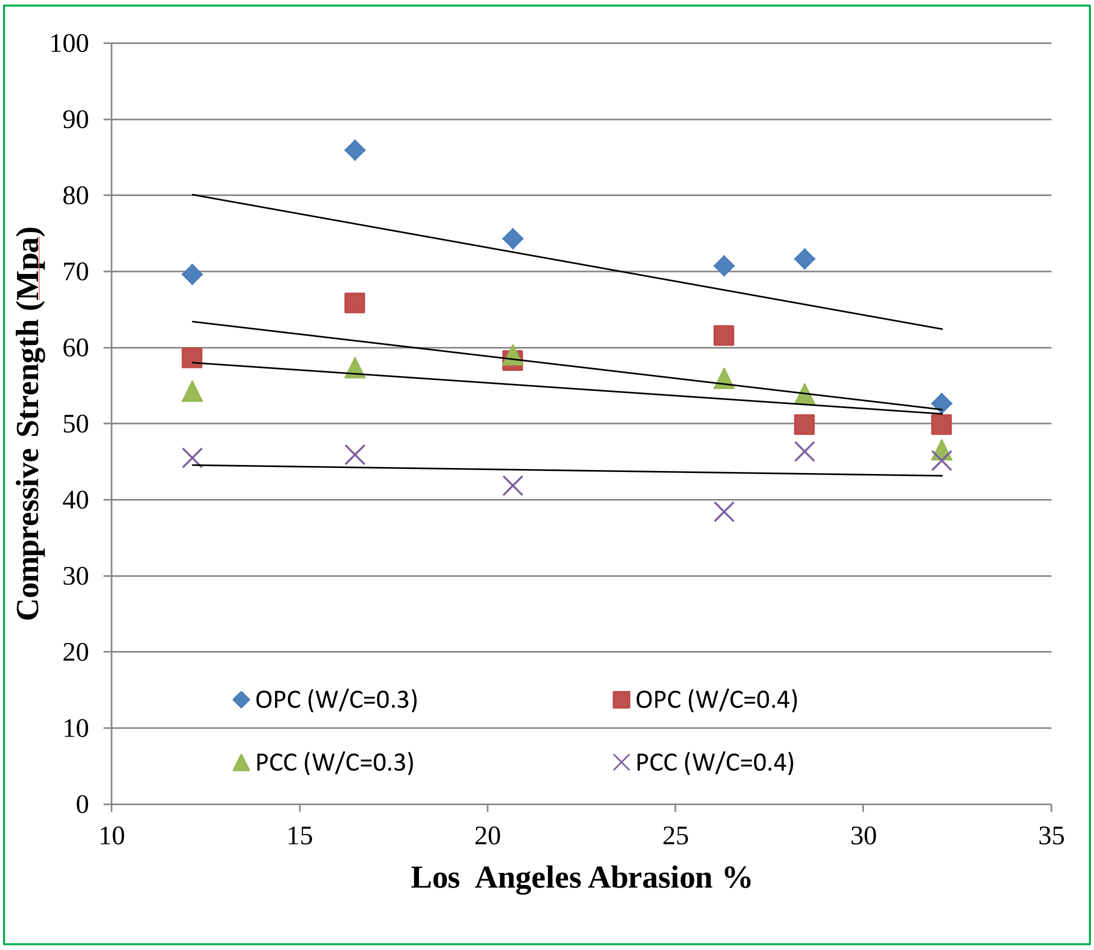


Figure 4.18: LAA vs compressive strength

Table 4.24 and 4.25, the Figure 4.18 represent that aggregate having less LAA provide more compressive strength. It is very clear from above Figure that this trend is much effective for high strength concrete and it is above 50 MPa.

4.7.4 **FI vs compressive strength**

Flakiness Index of aggregate represent the shape of aggregate. Analysis is done to have idea regarding the effect of FI on concrete strength. The test result of Flakiness Index is shown bellow. A trend line is also drawn to get the true picture of effect of FI on concrete.

Table 4.26: Correlation between flakiness index vs compressive strength (OPC)

Aggregate	FI	Variation (%)	Compressive Strength			
			OPC			
			w/c 0.3	Variation (%)	w/c 0.4	Variation (%)
SM	12	0.0	85.9	0.0	65.8	0.0
KV	15	-25.1	74.3	-13.5	58.2	-11.6
PI	17	-38.0	69.6	-19.0	58.6	-10.9
Mo	19	-59.2	70.7	-17.7	61.5	-6.5
Bh	19	-59.6	71.6	-16.6	49.8	-24.3
Ja	20	-69.2	52.6	-38.8	49.8	-24.3

Table 4.27: Correlation between flakiness index vs compressive strength (PCC)

Aggregate	FI	Variation (%)	Compressive Strength			
			PCC			
			w/c 0.3	Variation (%)	w/c 0.4	Variation (%)
SM	12	0.0	57.3	0.0	45.9	0.0
KV	15	-25.1	59	3.0	41.8	-8.9
PI	17	-38.0	54.2	-5.4	45.5	-0.9
Mo	19	-59.2	55.9	-2.4	38.4	-16.3
Bh	19	-59.6	53.9	-5.9	46.3	0.9
Ja	20	-69.2	46.5	-18.8	45.1	-1.7

