Bachelor of Science in Civil and Environmental Engineering

Effects of Maximum Size of Brick Coarse Aggregate on Fresh and Hardened Properties of Concrete

Presented by

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Adnan Sakib
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Thesis Report Approval

The thesis titled "**Effects of Maximum Size of Brick Coarse Aggregate on Fresh and Hardened Properties of Concrete**" submitted by Fahim Ahmed Khan, Adnan Sakib, Shafakat Islam Shopnil; Student ID 145409, 145411 and 145426 of Academic Year 2017-2018 has been found as satisfactory and accepted as partial fulfillment of the requirement for the degree of Bachelor of Science in Civil and Environmental Engineering.

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Declaration of Candidate

It is hereby declared that this thesis/project report or any part of it has not been submitted elsewhere for the award of any Degree or Diploma.

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Table of Contents

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Abstract

Investigation was carried out to study the effects of maximum aggregate size (MAS) of brick coarse aggregate (10 mm) on fresh and hardened properties of concrete. Previous researches were conducted on the MAS of 12.5 mm, 19 mm, 25 mm, 37.5 mm and 50 mm (T. Uddin, 2017). This is the continuation of the previous work of lower MAS. For investigation, first class bricks were collected and broken into pieces to make coarse aggregate according to the gradation requirements of ASTM C 33. The aggregates were tested for specific gravity, absorption capacity, unit weight, and abrasion resistance. Cylindrical concrete specimens of diameter 100 mm and length 200 mm were made for MAS of 10 mm with varying sand to aggregate volume ratio (s/a) (0.40, 0.45 and 0.50), W/C ratio (0.45, 0.50, and 0.55), and cement content (375 kg/m^3 and 400 kg/m^3). A total of 18 different cases were considered and a total of 144 concrete specimens were made for testing. The specimens were tested for splitting tensile strength at the age of 28 days, and compressive strength, stress-strain curve, and Young's modulus at the age of 7 days and 28 days. Ultrasonic Pulse Velocity (UPV) through the specimens was measured using Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT).The rebound number on the specimen surface was also measured using a Schmidt hammer.

Results have revealed that for a higher cement content, smaller sized brick coarse aggregate (10.0 mm) give lower compressive strength and splitting tensile strength. But for a lower cement content, and lower W/C ratio, these properties tend to increase with an increase in maximum size of aggregate up to 37.5 mm. The compressive strength of concrete increases with an increase in s/a ratio from 0.40 to 0.45. Moreover, the UPV is lower for the MAS of 10.0 mm of brick coarse aggregate. Based on the experimental results, relationship between compressive strength and w/c ratio, tensile strength and w/c ratio, UPV, cement content and s/a ratio are proposed for MAS of 10.0 mm of brick aggregate.

CHAPTER 1: INTRODUCTION

1.1 General

Coarse aggregate plays an important role in concrete as it typically occupies over half of the volume of concrete (Meddah, 2010), and it is likely that changes in coarse aggregate properties can affect the fresh and hardened properties of concrete. The mechanical properties of coarse aggregate are often considered to impart strength to concrete. Moreover, physical properties of coarse aggregate like the maximum aggregate size (MAS), surface texture, shape, gradation etc. also influence concrete properties. To predict the behavior of concrete under general loading requires an understanding of the effects of these physical properties of aggregate as well. The understanding of the effects of maximum aggregate size (MAS) on concrete properties can lead to important findings in the research field of Concrete Technology. This understanding can only be gained through extensive testing and observation.

In Bangladesh, the most commonly used coarse aggregate is brick aggregate which is made by crushing bricks into brick chips. Bricks are often broken into pieces without considering the MAS that may influence the properties of concrete. Though coarse aggregate is used to occupy volume in concrete, use of larger size aggregate can reduce the cement content in concrete, which is largely responsible for shrinkage and creep (Ioannides and Jeff, 2006). On the other hand, larger size coarse aggregates lower the water demand resulting a decrease in the water/cement ratio (W/C), which gives strength to concrete (Neville, 2011). This is because as aggregate size increases, the surface area to be wetted decreases. Though several studies with contradictory conclusions have been conducted to find the optimum MAS of coarse aggregate to make concrete, no such study has been done on brick chips as coarse aggregate.

In light of the above discussion, it is expected that a study that investigates the effects of maximum aggregate size (MAS) of brick coarse aggregate on fresh and hardened properties of concrete is necessary. Thus, this study has been planned to

Investigate the effects of MAS of brick coarse aggregate on fresh and hardened properties of concrete. Another proposal of this study is to study the effects of sand to aggregate volume ratio and cement content on properties of concrete. With this view, a research project was undertaken in the Department of Civil and Environmental Engineering (CEE) of Islamic University of Technology (IUT), under the supervision of Prof. Dr. Md. Tarek Uddin, to study the variation of the fresh properties (e.g. workability), as well as hardened properties (e.g. compressive strength, tensile strength, and Young's Modulus) of concrete with different MAS of brick aggregate. This investigation also adopted means to study some non-destructive test (NDT) methods, such as, determining Ultrasonic Pulse Velocity (UPV) through concrete specimen and determining rebound number using Schmidt hammer and tried to correlate the results from NDT with concrete strength. This investigation also focused on understanding the failure pattern of concrete made with different MAS, sand to aggregate volume ratio (s/a), cement content, and W/C ratio. The study was undertaken with MAS of 12.5 mm, 19 mm, 25 mm, 37.5 mm & 50 mm. This is extended part where MAS of brick coarse aggregate is 10 mm.

1.2 Background

In Bangladesh brick chips are most widely used aggregate in construction (Mohammed, 2014). But proper investigation on the effects of Mas of brick aggregate on properties of concrete is still limited. Thorough investigation on the effects of MAS of coarse aggregate on fresh and harden properties of low-strength, high strength and traditional concrete were done by researchers; and the findings show that it is important to know how MAS influences the structural and durability of concrete. Proper investigations were carried out by Department of Civil and Environmental Engineering (CEE) of Islamic University of Technology (IUT), under the supervision of Prof. Dr. Md. Tarek Uddin, to find out the effects of MAS of brick aggregate on the properties of concrete.

Moreover, in Bangladesh, the most widely used maximum size of coarse aggregate in construction is often termed as 20 mm down, i.e., the MAS of aggregate is 20.0 mm. But, literature review suggests, use of smaller or larger maximum sizes can give better strength to structural concrete (Cetin and Carrasquillo, 1998). Therefore, this study has been planned to find the effect of maximum size of brick coarse aggregate on properties of concrete.

1.3 Objectives of the Study

The objectives of this study are as follows:

1.! To understand the variation of fresh and hardened properties of concrete with the variation of maximum size of coarse aggregate.
2.! To understand the effects of variation of s/a ratio and cement content on properties of concrete.
3.! To study the effects of maximum aggregate size on ultrasonic pulse velocity through concrete.

1.4 Methodology

This study investigated the effects of MAS of brick aggregate on fresh and hardened properties of concrete. For investigation, first class bricks were collected from local market and broken manually into maximum sizes of 12.5 mm, 10 mm, 4.75 mm and 2.36 mm. To comply with the grading requirements specified by ASTM C 33, brick aggregate of sizes 9.5 mm and 4.75 mm were also sieved. The aggregates were tested for specific gravity, absorption capacity, abrasion resistance, and unit weight. The mixture proportion was prepared with varying W/C ratios of 0.45, 0.50, and 0.55; s/a ratio of 0.40 and 0.45; and cement contents of 375 kg/m^3 and 400 kg/m^3.

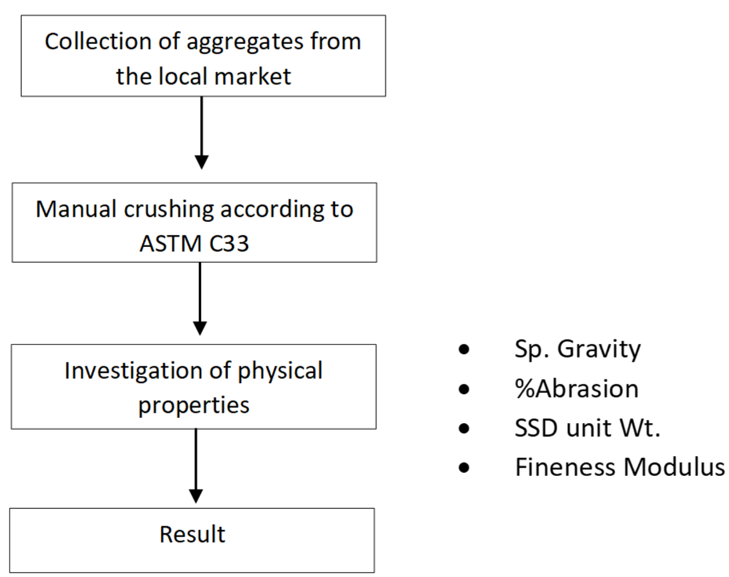
144 cylindrical concrete specimens of 100 mm diameter and 200 mm height were made for MAS of 10 mm.

Prior to compressive strength test, UPV was measured on unloaded wet specimens by using Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT) according to ASTM C 597 (2003). UPV was obtained by measuring the time, in microseconds (μs), that an ultrasonic pulse took to travel between the transmitter and the receiver across the length of each concrete specimen, using the PUNDIT. The specimen length was divided by the time recorded to calculate the pulse velocity. The transducers used were 75 kHz (the range specified by ASTM C 597 is 20 to 100 kHz). A thin couplant (solid vaseline) was used in between the transducers and concrete to ensure good contact between the specimen surface and the receiver.

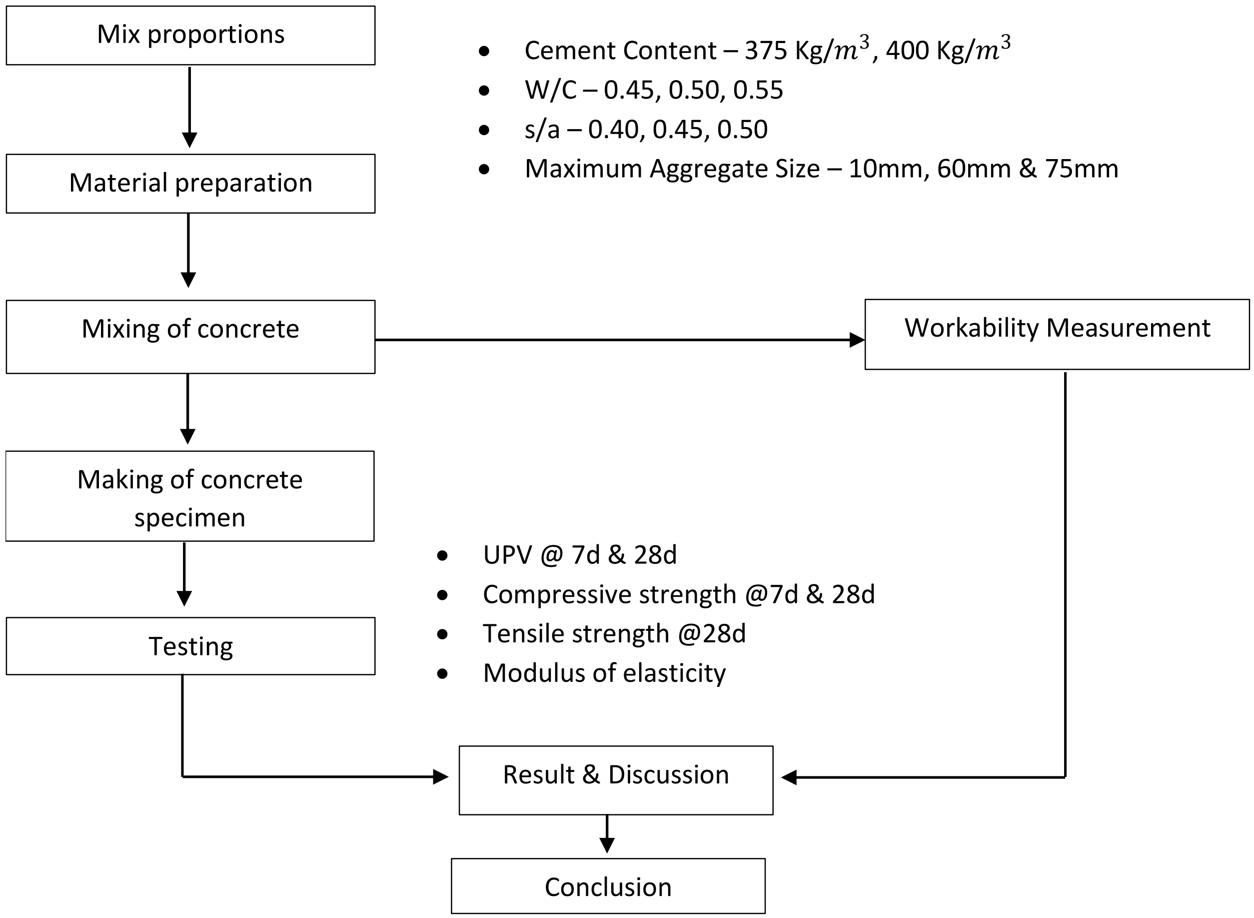
The rebound number on specimen surfaces was also measured according to ASTM C 805 (2003) using a Schmidt hammer. Careful selection and preparation of the concrete surface to be tested was ensured for the test and a fixed amount of energy was applied by pushing the hammer against the test surface. The plunger was allowed to strike perpendicularly to the surface, as the angle of inclination of the hammer affects the results. After impact, the rebound number was recorded by taking at least 10 readings from each tested area.