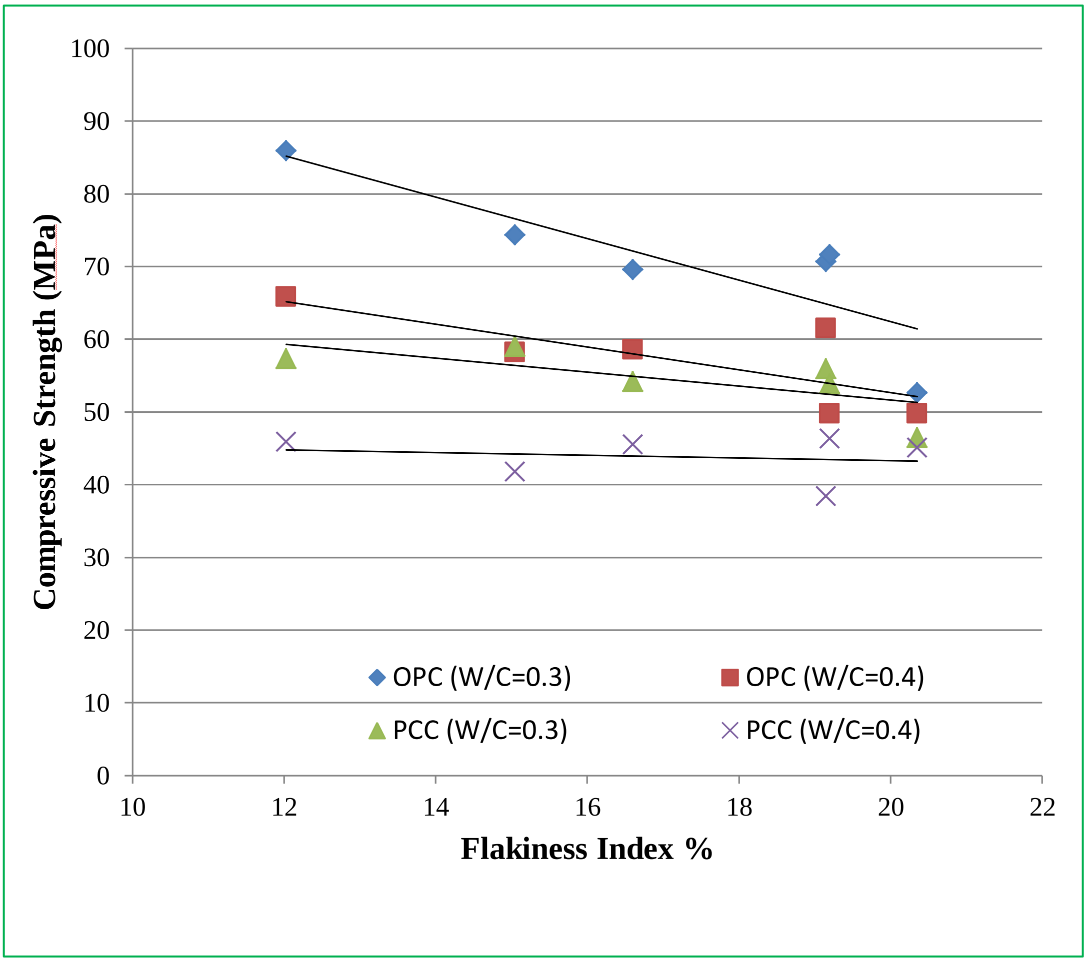


Figure 4.19: Flakiness index vs compressive strength

Table 4.26 and 4.27 and the Figure 4.19 represent that aggregate having less FI provide more compressive strength. It is very clear from above Figure that this trend is much effective for high strength concrete and it is above 50 MPa.

4.7.5 **EI vs compressive strength**

Elongation Index of aggregate represents the shape of aggregate. Analysis is done to have idea regarding the effect of EI on concrete strength. The test result of Elongation Index is shown bellow. A trend line is also drawn to get the true picture of FI effect on concrete.

Table 4.28: Correlation elongation index vs compressive strength (OPC)

Aggregate	EI	Variation (%)	Compressive Strength			
			OPC			
			w/c 0.3	Variation (%)	w/c 0.4	Variation (%)
SM	16	0.0	85.9	0.0	65.8	0.0
Ja	16	-1.2	52.6	-38.8	49.8	-24.3
Mo	21	-29.6	70.7	-17.7	61.5	-6.5
Bh	23	-42.2	71.6	-16.6	49.8	-24.3
KV	23	-44.0	74.3	-13.5	58.2	-11.6
PI	23	-44.3	69.6	-19.0	58.6	-10.9

Table 4.29: Correlation elongation index vs compressive strength (PCC)

Aggregate	EI	Variation (%)	Compressive Strength			
			PCC			
			w/c 0.3	Variation (%)	w/c 0.4	Variation (%)
SM	16	0.0	57.3	0.0	45.9	0.0
Ja	16	-1.2	46.5	-18.8	45.1	-1.7
Mo	21	-29.6	55.9	-2.4	38.4	-16.3
Bh	23	-42.2	53.9	-5.9	46.3	0.9
KV	23	-44.0	59	3.0	41.8	-8.9
PI	23	-44.3	54.2	-5.4	45.5	-0.9

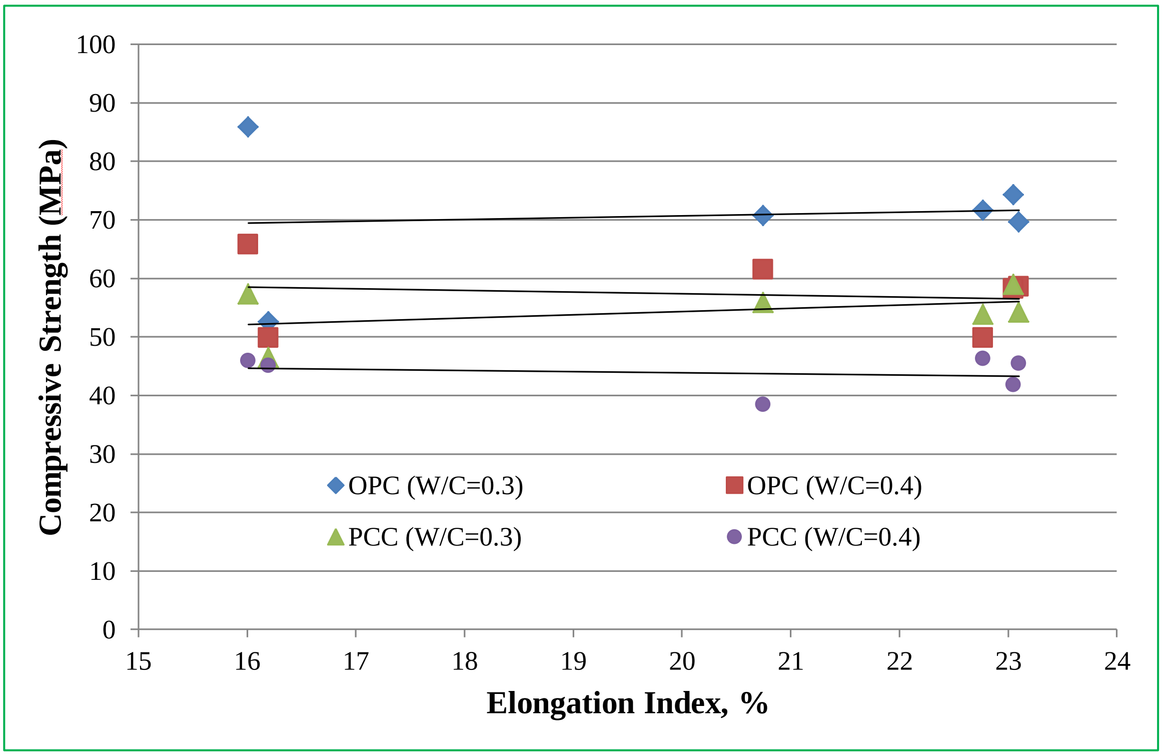


Figure 4.20: Elongation index vs compressive strength

Table 4.28 and 4.29, the Figure 4.20 represent that elongation property of aggregate has no effect on compressive strength of concrete. Trend line doesn't provide any clear idea regarding influence of EI on concrete strength.

4.8 Conclusion

To find out the specific relations between aggregate and concrete, all probable tests on aggregates and concrete are done and discussed in this chapter. For this specific study, six mostly used aggregates at our construction works have been considered. Graphs, trend lines and data provide the definite relationship between aggregates and concrete. In some cases, the relationship couldn't be marked very prominently though the trend of the relationship existed therein. For further study, it is required to consider more numbers of aggregates so as to achieve the best use of it. In next chapter, the summary of findings is sketched out.

CHAPTER 5
CONCLUSION

5.1 General

The overall objective of the research work is to evaluate the influence of aggregate characteristics on concrete properties. Scarcity of local aggregate has increased the dependency on foreign sources. In the field of infrastructural development works of Bangladesh about 89% foreign coarse aggregates and only 11% local course aggregates are used. In 1994 with the initiatives of RHD an analytical study on local aggregate was done which is named as Road Materials and Standard Study (RMSS) 1994. No other large scale research on locally used aggregate has been done in recent days. For economical use of aggregates, analysis on behavior of aggregate and concrete is essential. Reviewing the previous Para, objectives of the study were as mention bellow:

(a) To determine the physical and chemical properties of the aggregates

(b) To evaluate properties of concrete

(c) To correlate concrete properties with that of aggregates

All the objectives are pointing towards the properties of aggregate and concrete. To achieve the objectives of this study detail analysis is done on six aggregates (Local and Foreign).

5.2 Conclusions

In order to correlate the characteristics of aggregate on concrete properties, a number of laboratory tests of aggregate and concrete were performed. Outcome of this study was to verify the economical use of aggregate through identification of best aggregate for specific work. Following conclusions are drawn based on the investigation carried out under this study.

i. Strength and shape properties of aggregate have significant effect on compressive and tensile strength of high strength concrete. However, for concrete with 50 MPa or less compressive strength this influence becomes trivial.

ii. Concrete compressive strength increases linearly worth decreasing ACV and LAA values and with increasing TFVs. However, this relation is only valid for 50 to 90 MPa strength and for relatively lower elongation and flakiness indexes.

iii. Shape of aggregate has insignificant influence on flexural strength of concrete.

iv. Silica (Si) based aggregates are PI, SM, Mo, Bh, Ja and Calcium (Ca) based aggregates is KV. All six aggregates have well resistance against weather actions as well as resistant from Alkali–Silica reactivity and can be considered as innocuous.

v. KV aggregate is Sedimentary origin and of Lime stone rock. PI is igneous origin and of Basalt rock. SM and Mo are igneous origin and of Granite rock. Bh and Ja are Sedimentary and of Granite rock.

vi. From four categories of concrete mixes (with admixture) of six types aggregates it have been observed that:

   (a) PCC provide on average 54 and 43 MPa Compressive strength and OPC provide on average 70 and 57 MPa compressive strength for 0.3 and 0.4 w/c ratio respectively.

   (b) For High Strength concrete PCC will not be suitable and OPC is suggested.

   (c) SM and KV aggregates with OPC and 0.3 w/c achieve more than 70 MPa concrete

   (d) PI, Mo and Bh aggregates with OPC and 0.3 w/c achieve 60-70 MPa concrete

(e) SM, KV, PI and Mo aggregate with OPC and 0.4 w/c achieve 50-60 MPa concrete.