1.5 Research Flow Diagram

Physical Properties of Aggregate – Research Flow



Fresh and Hardened Properties of Concrete – Research Flow



CHAPTER 2: LITERATURE REVIEW

2.1 General

This chapter discusses concrete in general as well as the constituents of concrete. It emphasizes on coarse aggregate as a major constituent of concrete, and it's importance in ensuring concrete strength and durability. This chapter also discusses the effects of different maximum sizes of coarse aggregate on properties of concrete based on literature review. Literature review on some non-destructive tests of concrete are also presented in this chapter.

2.2 Aggregate in Concrete as a Constituent

Concrete is a composite material which is composed of coarse and fine granular materials called aggregates or filler embedded together in the form of a matrix with the help of the cement or binding material that fills the space between the aggregates particles and glues them together. Other materials like fly ash or ground granulated blast furnace slag may also be used as binding material. Coarse aggregates are usually obtained from natural rocks, either crushed stones or natural gravels, and fine aggregates are usually river sand. Water is added in the mix to initiate the binding process, as cement is a hydraulic material which gives strength once it starts reacting with this mixing water.

As at least 75% of the volume of concrete is occupied by aggregate, it's quality and different physical and mechanical properties are of paramount importance. Not only may the aggregate limit the strength of concrete, but the properties of aggregate greatly affect the durability and structural performance of concrete. Aggregate was originally viewed as an inert material to fill up the voids in concrete, and for economic reasons. However, it is possible for aggregates to influence the performance of concrete as a whole (Neville, 2011).

2.3 General Classification of Aggregate

Aggregates can be classified based on their origin. Aggregates can come from natural sources, or may be derived from industrial by-products. Natural aggregates may be basalt, granite, limestone, gabbros, quartzite, schist, shingles etc.; whereas, industrial aggregates can be made from bricks, iron slag, plastic, or recycled concrete as aggregate.

But, aggregates are usually classified based on their particle size. Aggregates passing through ASTM #4 sieve (4.75 mm) are termed as fine aggregate, while those retained on the sieve are termed as coarse aggregate.

2.4 Strength of Aggregate

The compressive strength of concrete clearly depends on the strength of it's major constituent – aggregate. Since it is difficult to test the crushing strength of individual aggregate particle, the required information has to be obtained from indirect test like crushing value of bulk aggregate, or resistance to abrasion. Inadequate strength of aggregate represents a limiting case because the physical and mechanical properties of aggregate have some influence on the strength of concrete. Walker and Bloem (1956) compared concretes made with different aggregates and observed that the influence of aggregate on the strength of concrete is qualitatively the same whatever the mix proportion, and is the same regardless of whether the concrete is tested in compression or tension.

In general, the strength and Young's modulus of aggregate depend on it's composition, texture, and structure. Though, the Young's modulus of aggregate isn't often determined, it is, however, not unimportant, because the Young's modulus of concrete is generally higher for aggregates with higher Young's modulus. It affects the magnitude of creep and shrinkage of concrete as well (Neville, 2011). On the other hand, aggregate of moderate or low strength and Young's modulus can be valuable in preserving the integrity of concrete.

2.5 Types of Aggregate

" Giaccio et al. (1992) studied the effects of coarse aggregate type (basalt, granite and limestone) on the mechanical properties of high-strength concrete. Compressive and flexural strength, modulus of elasticity, and stress-strain behavior were analyzed for concrete, mortar, and rock. They found that weaker aggregates, such as limestone, reduce compressive strengths significantly, since the concrete strength is limited by the aggregate strength. However, aggregate type did not affect flexural strength. Comparing fractured surfaces for the concretes show that nearly all of the exposed coarse aggregate particles are fractured in the limestone mixes. However, cracks form primarily at the matrix-aggregate interface, and only a few aggregate particles are fractured in the basalt mix. The highest modulus of elasticity was achieved in the basalt mix, followed by limestone and granite. The basalt mix also showed the highest compressive strength, followed by granite and limestone. The granite mix had the best elastic compatibility between the matrix and aggregate, but the granite had significantly lower tensile strength than the basalt.

Giaccio et al. (1993) compared fracture energies for concretes with a wide range of compressive strengths. Strength levels from 22 MPa to 100 MPa, aggregate type (basalt, limestone and gravel), aggregate size (8 mm, 16 mm and 32 mm), and aggregate surface roughness were included as variables in the study. Conclusions were drawn that concretes with weaker aggregates, such as limestone, yield lower compressive strengths than concrete with stronger coarse aggregate.

In Bangladesh, brick chips, crushed stone, shingles, jhama bricks are commonly used as coarse aggregate in construction. Brick chips is the most widely used coarse aggregate (Mohammed, 2014) and thus extensive study on the use of brick chips as coarse aggregate in concrete is necessary. Mohammed et al (2011) conducted extensive research on brick aggregate concrete, and concluded that, with similar abrasion value, brick aggregate concrete gives higher strength compared to the same with stone aggregate concrete. Moreover, concrete strength from 21 MPa to 25 MPa can be obtained using recycled coarse aggregate.

2.6 Maximum Aggregate Size

The effect of maximum aggregate size (MAS) on the fresh and hardened properties of concrete has been a major concern for researcher for quite a long time. The grading or size distribution of aggregate is an important characteristic because it determines the paste requirement for workable concrete (Tumidajski and Gong, 2006). The required amount of the concrete paste is dependent upon the amount of void space that must be filled and the total surface area that must be covered. When the particles are of uniform size the spacing is the greatest but when a range of sizes is used the void spaces are filled, the less workable the concrete becomes, and therefore a compromise between workability and economy is necessary.

The size of aggregate used in concrete ranges from tens of millimeters down to particles less than one-tenth of a millimeter in cross-section. The maximum size used may actually vary, but in any mix, particles of different sizes are incorporated as specified by ASTM C 33.

Oliveira et al. (2006), Tumidajski and Gong (2006) concluded that aggregates strongly influence concrete's fresh and hardened properties, mix proportions, and economy. Grading limits and MAS are specified since they affect the amount of aggregate used, cement and water requirements, workability, pumpability, and durability of concrete. Moreover, MAS has a significant influence on the fracture properties of the concrete matrix as well. An optimum size of aggregate gives a workable and dense concrete mix as well as improves the performance of concrete. The increase in fracture toughness with increasing aggregate size is the result of the increased resistance to propagating crack.

There is much controversy concerning the effects of coarse aggregate size on concrete. Some research (Strange and Bryant 1979, Nallathambi et al. 1984) has shown that there is an increase in strength and fracture toughness with an increase in aggregate size. However, Gettu and Shah (1994) have stated that, in some high-strength concretes where the coarse aggregates rupture during fracture, size is not expected to influence the strength and fracture parameters. Tests by Zhou, Barr, and Lydon (1995) show that compressive strength increases with an increase in coarse aggregate size. However, most other studies disagree.

Walker and Bloem (1960) studied the effects of coarse aggregate size on the properties of normal-strength concrete. Their work demonstrates that an increase in aggregate size from 10 mm to 64 mm results in a decrease in the compressive strength of concrete, by as much as 10 percent; however, aggregate size seems to have negligible effects on flexural strength. The study also shows that the flexural-to-compressive strength ratio remains at approximately 12 percent for concrete with compressive strengths between 35 MPa and 46 MPa.

Bloem and Gaynor (1963) studied the effects of size and other coarse aggregate properties on the water requirements and strength of concrete. Their results confirm that increasing the maximum aggregate size reduces the total surface area of the aggregate, thus reducing the mixing water requirements; however, even with the reduction in water, a larger size aggregate still produces lower compressive strengths in concrete compared to concretes containing smaller aggregate. Generally, in lower strength concretes, the reduction in mixing water is sufficient to offset the detrimental effects of aggregate size. However, in high-strength concretes, the effect of size dominates, and the smaller sizes produce higher strengths.

Cordon and Gillespie (1963) also reported changes in concrete strength for mixes made with various W/C ratios and aggregate sizes. They found that, at W/C ratios from 0.40 to 0.70, an increase in MAS from 19 mm to 38 mm decreases the compressive strength by about 30 percent. They also concluded that, in normal-strength concrete, failure typically occurs at the matrix-aggregate interface and that the stresses at the interface which cause failure can be reduced by increasing the surface area of the aggregate (decreasing the aggregate size). If the strength of the concrete is sufficiently high, such as with high-strength concrete, failure of the specimen is usually accompanied by the fracture of aggregate particles; therefore, in high-strength concrete, compressive strength depends on aggregate strength, not necessarily aggregate size.

Vu et al. (2011) conducted experimental investigation that concerned the effect of coarse aggregate size and cement paste volume on concrete behavior under high triaxial compression loading. Findings of the study suggested that the concrete strength slightly increases as the coarse aggregate size increases as observed under unconfined compression. Moreover, the coarse aggregate size has a significant influence on concrete strain limit-state at high confinement, the higher the coarse aggregate size, the lower is the mean stress level corresponding to concrete strain limit-state. At very high confinement levels and at very high deviatoric stress levels, the concrete axial tangent stiffness increases as the coarse aggregate size is reduced.

In light of the controversy, this study is aimed at improving the understanding of the role that brick coarse aggregate plays in the fresh and hardened properties of concrete. Furthermore, research focusing on the effect maximum size of brick coarse aggregate, is still limited and its effect is not yet well established. The present study investigates the influence of maximum size of brick coarse aggregate, which is the most commonly used aggregate in Bangladesh, on the fresh and hardened properties of concrete.

2.7 Cement Content

Cement, the binder of concrete components, has been a major focus of researchers for quite long, as cement content is perceived to control concrete strength. The term "cement content" refers to the mass of cement per m^3 of concrete. Literature suggests that with an increase in cement content, the strength of concrete increases. But use of excess cement can cause shrinkage of concrete and result in subsequent decrease in the strength of concrete (Neville, 2011). Based on this perception, a minimum cement content is often specified that may exceed the amount needed to achieve the desired strength and durability. This excessive amount should be minimized to prevent its negative impact on costs and environment because:

- cement is the most expensive component in concrete
- cement contributes about 90% of the CO_2 burden of a concrete mixture
- cement production emits approximately 5% of global carbon dioxide (CO_2) and 5% of global energy consumption (Yurdakul, 2010)

Previous studies (Wasserman et al., 2009; Popovics, 1990) suggest that high cement content in a mixture does not contribute to greater strength than the required design strength. On the contrary, high cement content causes the concrete to become sticky as well as have shrinkage and cracking problems. Therefore, cement content should be balanced to achieve performance while minimizing risk of these problems. Despite the published studies and documentation, there continues to be a misconception that more cement in a mix design means a better performing mix.

2.8 Sand to Aggregate Volume Ratio

The technical literature gives quite contradictory data on the effect of sand to aggregate volume ratio (s/a) on strength of concrete. Su et al. (2002) stated that, the s/a ratio is an important parameter and the rheological properties such as, the compressive and tensile strength of concrete increase with an increase in the s/a ratio. Moreover, Su et al. (2002) and Yang and Huang (1998) both concluded that the Young's modulus of concrete is not significantly affected by the change in s/a ratio.

However, Sizov (1997) stated that, an excessive amount of sand compared with the optimal causes a high consumption of cement, and its too low content leads to segregation and bleeding of concrete. Thus, it is important to study the strength of concrete for various s/a ratios and find the optimum s/a ratio for brick aggregate concrete.

2.9 Water to Cement Ratio

In usual engineering practice, the strength of concrete is assumed to depend primarily on two factors – the W/C ratio and the degree of compaction. The influence of W/C ratio on the strength of concrete has been a topic of study for researchers for quite long. In 1919, Duff Abrams proposed that when concrete is full compacted, it's strength can be taken to be inversely proportional to the W/C ratio.

From time to time, the W/C ratio rule of Duff Abrams has been criticized for not being sufficiently fundamental. Nevertheless, in practice, the W/C ratio is the largest single factor in the strength of concrete (Neville, 2011). Researchers have agreed that, with increase in the W/C ratio, the workability of fresh concrete increases, but the strength of hardened concrete is reduced. The nature of the curve representing W/C ratio as the abscissa and strength as the ordinate is still not beyond controversy. Neville (1959) suggested that the relationship between the strength and W/C ratio is approximately linear in the range of W/C ratio between 0.20 and 0.43. This linear relationship has also been confirmed by later research by Alexander and Ivanusec (1982) and by Kakizaki et al. (1992). But the relations discussed here may not be exactly precise. Hummel (1959) suggested that, as an approximation, the relation between logarithm of strength and the natural value of the W/C ratio can be assumed to be linear.

2.10 Ultrasonic Pulse Velocity

Assessments of concrete structures using non-destructive techniques have interested engineers all over the world; thus many non-destructive techniques have been adopted to evaluate concrete performance (Bungey, 1989). Several non-destructive techniques are available for concrete evaluation. Some of these techniques include radar, pulse velocity, acoustic emission, radiography, infrared thermography, and many others (Limaye, 1990). One of the earliest non-destructive techniques used to evaluate concrete strength is the ultrasonic pulse velocity (UPV) technique. In recent years, ultrasonic techniques have become popular within the civil engineering industry for a wide range of applications including the evaluation of concrete structures and pavements. A reviewing of the literature indicates that ultrasonic waves are used mainly to predict concrete strength. However, this method can also be used to detect the internal defects of concrete such as cracks, delamination, and/or honeycombs (Malhotra and Carino, 1991).

Ultrasonic waves are mechanical waves with frequencies in excess of 20 kHz (ASTM C 597). These waves behave essentially the same as audible sound waves. Since ultrasonic waves do not travel through air or vacuum, couplants such as grease are needed to fill the voids between transducers and concrete surface in order to transmit or receive the waves (Galan 1990).

Scattering of ultrasonic waves into concrete is due to the heterogeneity of the concrete structure. The transition zones between aggregate and hydraulic cement paste tend to reflect part of ultrasonic waves. In addition, the mode of conversion at aggregate boundaries tends to occur because of slight differences in acoustic velocities between the aggregate and hydraulic cement paste. Gaydeck et al. (1992) studied the attenuation and propagation of ultrasonic waves in concrete using frequencies in the range of 25–250 kHz. The results of the study indicated that attenuation characteristics of ultrasonic waves could give an idea about aggregate size distribution if careful analysis is performed.

Wave velocity and energy were used in another study to evaluate concrete. The results indicated that wave velocity has better capability to detect differences between Portland Cement (PC) concretes than that of wave energy (Al-Akhras, 1995). Facaoaru

(1969) reported that UPV through concrete is directly proportion to concrete strength and age.

Abo-Qudais (2005) studied UPV through concrete made with limestone aggregate of MAS 4.75 mm, 12.5 mm, 19.3 mm, and 25.0 mm. Abo-Qudais (2005) concluded that, with an increase in MAS, the UPV decreases. However, the magnitude of the UPV depends on the W/C ratio and as the W/C ratio increases, the influence of aggregate became more significant. He also concluded that, larger the aggregate size the higher will be the local water–cement ratio in the transition zone, consequently, the higher capillary voids in the transition zone, leading to reduce the ultrasound velocity into the concrete. On the contrary, Solís-Carcaño and Monero (2008) also conducted non-destructive evaluation of limestone aggregate concrete and concluded that with an increase in the transition zone, the path for ultrasonic wave becomes more tortuous and leads to lower UPV through concrete made with smaller sized aggregates. However, these findings are yet to be justified for brick coarse aggregates.

Mathematical models having the capability to predict UPV in concrete were also developed based on experimental studies (Lin et al., 2003). These models indicated that the changes in the ratio of fine aggregate volume to the total aggregate have little influence on pulse velocity. Also, pulse velocity of concrete decreased by increasing the volume of cement paste, especially for concrete with high water–cement ratio. Relationships between UPV and strength of brick aggregate concrete are yet to be established.

Moreover, the relationship between ultrasonic wave velocities measured using direct and indirect methods was evaluated by Yaman et al. (2001). The results indicated that the direct and indirect methods can be used interchangeably in evaluating the properties of the concrete.

From literature review, it is understood that the velocity of ultrasonic pulses traveling in a solid material depends on the density and elastic properties of that material. Thus MAS, aggregate gradation, W/C ratio, s/a ratio, cement content, and curing time are expected to have significant effects on the ultrasonic measurements. Many studies which evaluate concrete properties using ultrasonic techniques have been performed. Most of these studies either did not consider or failed in evaluating the effect of concrete mix parameters like MAS, s/a ratio, cement content, W/C ratio on the propagation of ultrasonic waves in the concrete. More importantly, no study on the non-destructive evaluation of MAS of brick coarse aggregate was found.

CHAPTER 3: EXPERIMENTAL METHOD

3.1 Introduction

In this chapter, the experimental method of the study is summarized. It includes the mix proportion of concrete, cases investigated in the study, collection and preparation of materials, material properties, experimental setup, sample preparation, curing, and testing.

3.2 Concrete Mixture Proportion and Cases Studied

100 mm by 200 mm cylindrical concrete specimens were made with varying s/a ratio (0.40, 0.45 and 0.50); W/C ratio (0.45, 0.50, and 0.55), and cement content (375 kg/m^3 and 400 kg/m^3) for MAS of 10.0 mm. A total of 18 independent cases and 144 cylindrical specimens were investigated; the mixture proportions of all 18 cases are summarized in **Table 3.1**. The notations used for the cases are explained at the bottom of **Table 3.1**

Table 3.1. Mixture proportion of concrete

Maximum Aggregate size (mm)	S/A	Cement content (kg/m^3)	W/C	Case ID	Unit content (kg/m^3)			
					Cement	Water	Sand	Aggregate
10	0.4	375	0.45	A10.0SA0.40C375WC0.45	375	169	676	953
			0.5	A10.0SA0.40C375WC0.50	375	188	658	927
			0.55	A10.0SA0.40C375WC0.55	375	206	640	901
		400	0.45	A10.0SA0.40C400WC0.45	400	180	658	926
			0.5	A10.0SA0.40C400WC0.50	400	200	638	898
			0.55	A10.0SA0.40C400WC0.55	400	220	618	871
	0.45	375	0.45	A10.0SA0.45C375WC0.45	375	169	761	873
			0.5	A10.0SA0.45C375WC0.50	375	188	740	849
			0.55	A10.0SA0.45C375WC0.55	375	206	720	826
		400	0.45	A10.0SA0.45C400WC0.45	400	180	740	849
			0.5	A10.0SA0.45C400WC0.50	400	200	718	823
			0.55	A10.0SA0.45C400WC0.55	400	220	696	798
	0.5	375	0.45	A10.0SA0.50C375WC0.45	375	169	846	794
			0.5	A10.0SA0.50C375WC0.50	375	188	823	772
			0.55	A10.0SA0.50C375WC0.55	375	206	800	751
		400	0.45	A10.0SA0.50C400WC0.45	400	180	822	772
			0.5	A10.0SA0.50C400WC0.50	400	200	797	749
			0.55	A10.0SA0.50C400WC0.55	400	220	773	726

Age	**Cylindrical Concrete Specimen**		
	Compressive strength	Tensile strength	UPV
7 days	3	_	3*
28 days	3	2	3*
Total	6	2	

Specimens per case of cylindrical concrete specimens = 6 + 2 = 8 Nos.
Total number of cases = 18
Total number of specimens = 18*8 = **144 Nos.**

The mix proportion used in this study was done in weight basis and the unit contents of the ingredients of concrete were assumed to sum up to 1 m^3 of concrete and can be correlated by the following equation:

$$\frac{C}{G_C\,\gamma_W} + \frac{S}{G_S\gamma_W} + \frac{A}{G_A\gamma_W} + \frac{Air\ (\%)}{100} = 1 \qquad \textbf{(3.1)}$$

Where,

C = Unit content of cement (kg/m^3 of concrete)

S = Unit content of fine aggregate (kg/m^3 of concrete)

A = Unit content of coarse aggregate (kg/m^3 of concrete)

W = Unit content of water (kg/m^3 of concrete)

γ_W = Unit weight of water ((kg/m^3)

G_C= Specific gravity of cement

G_S = Specific gravity of fine aggregate (SSD)

G_A = Specific gravity of coarse aggregate (SSD)

G_W = Specific gravity of water

Air (%) = Percentage of air in concrete (assumed at 2% without air entraining agent)

3.3 Preparation of Materials

Before casting, the materials were prepared to satisfy the specifications of ASTM C 39 (2003). For each day of casting, the total number of cylinders to be made was calculated. Then on the basis of the mixture proportion shown in **Table 3.1**, and the material properties shown in **Table 3.4** and **Table 3.5**, the total amount of material required for each day of casting was calculated on a weight basis. Prior to casting, both coarse and fine aggregates were brought to saturated surface dry (SSD) condition to ensure that the W/C ratio of the mix remained as specified by the mixture proportion. The W/C ratio of the mix was monitored carefully.

3.3.1 Coarse Aggregate

First class bricks were collected from local market and broken manually to give brick chips having MAS of 12.5 mm, 10.0 mm, 4.75 mm, 2.36 mm. Prior to casting, these coarse aggregates were sieved separately to satisfy ASTM C 33 (2003) and were batched separately for different MAS. Once the batch was prepared, the aggregates were kept in submerged condition for 24 hours and before casting, were rubbed with a clean cloth to eliminate excess water from the aggregate surface and ensure SSD condition of the aggregates.

3.3.2 Fine Aggregate

The fine aggregate used in this study was Sylhet sand and was procured from local market. Prior to casting, the sand was sieved through No. 4 (4.75 mm) sieve to separate any coarse aggregate from the mix and then washed to avoid mud and other organic materials. Sufficient water was mixed with sand several hours before casting and lump of sand was made in the palm of the hand. If the lump broke when the palm was stretched, the sand was considered to be in SSD condition. Once SSD sand was prepared, it was stored in air tight bags to avoid moisture loss.

3.4 Material Properties

The properties of materials used were evaluated before casting by testing them in the laboratory according to specifications. The aggregates used in this study were tested for specific gravity, absorption capacity, abrasion resistance, gradation, and unit weight. The specifications followed are summarized in **Table 3.2**.

Table 3.2. Specifications followed to test material properties

Name of the property evaluated	Specification/guideline followed
Specific gravity	ASTM C 127 (for coarse aggregate) ASTM C 128 (for fine aggregate)
Absorption capacity	ASTM C 127 (for coarse aggregate) ASTM C 128 (for fine aggregate)
Abrasion resistance	ASTM C 131
Unit weight	ASTM C 29
Gradation	ASTM C 33
Fineness Modulus	ASTM C 136

3.4.1 Coarse Aggregate

To study the effects of maximum aggregate size (MAS) of brick coarse aggregate, five MAS were used in this study – 12.5 mm, 19.0 mm, 25.0 mm, 37.5 mm, and 50.0 mm. First class bricks were procured from local market, and manually broken into pieces of desired size. The gradation of brick chips for different MAS was controlled as per ASTM C 33 (2003). The gradation followed in this study is shown in **Table3.3**, and the gradation curves are shown in **Fig..1**.

The coarse aggregates were tested for specific gravity, absorption capacity, abrasion resistance, unit weight, and fineness modulus (FM). The material properties of the coarse aggregates are summarized in **Table 3.4**. From the gradation shown in **Table 3.3**, it is evident that, with an increase in MAS, the amount of smaller sized aggregates is reduced. Thus the voids formed by larger aggregates are often left void due to the absence of small aggregates, which results in a reduction of unit weight of aggregate with an increase in MAS as shown in **Table 3.4**.

3.4.2 Fine Aggregate

For this study, locally available Sylhet sand was used as fine aggregate. Prior to casting, the fine aggregate was tested for specific gravity, absorption capacity, unit weight, and fineness modulus (FM). The material properties of fine aggregate are summarized in **Table 3.5**.The FM of 2.52 is the natural FM of the sand, and the natural gradation satisfies ASTM C 33 – 03 specifications, as shown in **Figure 3.2.**

3.4.3 Cement

CEM Type II A–M cement was used in this study that conforms to BDS EN 197 – 1: 2000, and ASTM C595. The composition of the mineral components is given in **Table 3.6** (as specified by the manufacturer). It is manufactured by inter-grinding three major mineral components – Pulverized Fuel Ash (PFA), Blast Furnace Slag, and Limestone with common raw materials, clinker, and gypsum.