(f) Bh and Ja aggregate with OPC and 0.4 w/c achieve < 50 MPa concrete.

5.3 Limitations

In this study the local aggregates were collected from original sources but it was not possible in case of foreign aggregates. Foreign aggregates had to collect from Dhaka–Mawa Highway N8 project area. Had to depend on the suppliers information and documents.

5.4 Future Study

i. In this study admixture were used in all four concrete mixes for analysis. In future at least two concrete mixtures can be without admixture to compare the results.

ii. More aggregates recently using in our construction works need to be used for further study (Other than these six aggregates).

iii. Effects of chemical properties of aggregate on concrete strength could be discussed more elaborately in future study.

iv. Effects of petrography properties of aggregate on concrete strength could be discussed more elaborately in future study.

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APPENDIX

A.1 **Test Result of PI Aggregate - Physical Properties**

Aggregate Crushing Value (ACV) Method-BS 812-110

Test No			1	2
Weight of Sample	(A)	gm	2996.9	3010.4
Weight of Passing 2.36 mm (No.8) Sieve	(B)	gm	349.4	371.2
Aggregate Crushing Value (ACV) =	(B/A)x100	%	11.66	12.33
Average		%	12.00	

Remarks: Specification limit- The aggregate crushing value shall be less than = 30%

Aggregate Crushing Value (ACV) Method-Bs 812-110

Specimen No	Test No	No of Charges	No of Revolutions	Weight before test (gm)	Weight in grams after test			Loss in weight (gm)	Percent Wear	Average Value (%)
					Retained no No.12 Sieve	Passing through No.12 Sieve	Total Quantity Available			
1	1	11	500	5000	4395	591.8	4986.8	13.2	12.10	12.15
	2	11	500	5000	4390	595.9	4985.9	14.1	12.20	

Ten Percent Fine Value (TFV)-(Method-Bs 812-111)

Test No			1	2	3
Maximum Load	(F)	KN	290	297	
Weight of Sample	(A)	gm	3090	3089.2	
Weight of Passing 2.36 mm (No.8) Sieve	(B)	gm	314.9	323.7	
Percent Fines	(B/Ax100)		10.19	10.48	
Mean Value Percent Fines	(Y)		10.34		
Load require to produce ten percent fines. (TFV) = (14xF)/(Y+4)			286.5		

Remarks: Ten percent fines value greater than 150 KN

Elongation Index (BS 812)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Retained %	Average
50.0-37.5				23.1%
37.5-28.0				
28.0-20.0	1246.7	286.4	22.97	
20.0-14.0	1786.2	396.4	22.19	
14.0-10.0	1989.2	475.3	23.84	
10.0-6.3	408.3	96.4	23.61	
Total	5430.4	1254.5	23.1	

Remarks: Total Wt. Retained/Total Wt. of Test Sample x 100
= 1254.5/5430.4 x 100
= 23.1% < 25% Hence ok

Flakiness Index (BS-812)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Weight Passing (gm)	Passing %	Average
63.0-50.0					
50.0-37.5					16.6
37.5-28.0					
28.0-20.0	38.2	29.8	8.4	21.98	
20.0-14.0	1478.4	1241.9	236.5	15.99	
14.0-10.0	1517.6	1245.3	272.3	17.94	
10.0-6.3	485.8	418.8	67.0	13.79	
Total	3520	2935.8	584.3	16.6	

Remarks: Flakiness Index=Total Wt. Passing/Total Wt. of test sample*100

Sp. Gravity and Water Absorption of Coarse Aggregate(AASHTO-T85)

Test No			1	2	Average
Weight of saturated surface dry sample in air	(A)	gm	3712.7	3623.7	
Weight of oven dry sample in air	(B)	gm	3669	3580.9	
Weight of saturated surface dry sample in water	(C)	gm	2424.9	2365.9	
Water Absorption	A-B	gm	43.7	42.8	
Percent Water Absorption	100*(A-B)/B%		1.191	1.195	1.193
Bulk specific gravity (oven dry)	B/(A-C)		2.849	2.847	2.848
Bulk specific gravity (SSD)	A/(A-C)		2.883	2.882	2.882
Apparent specific gravity	B/(B-C)		2.949	2.948	2.948

Rodded Unit Weight

Test No			1	2	3
Weight of Mould + Sample	(gm)	(a)	22702	22800	22760
Weight of Mould	(gm)	(b)	6216	6216	6216
Weight of Sample	(gm)	(c)	16486	16584	16544
Volume of Mould	(gm)	(d)	9883	9883	9883
Unit weight of Sample	g/cc	(c/d)	1.668	1.678	1.674
Average =				1.673	

Remarks: Rodded unit weight found= 1.673 gm/cc

A.2 **Test Result of KV Aggregate - Physical Properties**

Aggregate Crushing Value (ACV) Method-Bs 812-110

Test No			1	2
Weight of Sample	(A)	gm	2925	2930
Weight of Passing 2.36 mm (No.8) Sieve	(B)	gm	670	669.2
Aggregate Crushing Value (ACV) =	(B/A)x100	%	22.90	22.84
Average		%	22.87	

Remarks: Specification limit- The aggregate crushing value shall be less than = 30%

Aggregate Crushing Value (ACV) Method-Bs 812-110

Specimen No	Test No	No of Charges	No of Revolutions	Weight before test (gm)	Weight in grams after test			Loss in weight (gm)	Percent Wear	Average Value (%)
					Retained no No.12 Sieve	Passing through No.12 Sieve	Total Quantity Available			
1	1	11	500	5000	3807.1	1192.9	4984.8	15.2	23.93	23.87
	2	11	500	5000	3813.6	1186.4	4983.0	17.0	23.81	