3.4.4 Water

Water used in this study for concrete mixing and curing was potable tap water whose unit weight was 1000 kg/m^3.

Table 3.3. Gradation of coarse aggregate (according to ASTM C 33)

Nominal size	Amounts finer than each laboratory sieve, Mass percent			
	12.5 mm	**9.5 mm**	**4.75 mm**	**2.36 mm**
12.5 to 2.36 mm	100	85	15	0

Table 3.4. Properties of coarse aggregate

Aggregate Type	Specific Gravity	Absorption Capacity (%)	Abrasion (%)	SSD Unit Weight(kg/m3)	Fineness Modulus
Brick Coarse Aggregate	1.93	17.12	39	1172	It is to be controlled by ASTM c33

Table 3.4. Properties of coarse aggregate

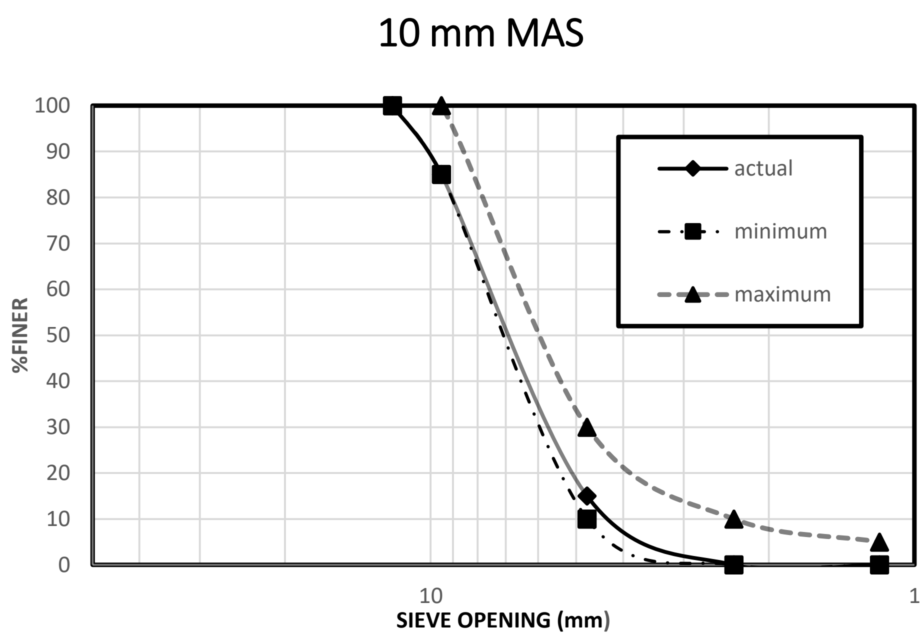


Fig. 3.1. Gradation of coarse aggregate

Aggregate Type	Specific Gravity	Absorption Capacity (%)	Abrasion (%)	SSD Unit Weight(kg/m3)	Fineness Modulus
Sylhet sand	2.53	4.25	33	1593	2.31

Table 3.4. Properties of fine aggregate.

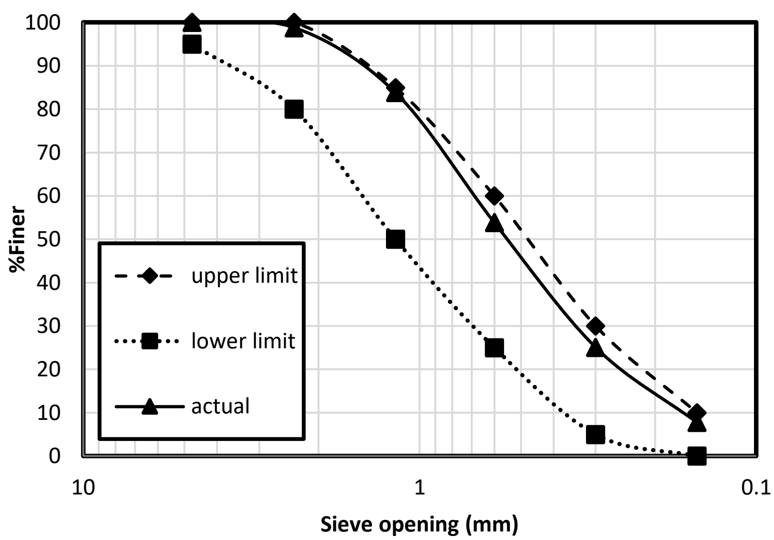


Fig. 3.2. Gradation of fine aggregate

Table 3.6. Composition of cement

Component	Percentage
Clinker	80–94%
Slag, Fly Ash, and Limestone	6–20%
Gypsum	0–5%

3.5 Experimental Setup

After casting of concrete specimens, they were cured initially for 24 hours by covering the cylindrical molds with wet clothes and polythene to prevent moisture loss. The specimens were demolded after 24 hours of casting, followed by curing under water till the age of testing according to ASTM C 31.

The strain of concrete specimens was measured by a strain measurement setup of gauge length 100 mm with two dial gauges. The stress of concrete at strain level 0.0005 was used to determine the Young's modulus of concrete. The splitting tensile strength of concrete was tested at 28 days. The failure surfaces of broken concrete specimens were also checked carefully after crushing of the concrete cylinders to corroborate the findings of this investigation.

Prior to compressive strength test, UPV was measured on unloaded wet specimens by using Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT) according to ASTM C 597 (2003). The rebound number on concrete specimen was measured using Schmidt Hammer according to ASTM C 805 (2003).

3.6 Sample Preparation

3.6.1 Mold Preparation

For studying the effects of MAS of brick coarse aggregate, cylindrical molds of diameter 100 mm and height 200 mm were used for 10.0 mm MAS. Prior to casting, the cylinders were made air-tight by adjusting the screws, and the inner surface was lubricated by using grease according to ASTM C 31 (2003).

3.6.2 Casting and Mixing of Fresh Concrete

For casting of fresh concrete, mixture machine available in the Concrete Lab of Islamic University of Technology (IUT) was used. Trial mix was done for every case before the final mix. The mixing procedure followed in this study was quite different than the conventional mixing technique followed in construction sites in Bangladesh. The conventional technique is to put all the ingredients (cement, sand, coarse aggregate, water) simultaneously in the mixture. But in fact, it is not the best way to attain the desired strength of concrete. To ensure the quality of concrete, the following steps were followed to mix concrete:

Step 1: The inner surface of the mixing machine was wiped with a moist piece of cloth, so that the surface wouldn't absorb the mixing water.

Step 2: Half of the sand was poured into the machine and spread to give a notable bed like surface for the cement to put upon it.

Step 3: Cement was then placed on the sand bed.

Step 4: Rest of the sand was then poured on top of the cement.

Step 5: The sand and cement was then mixed for 30 seconds.

Step 6: Water was then poured into the sand-cement mixture carefully to avoid accidental spillage from the mixture machine. The machine was let to rotate and mix the cement-sand paste for one and a half minute more.

Step 7: The coarse aggregate was then introduced inside the mixing machine and the mixing was continued for further 3 minutes.

The total mixing time was 5 minutes. After five minutes, the concrete mix was poured on a non-absorbent sheet to continue with the slump test and casting procedure simultaneously.

3.6.3 Slump Test

Slump is a term used to describe how consistent a concrete sample is. The test also determines the workability of concrete, i.e. how easy it is to handle, compact, and mold concrete. The slump test of concrete in this study was done according to ASTM C 143 (2003).

A sample of freshly mixed concrete was placed and compacted by rodding with a tamping rod, in a mold shaped as the frustum of a cone. The tamping rod was a round, straight steel rod, 16mm in diameter and approximately 600 mm in length, having the tamping end rounded to a hemispherical tip, the diameter of which was 16 mm. The mold was made of non-absorbent metal that wasn't readily attacked by the cement paste. The metal was not thinner than 1.5 mm. The mold was in the form of a frustum of a cone with a base of 200 mm in diameter, a top of 100 mm in diameter, and a height of 300 mm. After placing and compacting the concrete, the mold was raised, and the concrete was allowed to subside. The vertical distance between the original and displaced position of the center of the top surface of the concrete was measured and reported as the slump of the concrete.

Concrete was poured into the mold in three layers of approximately equal volume, and each layer was tamped 25 times with the tamping rod.

3.6.4 Casting of Concrete Samples

In this study, concrete cylindrical specimens of 100 mm and height 200 mm were made. The specifications followed are briefly stated below. The cylindrical samples were made according to ASTM C 31 (2003).

Tamping rod of diameter 10 mm and length 300 mm was used to compact concrete cylinders of diameter 100 mm and height 200 mm in two layers.First of all, the concrete sample was placed in the cylinder mold by moving the sampling tool used to pour concrete around the perimeter of the mold, to ensure even distribution and minimize segregation. Each layer of concrete was rodded 25 times with the hemispherical end of the tamping rod. The bottom layer was rodded throughout its depth. The rodding was distributed uniformly over the cross section of the mold. For each upper layer, the tamping rod was allowed to penetrate through the layer being rodded, and into the layer below by approximately 25 mm.

After rodding each layer, the outside of each mold was tapped lightly 10 – 15 times with a hammer, to close any holes left by rodding and to release any large air bubbles that may have been trapped. After tapping, each layer of the concrete along the side of each mold was scaled with a steel scale. Under filled molds were adjusted with representative concrete during consolidation of the top layer. After consolidation, excess concrete from the surface was stroked off with a trowel.

3.6.5 Curing of Specimen

The curing of specimens was done according to ASTM C 192 (2003). To prevent the evaporation of water from the unhardened concrete, each specimen was immediately covered with a wet burlap and a non-absorptive polythene sheet on top of the wet burlap. This initial curing of the specimens continued until the samples were demolded.

Each specimen was demolded after 24 hours of casting and taken immediately for moist curing. All specimens were moist cured at 23.0 ± 2^0 C from the time of the molding until the moment of test. Each specimen was placed in a curing bath so as to allow free water on entire surface area of the specimen. This final curing of each specimen continued until the day of testing.

3.7 Testing

The properties of hardened concrete were evaluated by means of both destructive and non-destructive testing. In destructive tests (DT), a specimen is completely destroyed by applying pressure to evaluate the concrete strength, e.g. compressive strength, tensile strength, Young’s modulus, and stress-strain curve. In non-destructive tests (NDT), the specimen strength is determined without damaging the specimen. In this study, concrete properties were evaluated by means of NDTs like Ultrasonic Pulse Velocity (UPV) test and Schmidt hammer.

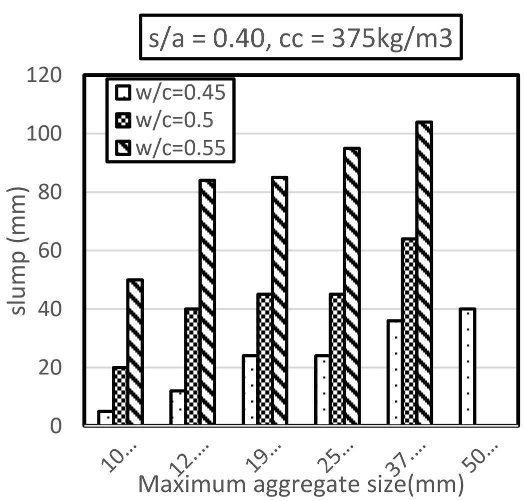
CHAPTER 4: RESULTS AND DISCUSSIONS

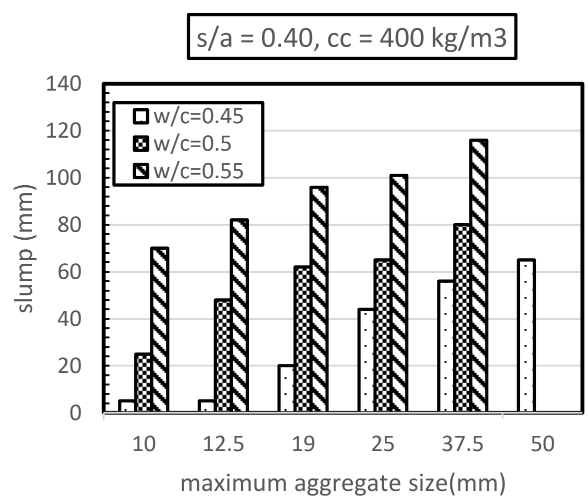
4.1 General

In this chapter, the results obtained throughout the investigation are summarized and discussed. The effects of MAS of brick aggregate concrete on compressive strength, splitting tensile strength, Young's modulus, and UPV are discussed. The effects of s/a ratio and cement content on compressive strength and splitting tensile strength are also discussed.

4.2.1 Workability of Concrete

The effect of MAS of brick aggregate on workability of concrete for different s/a ratio, cement content (cc) and W/C ratio is shown in **Fig. 4.1**. Results of MAS of 10.0 mm are combined with the previous results of MAS of 12.5 mm, 19 mm, 25 mm, 37.5 mm and 50.0 mm. The workability of concrete increases with an increase in the MAS. It is well established that, besides aggregate shape and surface texture, the gradation of aggregate is an important parameter that influences workability of concrete, as gradation of aggregate determines how efficiently the particles pack together.





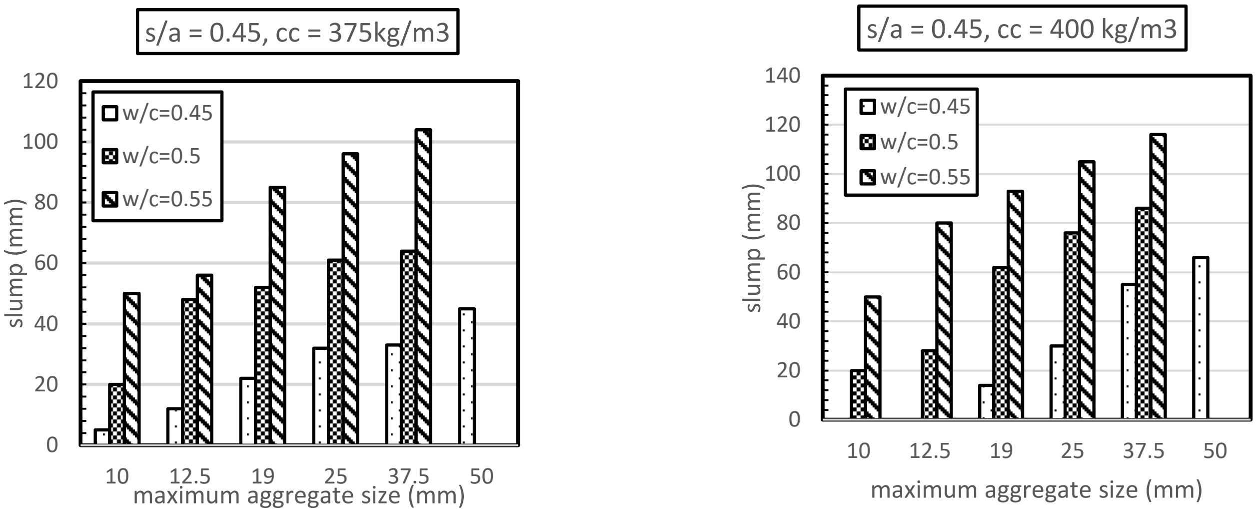
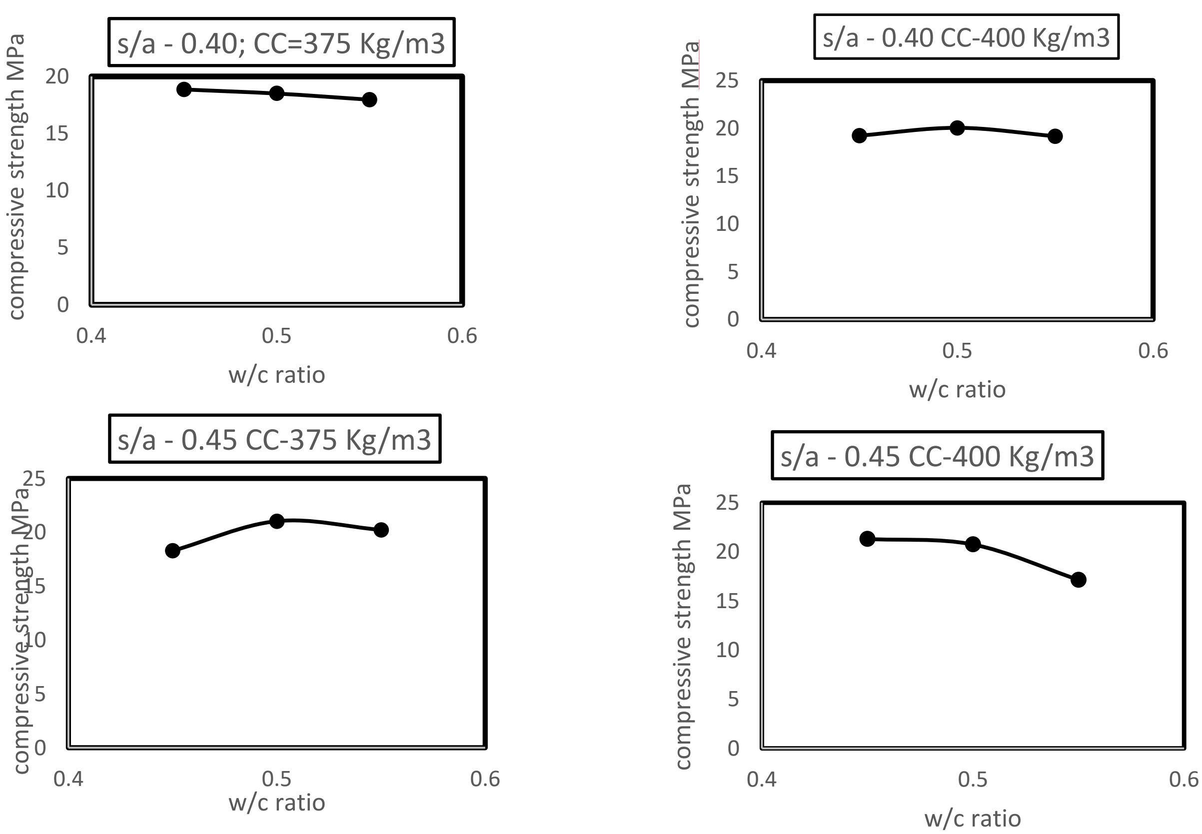
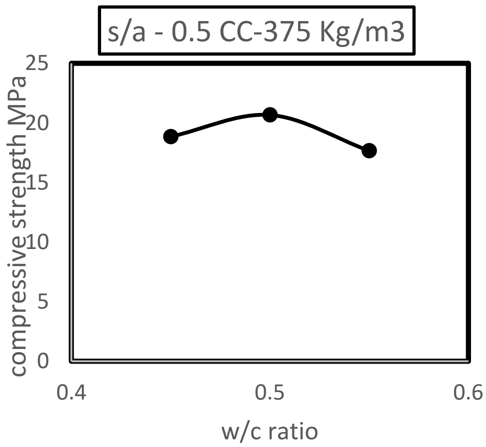


Fig. 4.1. Effect of maximum size of aggregate on workability of concrete

4.2.2 Compressive Strength vs W/c ratio for 7 days

The effect of MAS of brick coarse aggregate on 7 days compressive strength of concrete is shown in **Fig 4.2.** As the W/C ratio increases the strength of concrete decreases. At lower cement content of 375 kg/m^3, the strength of concrete is low irrespective of the variation in s/a from 0.40 to o.45. At lower cement content, the failure in concrete specimen is initiated in the aggregate-mortar interface and visual inspection of broken samples suggests mortar failure.





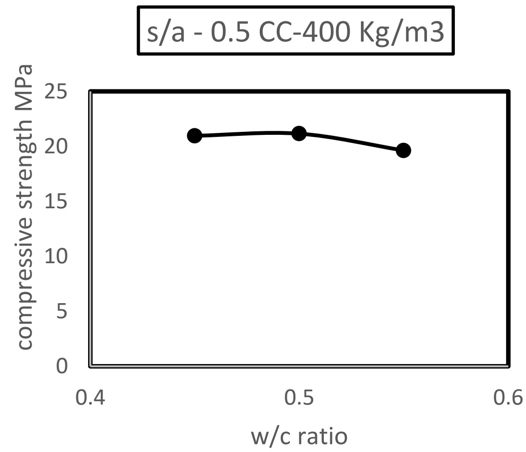
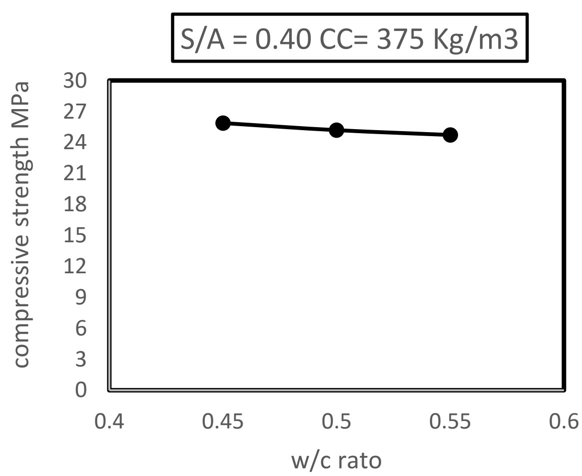
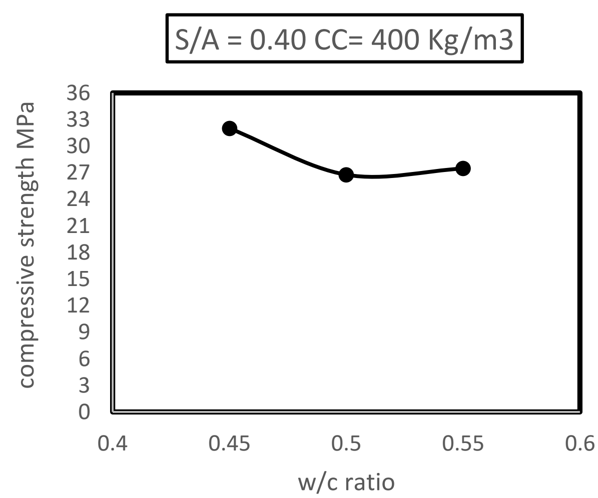


Fig. 4.2. Compressive strength of concrete vs W/C ratio for 7 days.

4.2.3 Compressive Strength vs W/c ratio for 28 days

The effects of MAS of brick aggregate of 10.0 mm on 28 days compressive strength of concrete is shown in **Fig.4.3.** At higher cement content of 400 kg/m^3 and lower W/C ratio of 0.40 and 0.45 the compressive strength is high irrespective of the variation of s/a ratio from 0.40 to 0.50. As the increase in W/C ratio the compressive strength decreases irrespective of the change of s/a ratio.