Ten Percent Fine Value (TFV)-(Method-BS 812-111)

Test No			1	2	3
Maximum Load	(F)	KN	175	180	
Weight of Sample	(A)	gm	2820	2830	
Weight of Passing 2.36 mm (No.8) Sieve	(B)	gm	255	268.9	
Percent Fines	(B/Ax100)		9.0	9.5	
Mean Value Percent Fines	(Y)		9.25		
Load require to produce ten percent fines. (TFV) = (14xF)/(Y+4)			187.5		

Remarks: Ten percent fines value greater than 150 KN

Elongation Index (BS 812)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Retained %	Average
50.0-37.5				23.05%
37.5-28.0				
28.0-20.0	767	65	8.16	
20.0-14.0	1892	400	21.14	
14.0-10.0	2716	772	28.42	
10.0-6.3	534	132	24.72	
Total	5939	1369	23.05	

Remarks: Total Wt. Retained/Total Wt. of Test Sample x 100
= 1254.5/5430.4 x 100
= 23.1% < 25% Hence ok

Flakiness Index (BS-812)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Weight Passing (gm)	Passing %	Average
63.0-50.0					
50.0-37.5					15.05
37.5-28.0					
28.0-20.0	796	564	232	29.14	
20.0-14.0	1894	1680	205	10.82	
14.0-10.0	2726	2348	378	13.86	
10.0-6.3	532	452	80	15.03	
Total	5948	5053	895	15.05	

Remarks: Flakiness Index=Total Wt. Passing/Total Wt. of test sample*100

SP. Gravity and Water Absorption of Coarse Aggregate (AASHTO-T85)

Test No			1	2	Average
Weight of saturated surface dry sample in air(A)		gm	4306.5	4987.6	
Weight of oven dry sample in air	(B)	gm	4282.7	4959.2	
Weight of saturated surface dry sample in water(C)		gm	2764.7	3204.7	
Water Absorption	A-B	gm	23.8	23.4	
Percent Water Absorption	100*(A-B)/B	%	0.56	0.57	0.57
Bulk specific gravity (oven dry)	B/(A-C)		2.778	2.732	2.780
Bulk specific gravity (SSD)	A/(A-C)		2.793	2.797	2.795
Apparent specific gravity	B/(B-C)		2.821	2.827	2.824

Rodded Unit Weight

Test No			1	2	3
Weight of Mould + Sample	(gm)	(a)	22786	22819	22780
Weight of Mould	(gm)	(b)	6216	6216	6216
Weight of Sample	(gm)	(c)	16570	16564	16564
Volume ofMould	(gm)	(d)	9883	9883	9883
Unit weight of Sample	g/cc	(c/d)	1.679	1.676	1.676
Average		=		1.677	

Remarks: Rodded unit weight found= 1.673 gm/cc

A.3 **Test Result of SM Aggregate - Physical Properties**

Aggregate Crushing Value (ACV) Method-BS 812-110

Test No			1	2
Weight of Sample	(A)	gm	2867	2830
Weight of Passing 2.36 mm (No.8) Sieve	(B)	gm	490	500
Aggregate Crushing Value (ACV) =	(B/A)x100	%	17.1	17.7
Average		%	17.4	

Remarks: Specification limit- The aggregate crushing value shall be less than = 30%

Aggregate Crushing Value (ACV)Method-BS 812-110

Specimen No	Test No	No of Charges	No of Revolutions	Weight before test (gm)	Weight in grams after test			Loss in weight (gm)	Percent Wear	Average Value (%)
					Retained no No.12 Sieve	Passing through No.12 Sieve	Total Quantity Available			
1	1	11	500	5000	4028	970.0	4998	2.00	19.4	19.80
	2	11	500	5000	3989	1010	4999	1.00	20.2	

Ten Percent Fine Value (TFV)-(Method-BS 812-111)

Test No			1	2	3
Maximum Load	(F)	KN	200	188	188
Weight of Sample	(A)	gm	2947	2875	2877
Weight of Passing 2.36 mm (No.8) Sieve(B)		gm	320	300	292
Percent Fines	(B/Ax100)		10.9	10.4	10.1
Mean Value Percent Fines	(Y)		10.3		
Load require to produce ten percent fines. (TFV) = (14xF)/(Y+4)			184.6		

Remarks: Ten percent fines value greater than 150 KN

Elongation Index (BS 812)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Retained %	Average
50.0-37.5				16.01
37.5-28.0				
28.0-20.0	830	182.6	22.0	
20.0-14.0	1190	190.4	16.0	
14.0-10.0	683	47.8	7.0	
10.0-6.3	411	77.8	18.93	
Total	3114	498.6	16.01	

Remarks: Total Wt. Retained/Total Wt. of Test Sample x 100
= 1254.5/5430.4 x 100
= 23.1% < 25% Hence ok

Flakiness Index (BS-812)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Weight Passing (gm)	Passing %	Average
63.0-50.0					
50.0-37.5					12.30
37.5-28.0					
28.0-20.0	1260	975.5	284.5	22.58	
20.0-14.0	3580	3280	300	8.38	
14.0-10.0	2720	2361	359	13.20	
10.0-6.3	411	374	37	9.0	
Total	7971	6990.5	980.5	12.30	

Remarks: Flakiness Index=Total Wt. Passing/Total Wt. of test sample*100

SP. Gravity and Water Absorption of Coarse Aggregate(AASHTO-T85)