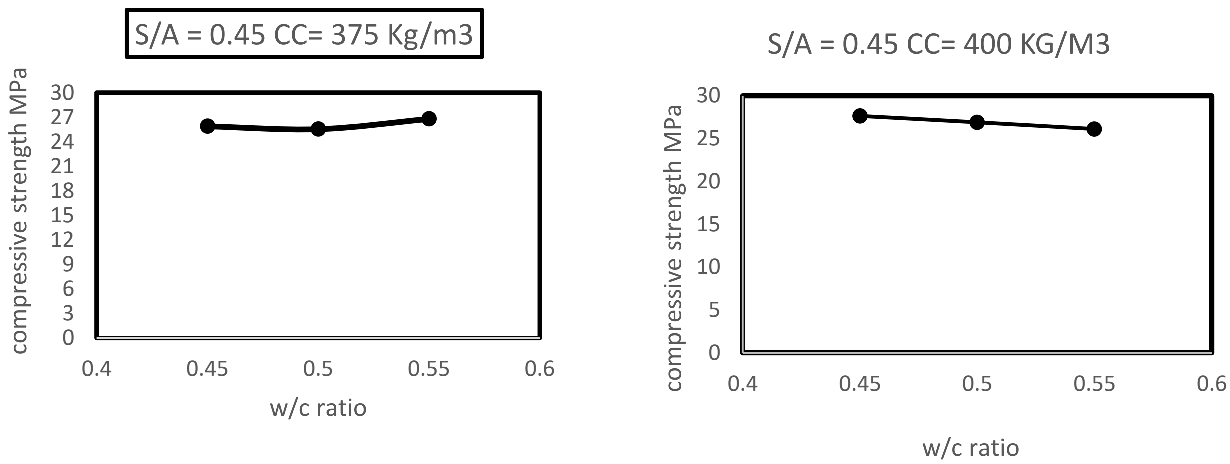
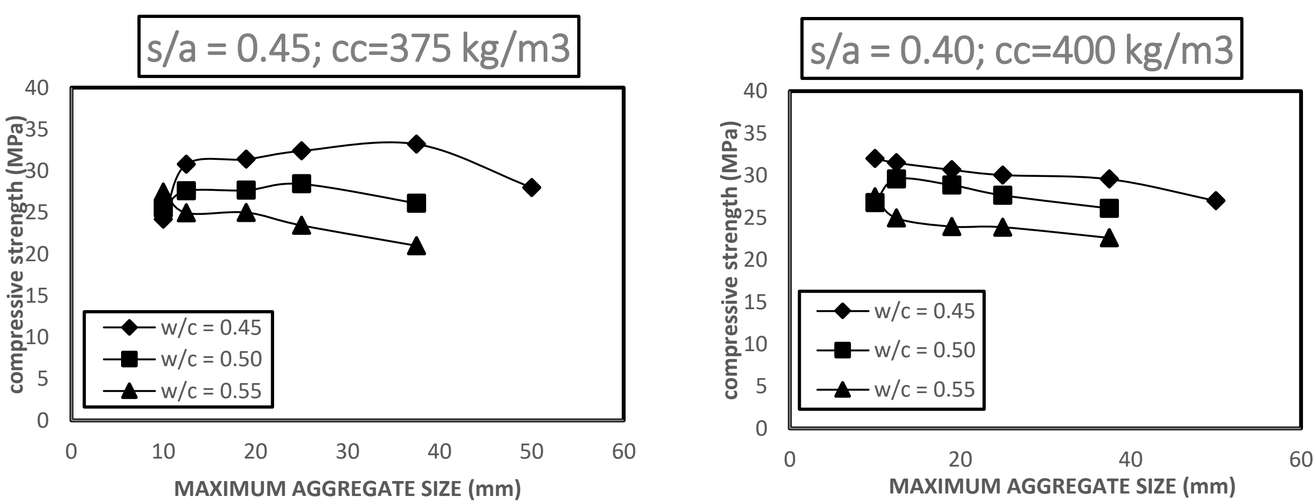


Fig. 4.3. Compressive strength of concrete vs W/C ratio for 28 days.

4.2.4 Compressive Strength of Concrete

The effect of MAS of brick aggregate on 28 days compressive strength of concrete is shown in **Fig.4.4**. Results of MAS of 10.0 mm has been combined with the previous results of the MAS of 12.5 mm , 19 mm, 25 mm, 37.5 mm and 50 mm. Results show that the increase in MAS increases the compressive strength of concrete. At lower cement content of 375 kg/m^3, and W/C ratio of 0.45 and 0.50 the compressive strength increases with the increase in MAS upto 37.5 mm. and then decreases.



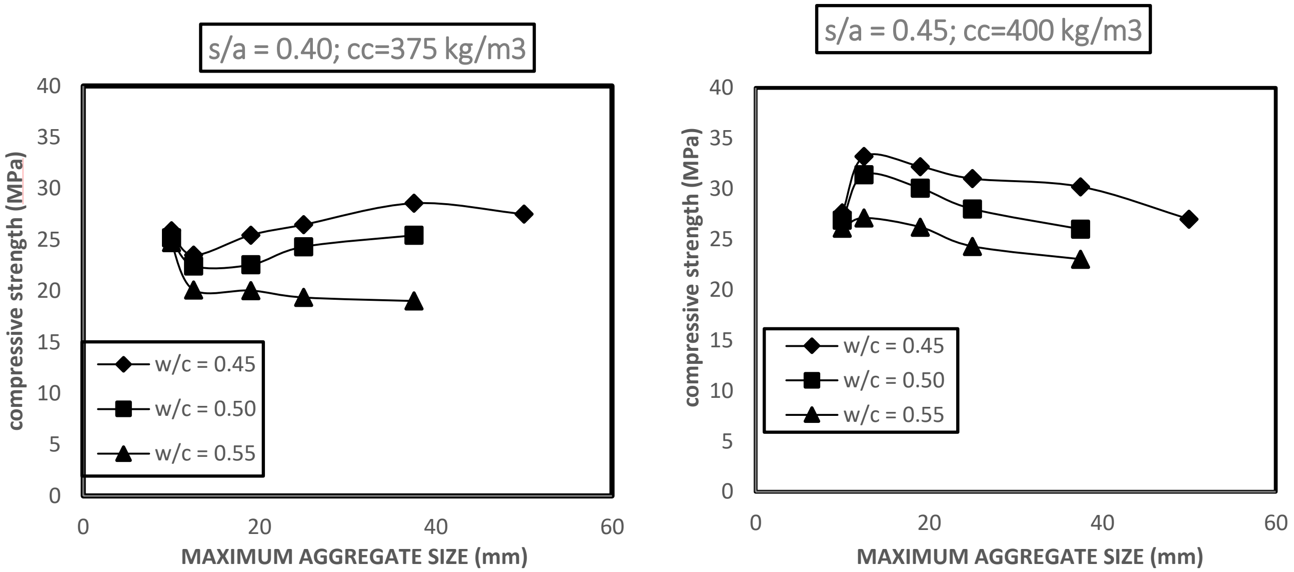
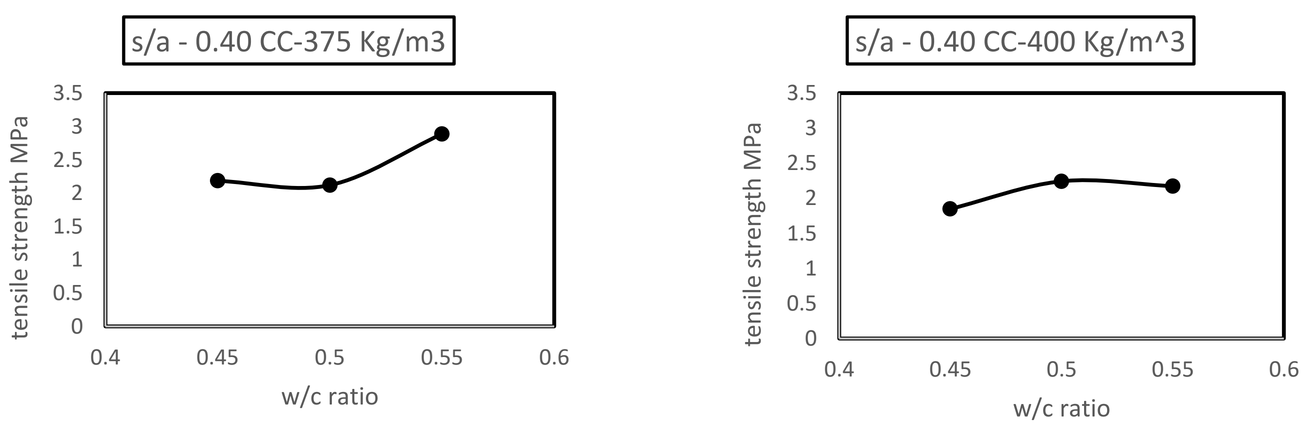


Fig. 4.4. Effect of maximum size of aggregate on compressive strength of concrete

4.2.5 Splitting Tensile Strength vs W/C ratio on 28 days

The effect of MAS of brick aggregate on 28 days splitting tensile strength of concrete is shown in **Fig.4.5**. Results show that increase in W/C ratio the tensile of concrete decreases irrespective of s/a ration. Results show some irregular strength of concrete due to some experimental problems.



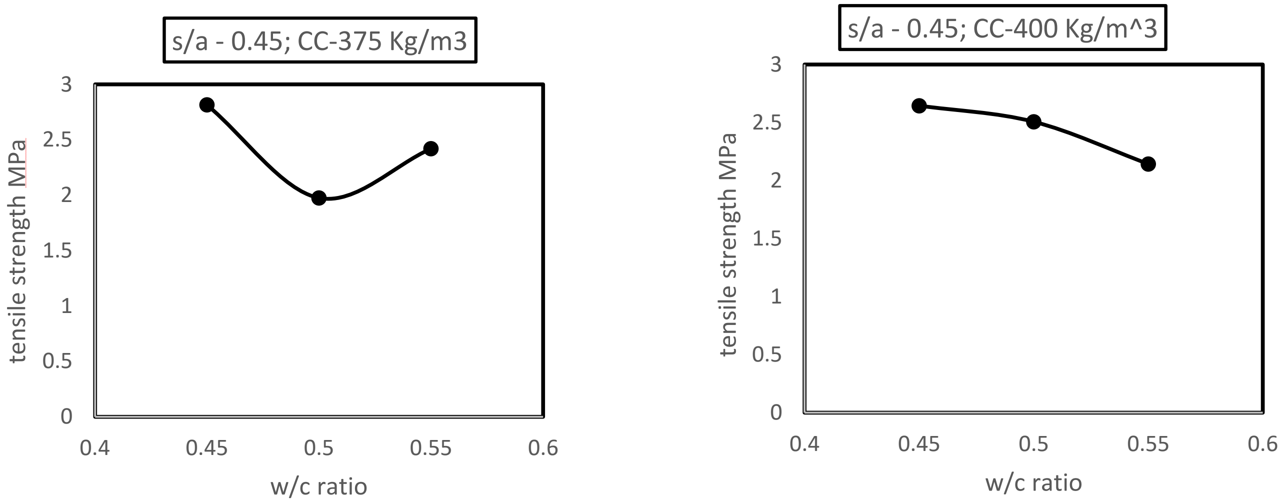
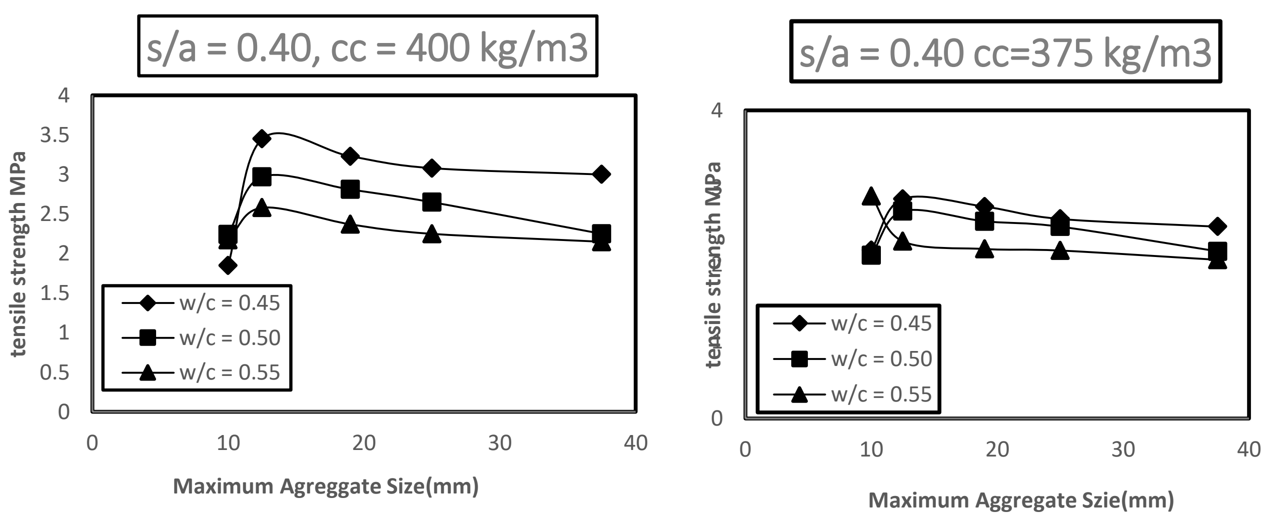


Fig. 4.5. Spliting tensile strength of concrete vs W/C ratio for 28 days.

4.2.6 Splitting Tensile Strength of Concrete

The effect of MAS on 28 days splitting tensile strength of brick aggregate concrete is shown in **Fig. 4.6**. With an increase in MAS, the splitting tensile strength decreases irrespective of variation of cement content and s/a ratio. The trend of the results related to tensile strength is different from the results of compressive strength of concrete. It is understood that separate relationships between compressive strength and splitting tensile strength of concrete for different MAS are to be developed instead of a general relationship as proposed in codes (ACI 318-14).



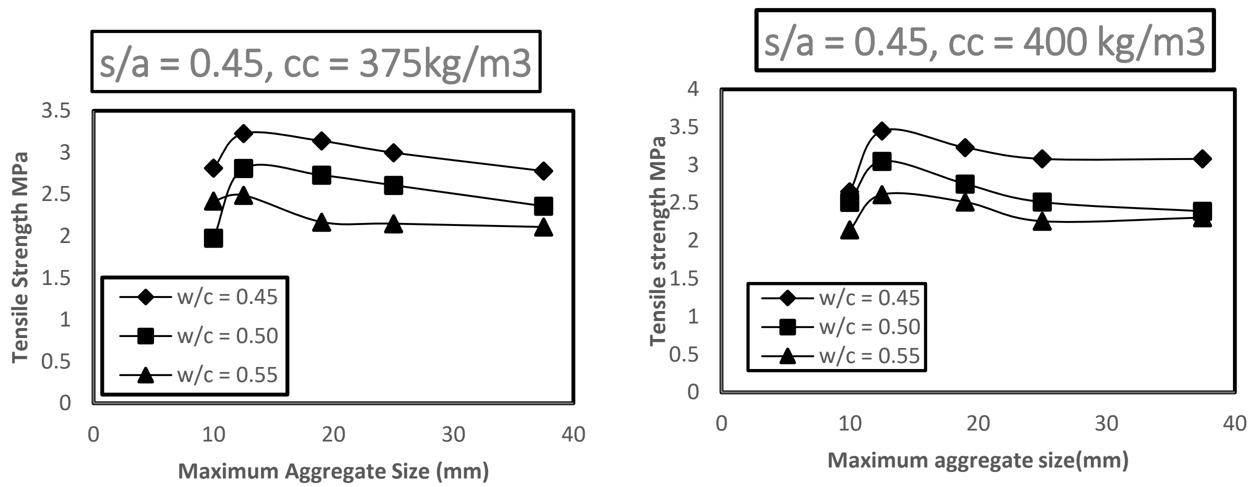


Fig. 4.6. Effect of maximum size of aggregate on splitting tensile strength of concrete

4.2.7 Ultrasonic Pulse Velocity

The effect of MAS of brick aggregate concrete on UPV through concrete is shown in **Fig. 4.7**. Results of 10.0 mm were combined with the previous work done on the MAS of 12.5 mm, 19 mm, 25 mm, 37.5 mm and 50 mm. For all the cases, irrespective of change in the s/a ratio and cement content, the UPV through the concrete increases with the increase in MAS. Its is evident that in concrete samples made with 10.0 mm MAS, the mortar-aggregate interface, i.e the Interfacial Transition Zone (ITZ) is higher compared to other MAS which leads to a tortuous path for the ultrasonic pulse to move towards the receiver. This results in an increase in travel time, and consequent lower velocity.

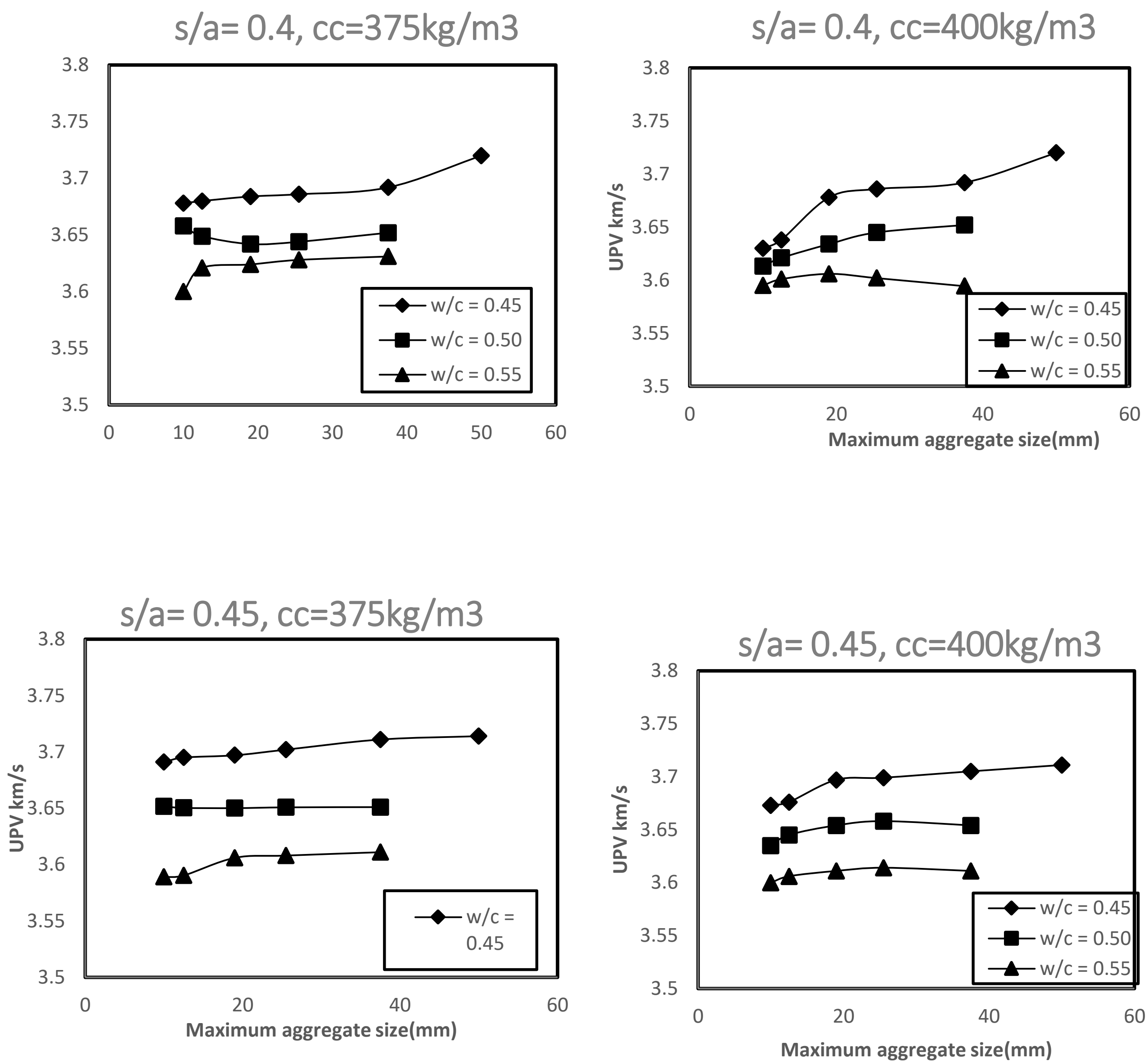


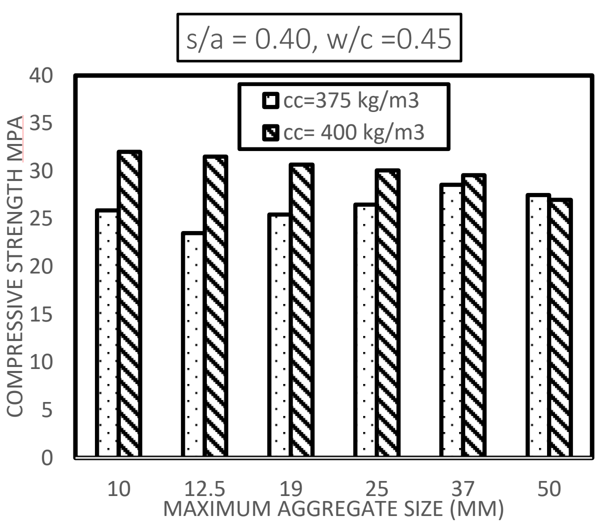
Fig. 4.7. Effect of maximum size of aggregate on UPV.

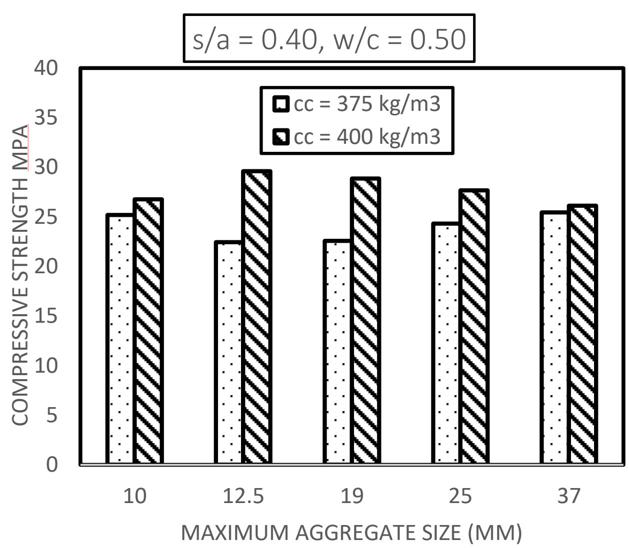
4.3 Effect of Cement Content

4.3.1 Compressive Strength of Concrete

Fig. 4.12 illustrates the effect of cement content on compressive strength of concrete for different s/a ratio and W/C ratio. Two cement contents of 375 kg/m^3 and 400 kg/m^3 were used in this study. Based on **Fig. 4.8**, it can be summarized that, for W/C ratio of 0.45 and 0.50, the compressive strength increases with an increase of cement content for MAS of 10.0 mm, 12.5 mm, 19.0 mm, and 25.0 mm irrespective of variation in s/a ratio.

However, for MAS of 37.5 mm and 50.0 mm, the compressive strength decreases with an increase in cement content. . Furthermore, the variation in strength in compressive strength due to variation in cement content is relatively more for concrete made with smaller MAS. For a W/C ratio of 0.55, the compressive strength of concrete increases with an increase in MAS irrespective of change in s/a ratio.