Test No			1	2	Average
Weight of saturated surface dry sample in air(A)		gm	2000.0	1500.0	
Weight of oven dry sample in air	(B)	gm	1986.0	1489.0	
Weight of saturated surface dry sample in water(C)		gm	1247.0	934.0	
Water Absorption	A-B	gm	14.0	11.0	
Percent Water Absorption	100*(A-B)/B	%	0.70	0.74	0.72
Bulk specific gravity (oven dry)	B/(A-C)		2.637	2.631	2.634
Bulk specific gravity (SSD)	A/(A-C)		2.656	2.650	2.653
Apparent specific gravity	B/(B-C)		2.687	2.683	2.685

Rodded Unit Weight

Test No			1	2	3
Weight of Mould + Sample	(gm)	(a)	5682	5688	5755
Weight of Mould	(gm)	(b)	2525	2525	2525
Weight of Sample	(gm)	(c)	3157	3163	3230
Volume of Mould	(gm)	(d)	1958	1958	1958
Unit weight of Sample	g/cc	(c/d)	1.612	1.615	1.650
Average	=		1.626		

Remarks: Rodded unit weight found= 1.673 gm/cc

A.4 **Test Result of Mo Aggregate - Physical Properties**

Aggregate Crushing Value (ACV)

Test No				1
Weight of Sample		(A)	gm	2856.6
Weight of Passing 2.44 mm (No.8) Sieve		(B)	gm	548.5
Aggregate Crushing Value (ACV)	=	(B/A)x100	%	19.2
Average			%	19.2

Remarks: The aggregate crushing value shall be less than = 30%

Ten Percent Fine Value (TFV)

Test No			1
Weight of Sample	(A)	gm	2862.4
Weight of Passing 2.4 mm (No.8) Sieve	(B)	gm	292.0
Maximum Load		KN	246.0
Avg		KN	

Calculation:
Percent Fines = (B/A) x 100
Test-1 = 10.2 KN
Test-2 = KN
Test-3 = KN
Mean Value (Y) =
Load required to produce ten percent Fines = $\frac{14xF}{Y+4}$ =
242.5 KN

Remarks: Ten percent Fines Value Greater than = 150 KN

Sieve Analysis for Coarse Aggregate

Sieve Size	Weight Retained	Cumulative Weight Retained	Cumulative% Retained	% Passing	Specification
25.00	00	00	00	100	100
20.00	789	789	2.89	97.11	90~100
12.50	17220	18009	65.99	34.01	20~55
10.00	4680	22688	83.14	16.86	5~20
5.00	3479	26167	95.89	4.11	0~5
Pan	1122				
Total	27289				

Elongation Index (BS 812)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Retained %	Average
50.0-37.5	-	-		20.75%
37.5-28.0	-	-		
28.0-20.0	-	-		
20.0-14.0	3071.0	422.5		
14.0-10.0	2016.7	642.5		
10.0-6.3	507.6	96.0		
Total	5595.3	1161.0		

Remarks: Total Wt. Retained/Total Wt. of Test Sample x 100
= 1254.5/5430.4 x 100
= 23.1% < 25% Hence ok

Flakiness Index (STP 7.3.1)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Weight Passing (gm)	Passing %	Average
63.0-50.0	-	-	-		
50.0-37.5	-	-	-		21.73%
37.5-28.0	-	-	-		
28.0-20.0	247.4	184.8	62.6		
20.0-14.0	3071.0	2329.8	741.2		
14.0-10.0	2016.7	1642.4	348.3		
10.0-6.3	507.6	416.0	91.6		
Total	5842.7	4573	1269.7		

Remarks: Flakiness Index=Total Wt. Passing/Total Wt. of test sample*100

= 1269.7/5842.7x 100

= 21.73 < 30%

SP. Gravity andWater Absorption of Coarse Aggregate

Test No			1	2	Average
Weight of saturated surface dry sample in air	(A)	gm	3215.5	3218.6	
Weight of oven dry sample in air	(B)	gm	3188.2	3191.6	
Weight of saturated surface dry sample in water	(C)	gm	2050.0	2053.4	
Water Absorption	A-B	gm	27.3	27.0	
Percent Water Absorption	100*(A-B)/B	%	0.86	0.84	0.85
Bulk specific gravity (oven dry)	B/(A-C)		2.735	2.739	2.737
Bulk specific gravity (SSD)	A/(A-C)		2.759	2.762	2.761
Apparent specific gravity	B/(B-C)		2.801	2.804	2.803

Loss/Rodded Unit Weight (C.A)

Test No			1	2	3
Weight of Mould + Sample	(gm)	(a)	16665	16680	16690
Weight of Mould	(gm)	(b)	4890	4890	4890
Weight of Sample	(gm)	(c)	11775	11790	11800
Volume of Mould	(gm)	(d)	7006	7006	7006
Unit weight of Sample	g/cc	(c/d)	1.680	1.683	1.684
Average	=			1.682	

Remarks: Rodded unit weight found= 1.682 gm/cc

= 1682kg/m³

Abrasion Test of Aggregate by Loss Angeles (Method AASHTO T-96)

Speci men No	No of Charg es	No of Revol utions	Weight before test (gm)	Weight in grams after test			Loss in weigh t (gm)	Perce nt Wear	Averag e Value (%)
				Retained no No.12 Sieve	Passing through No.12 Sieve	Total Quantity Available			
1	11	500	5000	3487	1495	4982	18	29.3	29.9