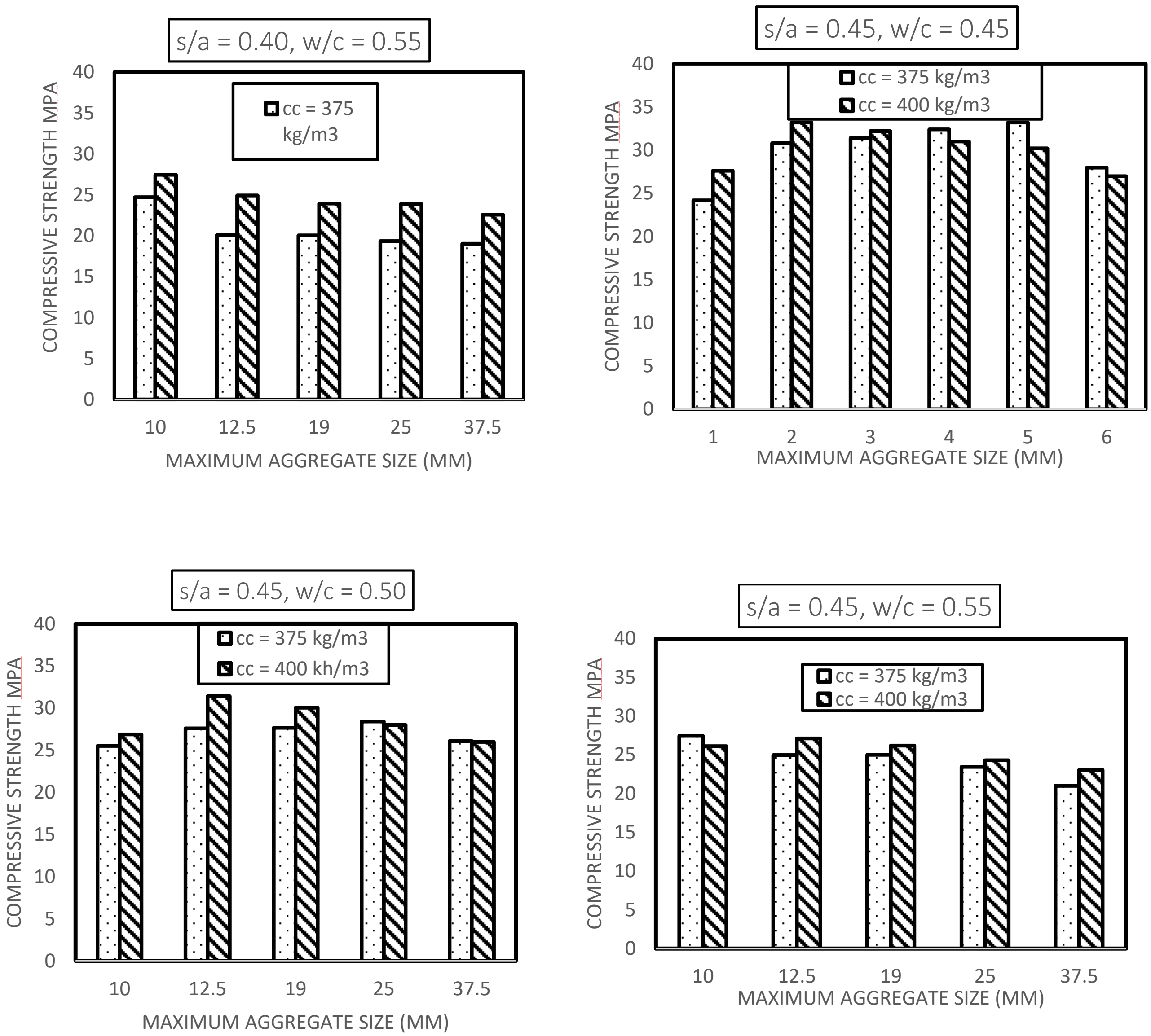
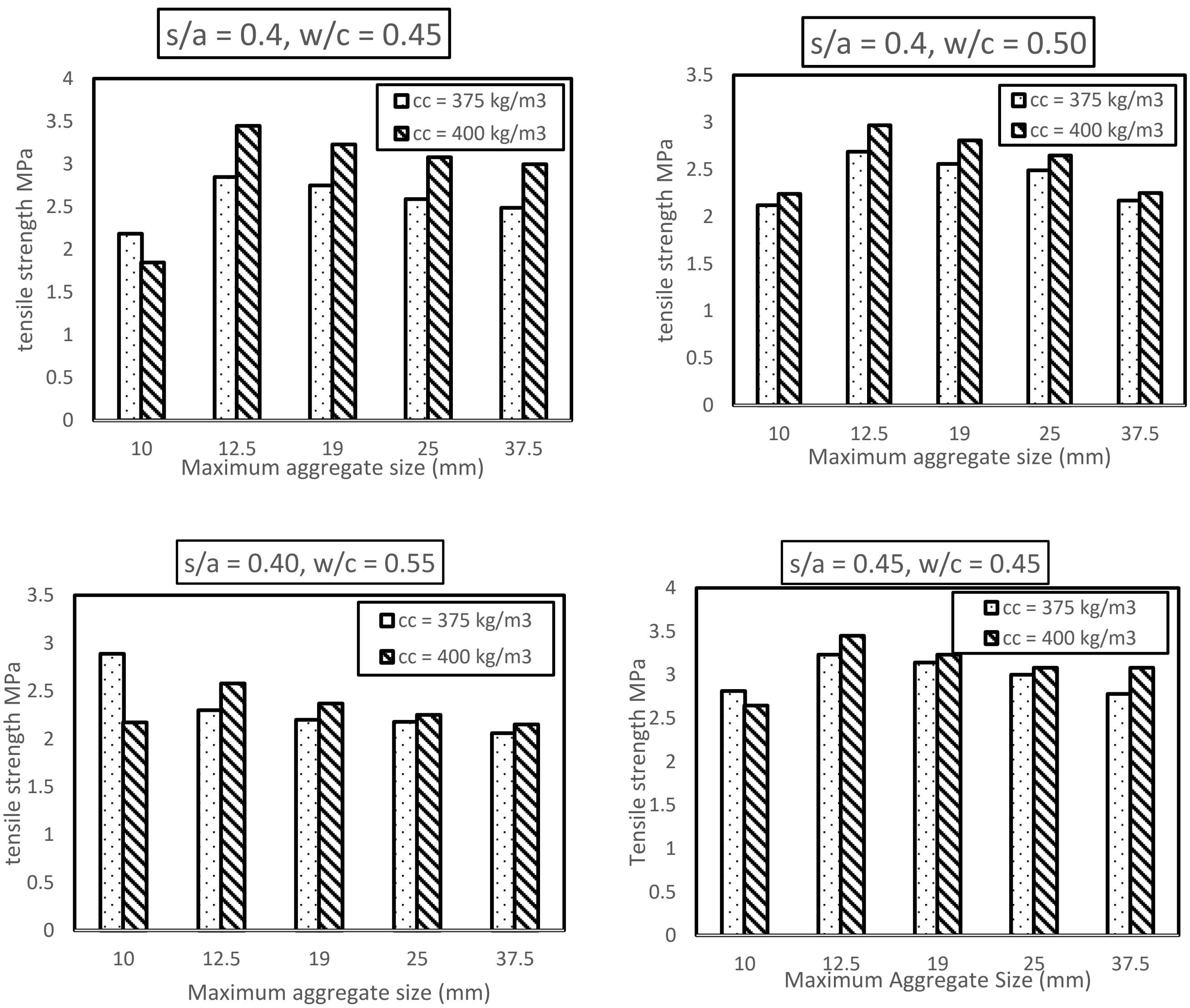


Fig. 4.8. Effect of cement content on compressive strength

4.3.2 Splitting Tensile Strength of Concrete

The effect of variation of sand to aggregate volume ratio (s/a) on splitting tensile strength of concrete is shown in **Fig. 4.16**. It is evident from **Fig. 4.16** that the splitting tensile strength of concrete increases with an increase in the s/a ratio irrespective of the variation of cement content and W/C ratio. Similar conclusion is also drawn in Section 4.6.1, which discusses the effect of s/a ratio on compressive strength of concrete.



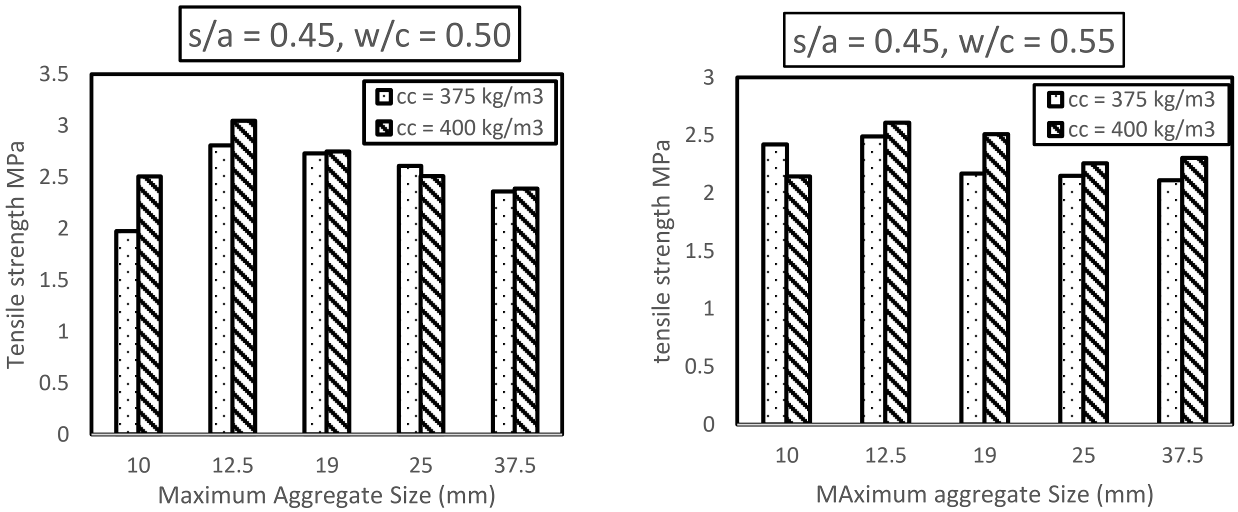


Fig. 4.13. Effect of cement content on splitting tensile strength of concrete

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 General

This chapter includes the summary of the research findings based on discussions in Chapter 4. Moreover, recommendations and future works related to this investigation are also proposed in this chapter.

5.2 Conclusions

Based on the experimental results of this study, the following conclusions are drawn:

- Ultrasonic pulse velocity is less for MAS of 10mm irrespective of change in s/a ratio and cement content because of higher mortar interface causes lower velocity.

- Compressive strength of MAS of 10mm varies with s/a ratio and cement content. At higher cement content the compressive strength is high and at higher w/c ratio the compressive strength is low.

- Splitting tensile strength of MAS of 10mm varies with s/a ratio and cement content. At lower cement content tensile strength decreases with increase in w/c ratio and at higher cement content the strength increases with increase in w/c ratio.

5.3 Recommendations

From this study, this is evident that at a lower cement content of 375 kg/m^3, construction engineers can go for larger sized aggregates to make concrete, if strength of concrete is to be improved. But if larger sized aggregate is discouraged considering the reinforcement cover, then smaller sized coarse aggregates can be used for better strength at a relatively higher cement content of 400 kg/m^3. Smaller sized aggregates can also be useful for better tensile strength of concrete.

5.4 Limitations and Future Work

Though this study has been done to find out the effects of MAS of brick coarse aggregate on fresh and harden properties of concrete but it also studied the effects of s/a ratio and cement content. Only two types of cement content and three types of s/a ratio was taken in this experiment. In future experiments can be done to study the effects of s/a ratio and cement content variations to find an optimum s/a ratio and cement content for brick aggregate concrete.

REFERENCES

Abo-Qudais, S. A. (2005), "Effect of concrete mixing parameters on propagation of ultrasonic waves", *Construction and Building Materials*, Vol. 19, pp. 257–263.

ACI 318-14, “Building Code Requirements for Structural Concrete”, *American Concrete Institute*, 2014.

Akashi, T. and Amasaki, S. (1984), "Study of the stress waves in the plunger of a rebound hammer at the time of impact", V.M. Malhotra (Ed.), *Insitu/Nondestructive Testing of Concrete*, ACI SP-82, Detroit, pp. 19–34.

Al-Akhras, N. (1995), "Characterization and deterioration detection of portland cement concrete using ultrasonic waves", *Ph.D. dissertation*, Civil Engineering Department, Virginia Polytechnic Institute and State University, Blacksburg, (VA, USA).

Amasaki, S. (1991), "Estimation of strength of concrete structures by the rebound hammer", *CAJ Proceedings of Cement and Concrete*, Vol. 45, pp. 345–351.

American Society of Concrete Contractors (2005), “The contractor's guide to quality concrete construction”, 3rd Ed., *American Concrete Institute*, USA.

ASTM C 127, "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate", *American Society for Testing and Materials*, 2003.

ASTM C 128, "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate", *American Society for Testing and Materials*, 2003

ASTM C 131, "Standard Test Method for Resistance to Degradation of Small Sized Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine", *American Society for Testing and Materials*, 2003.

ASTM C 136, "Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates", *American Society for Testing and Materials*, 2003.

ASTM C 143, "Standard Test Method for Slump of Hydraulic-Cement Concrete", *American Society for Testing and Materials*, 2003.

ASTM C 192, "Standard Test Method for Making and Curing Concrete Test Specimens in the Laboratory", *American Society for Testing and Materials*, 2003.

ASTM C 29, "Standard Test Method for Bulk Density and Voids in Aggregate", *American Society for Testing and Materials*, 2003.

ASTM C 31, "Standard Practice for Making and Curing Concrete Test Specimens in the Field", *American Society for Testing and Materials*, 2003.

ASTM C 33, “Standard Specification for Concrete Aggregates”, *American Society for Testing and Materials*, 2003.

ASTM C 39, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimen", *American Society for Testing and Materials*, 2003.

ASTM C 597, "Standard Test Method for Pulse Velocity Through Concrete", *American Society for Testing and Materials*, 2002.

BDS EN 191–1:2000, Bangladesh Standard, European Norm, Cement – Part 1: Composition, Specifications, and Conformity Criteria for Common Cements, 2000.

Ben-Zeitun, A. E. (1986), "Use of pulse velocity to predict compressive strength of concrete", *International Journal of Cement Composites and Lightweight Concrete,* Vol. 8, No. 1, pp. 51–59.

Bloem, D. L. and Gaynor, R. D. (1963) "Effects of Aggregate Properties on Strength of Concrete," *ACI Journal Proceedings*, Vol. 60, No. 10, October, pp. 1429-1456.

Bogas, J. A., Gomes, M. G., Gomes, A. (2013), “Compressive strength evaluation of structural lightweight concrete by non-destructive ultrasonic pulse velocity method”, *Ultrasonics*, Vol. 53, pp. 962–972.

Bungey, J. (1989),"The testing of concrete in structures", London, UK: Surrey University Press.

Cetin, A., Carrasquillo, R. L. (1998), "High-performance Concrete: Influence of Coarse Aggregates on Mechanical Properties", *ACI Materials Journal*, Vol. 95, No. 3, pp. 252–259.

Cook, J. E. (1989), "10,000 psi Concrete," *Concrete International*, October, pp. 67-75.

Cordon, W. A., and Gillespie, H. A. (1963) "Variables in concrete aggregates and portland cement paste which influence the strength of concrete," *ACI Journal Proceedings*, Vol. 60, No.8, pp. 1029-1052.