Remarks: Grading -B = 19.5 mm to 12.5 mm Retained = 2500 gm, 12.5 mm to 9.50 mm = 2500 gm (Total = 5000 gm)

A.5 **Test Result of Bh Aggregate - Physical Properties**

Aggregate Crushing Value (ACV)

Test No				1
Weight of Sample		(A)	gm	2785.3
Weight of Passing 2.44 mm (No.8) Sieve		(B)	gm	590.6
Aggregate Crushing Value (ACV)	=	(B/A)x100	%	21.4
Average			%	21.4

Remarks: The aggregate crushing value shall be less than = 30%

Ten Percent Fine Value (TFV)

Test No			1
Weight of Sample	(A)	gm	2765.0
Weight of Passing 2.4 mm (No.8) Sieve	(B)	gm	326.3
Maximum Load		KN	187
Avg		KN	

Calculation:

Percent Fines	= (B/A) x 100	
Test-1	= 10.2	KN
Test-2	=	KN
Test-3	=	KN
Mean Value (Y)	=	
Load required to produce ten percent Fines	= $\frac{14xF}{Y+4}$	=

242.5 KN

Remarks: Ten percent Fines Value Greater than = 150 KN

Sieve Analysis for Coarse Aggregate

Sieve Size	Weight Retained	Cumulative Weight Retained	Cumulative% Retained	% Passing	Specification
25.00	00	00	00	100	100
20.00	3330	3330	4.34	95.66	90~100
12.50	56083	59413	77.44	22.56	20~55
10.00	11002	70415	91.78	8.22	5~20
5.00	4373	74788	97.48	2.52	0~5
Pan	1933				
Total	76721				

Elongation Index (BS 812)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Retained %	Average
50.0-37.5	-	-		
37.5-28.0	-	-		
28.0-20.0	-	-		
20.0-14.0	3204.4	511.4		23.77%
14.0-10.0	3248.6	1001.0		
10.0-6.3	422.6	122.2		
Total	6875.6	1634.6		

Remarks: Total Wt. Retained/Total Wt. of Test Sample x 100
= 1254.5/5430.4 x 100
= 23.1% < 25% Hence ok

Flakiness Index (STP 7.3.1)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Weight Passing (gm)	Passing %	Average
63.0-50.0	-	-	-		
50.0-37.5	-	-	-		19.20%
37.5-28.0	-	-	-		
28.0-20.0	413.4	251.2	162.2		
20.0-14.0	3204.4	2286.4	918.0		
14.0-10.0	3248.6	1948.2	1300.4		
10.0-6.3	422.6	262.4	160.2		
Total	13205.1	4748.2	2540.8		

Remarks: Flakiness Index=Total Wt. Passing/Total Wt. of test sample*100

= 1269.7/5842.7x 100

= 21.73 < 30%

SP. Gravity and Water Absorption of Coarse Aggregate

Test No			1	2	Average
Weight of saturated surface dry sample in air(A)		gm	3066.8	2774.1	
Weight of oven dry sample in air	(B)	gm	3038.8	2747.7	
Weight of saturated surface dry sample in water(C)		gm	1905.5	1723.2	
Water Absorption	A-B	gm	28.0	26.4	
Percent Water Absorption	100*(A-B)/B	%	0.92	0.96	0.94
Bulk specific gravity (oven dry)	B/(A-C)		2.617	2.615	2.616
Bulk specific gravity (SSD)	A/(A-C)		2.641	2.640	2.641
Apparent specific gravity	B/(B-C)		2.681	2.682	2.682

Loss/Rodded Unit Weight(C.A)

Test No			1	2	3
Weight of Mould + Sample	(gm)	(a)	15898	15827	15880
Weight of Mould	(gm)	(b)	4890	4890	4890
Weight of Sample	(gm)	(c)	11008	10937	10990
Volume of Mould	(gm)	(d)	7006	7006	7006
Unit weight of Sample	g/cc	(c/d)	1.571	1.562	1.569
Average =			1.567		

Remarks: Rodded unit weight found= 1.682 gm/cc

= 1682kg/m³

Abrasion Test of Aggregate by Loss Angeles (Method AASHTO T-96)

Specimen No	No of Charges	No of Revolutions	Weight before test (gm)	Weight in grams after test			Loss in weight (gm)	Percent Wear	Average Value (%)
				Retained no No.12 Sieve	Passing through No.12 Sieve	Total Quantity Available			
1	11	500	5000	3240	1745	4985	15	34.9	34.9

Remarks: Grading -B = 19.5 mm to 12.5 mm Retained = 2500 gm, 12.5 mm to 9.50 mm = 2500 gm (Total = 5000 gm)

A.6 **Test Result of Ja Aggregate - Physical Properties**

Aggregate Crushing Value (ACV)

Test No				1
Weight of Sample		(A)	gm	2807.7
Weight of Passing 2.44 mm (No.8) Sieve		(B)	gm	570.2
Aggregate Crushing Value (ACV)	=	(B/A)x100	%	20.3
Average			%	20.3

Remarks: The aggregate crushing value shall be less than = 30%

Ten Percent Fine Value (TFV)

Test No			1
Weight of Sample	(A)	gm	2830.2
Weight of Passing 2.4 mm (No.8) Sieve	(B)	gm	317.0
Maximum Load		KN	202.0
Avg		KN	

Calculation:

Percent Fines = (B/A) x 100

Test-1 = 10.2 KN

Test-2 = KN

Test-3 = KN

Mean Value (Y) =

Load required to produce ten percent Fines = $\frac{14xF}{Y+4}$ = 242.5 KN

Remarks: Ten percent Fines Value Greater than = 150 KN

Sieve Analysis for Coarse Aggregate

Sieve Size	Weight Retained	Cumulative Weight Retained	Cumulative% Retained	% Passing	Specification
25.00	00	00	00	100	100
20.00	670	670	5.18	94.92	90~100
12.50	7470	8140	62.88	37.12	20~55
10.00	2449	10589	81.80	18.20	5~20
5.00	1784	12373	95.58	4.42	0~5
Pan	572	12945			
Total	12945				

Elongation Index (BS 812)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Retained %	Average
50.0-37.5	-	-		13.20%
37.5-28.0	-	-		
28.0-20.0	-	-		
20.0-14.0	2098.3	134.1		
14.0-10.0	1771.4	376.0		
10.0-6.3	308.2	39.8		
Total	4177.9	549.9		

Remarks: Total Wt. Retained/Total Wt. of Test Sample x 100
= 1254.5/5430.4 x 100
= 23.1% < 25% Hence ok

Flakiness Index (STP 7.3.1)

Sieve Size (mm)	Weight of Total Sample (gm)	Weight Retained (gm)	Weight Passing (gm)	Passing %	Average
63.0-50.0	-	-	-		
50.0-37.5	-	-	-		20.35%
37.5-28.0	-	-	-		
28.0-20.0	258.1	47.1	211.0		
20.0-14.0	2098.3	1707.8	390.5		
14.0-10.0	1771.4	1542.6	228.8		
10.0-6.3	308.2	235.9	72.3		
Total	4436	3533.4	902.6		

Remarks: Flakiness Index=Total Wt. Passing/Total Wt. of test sample*100

= 1269.7/5842.7x 100

= 21.73 < 30%

SP. Gravity and Water Absorption of Coarse Aggregate

Test No			1	2	Average
Weight of saturated surface dry sample in air(A)		gm	3025.74	3200.1	
Weight of oven dry sample in air	(B)	gm	3003.3	3178.9	
Weight of saturated surface dry sample in water(C)		gm	1889.9	1998.0	
Water Absorption	A-B	gm	22.1	21.2	
Percent Water Absorption	100*(A-B)/B	%	0.736	0.67	0.70
Bulk specific gravity (oven dry)	B/(A-C)		2.645	2.644	2.645
Bulk specific gravity (SSD)	A/(A-C)		2.664	2.662	2.663
Apparent specific gravity	B/(B-C)		2.698	2.692	2.695

Loss/Rodded Unit Weight (C.A)

Test No			1	2	3
Weight of Mould + Sample	(gm)	(a)	16560	16600	16590
Weight of Mould	(gm)	(b)	4890	4890	4890
Weight of Sample	(gm)	(c)	11670	11710	11700
Volume of Mould	(gm)	(d)	7006	7006	7006
Unit weight of Sample	g/cc	(c/d)	1.666	1.671	1.670
Average	=		1.669		

Remarks: Rodded unit weight found= 1.682 gm/cc

= 1682kg/m³

Abrasion Test of Aggregate by Loss Angeles (Method AASHTO T-96)

Specimen No	No of Charges	No of Revolutions	Weight before test (gm)	Weight in grams after test			Loss in weight (gm)	Percent Wear	Average Value (%)
				Retained no No.12 Sieve	Passing through No.12 Sieve	Total Quantity Available			
1	11	500	5000	3380	1605	4985	15	32.1	32.1

Remarks: Grading -B = 19.5 mm to 12.5 mm Retained = 2500 gm, 12.5 mm to 9.50 mm = 2500 gm (Total = 5000 gm)

A.7 Standard technical specification limits of RHD

Characteristic	Test	Specification Limits
Coarse Aggregates		
➢ Los Angeles Abrasion	AASHTO T96	Less than 30%
➢ Aggregate Impact Value	BS 812	Less than 30%
➢ Aggregate Crushing Value	STP 7.7.1	Less than 30%
➢ Ten Percent Fines Value	STP 7.8.1	150 kN
➢ Broken Faces (Retained 4.75 mm sieve)-2 or more faces		75%
➢ Clay Lumps and Friable Particles	AASHTO T112	2% maximum
➢ Lightweight Pieces	AASHTO T113	1% maximum
➢ Magnesium Sulphate Soundness (5Cycles)	AASHTO T104	Maximum 12% loss
➢ Flakiness Index	BS 712: Part1: 1975 Para 7.3	25% maximum for all fractions
➢ Elongation Index	BS 712: Part1: 1975 Para 7.4	25% maximum for all fractions
➢ Water Absorption	AASHTO T85	2% maximum
➢ Adherent Coating on Aggregate after First Day Sieving on 0.75 mm sieve	AASHTO T11	0.5% maximum
➢ Coating and Stripping of Bitumen	AASHTO T182	Minimum 95% retained
Fine Aggregates		
➢ Clay Lumps and Friable Particles	AASHTO T112	3% maximum
➢ Lightweight Pieces	AASHTO T113	1% maximum
➢ Water Absorption	AASHTO T84	2% maximum
➢ Plasticity Index (passing 0.425mm sieve)	AASHTO T90	Less than 4%
➢ Coating and Stripping of Bitumen	AASHTO T176	More then 45
Combined Aggregates Gradation (%passing by weight)	AASHTO T27, T11	Sieve Size % Passing

Sieve Size	% Passing
20 mm	100
10 mm	90-100
5 mm	44-74
2.4 mm	28-58
1.18 mm	16-38
0.60 mm	10-27
0.30 mm	5-20
0.15 mm	3-14
0.075 mm	2-8

Note: STP= Tests as described in “Standard Test Procedures” of RHD, May 2001