Utilization of Steel Slag in Concrete

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PROJECT REPORT APPROVAL

The thesis titled "Utilization of Steel Slag in Concrete" submitted by Arhab Elahi, Muntasir Ahmed, Majedul Hasan Mazumder, St. No. 125433, 125426, 125401 has been found as satisfactory and accepted as partial fulfillment of the requirement for the Degree Bachelor of Science in Civil Engineering.

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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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Dedication

We dedicate our thesis work to our family. A special feeling of gratitude to our loving parents.

We also dedicate this thesis to our many friends who have supported us throughout the process. We will always appreciate all they have done.

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Abstract

In Bangladesh, the availability of natural aggregates (like brick chips, Stone chips) is depleting rapidly with time. To overcome this problem, we need to focus on alternative building materials. Therefore, this investigation was carried out to explore the possibility of utilization of steel slag in concrete as coarse aggregate. The aggregates were tested for different physical and mechanical properties. Cylindrical concrete specimens (100 mm by 200 mm) were also made with different W/C ratios and sand to aggregate volume ratios. Brick aggregate was partially (50%) /fully (100%) replaced by steel slag. The concrete specimens were tested at 7, 28 and 90 days. Also, ultrasonic pulse velocity (UPV) was measured prior to crushing of the specimens.

Results show that the compressive strength of concrete increases by 50% partial replacement of brick chips by steel slag. Therefore, utilization of steel slag will help towards sustainable development of construction materials in Bangladesh.

CHAPTER 1: INTRODUCTION

1.1 General

Concrete is the largest construction material in the world. Aggregates are the major constituents of concrete where coarse aggregates occupy almost half the constituents of it (Seddik et al. 2010).They give body to the concrete, reduce shrinkage and effect economy (Malathy 2014). Moreover, physical properties of coarse aggregate also influence concrete properties. As Bangladesh is urbanizing rapidly, therefore the demand for coarse aggregates in the construction industry is increasing rapidly. Total concrete consumption in Bangladesh is 90 million tons and concrete consumption per capita per year is 0.56 tons (Nahar 2011). Therefore a huge supply of coarse aggregate is necessary as the demand for concrete is increasing rapidly.

In Bangladesh, the most commonly used coarse aggregate is brick aggregate which is made by crushing bricks into brick chips. There are about 8000 brick kilns in operation, producing about 17.5 billion bricks per year (Alam & Ahmad 2014). The amount of natural aggregates is depleting rapidly with time and the brick industries are responsible for various environmental effects. To overcome this problem, we need to focus on alternative building materials such as stone chips. The problem with stone chips is that, it is very expensive and need to be imported from India or other countries due to low availability in our country. Also, it is found mostly in Sylhet region only. The increase in demand may be met by partial replacement of aggregates by the waste materials which are obtained from various industries such as slag. Total production of steel in Bangladesh is estimated at 8 million tons per annum and production of slag is about 1, 20,000 to 1, 60,000 metric ton per annum (Nieri 2013) To utilize this large amount of steel slag in Bangladesh, it is necessary to investigate the possibility of using this by product as coarse aggregate in concrete.

In light of the above discussion, it is expected that a study that investigates the partial replacement of coarse aggregate with iron slag is conducted. Thus, this study has been planned to investigate the compressive strength, split tensile strength and ultrasonic pulse velocity of concrete with various percentages of slag aggregate and compare with conventional concrete. Another proposal of this study is to study the effects of sand to aggregate volume ratio and water/cement ratio 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) of concrete with partial replacement of aggregates.

1.2 Background

During production of steel, a significant portion of by-product (5-6% of total weight of steel production) is produced and these are classified as furnace slag (produced during melting of scrap and sponge iron and it becomes in lumped form after cooling in a slag pot, it is rich in silicon oxide, iron oxide and manganese oxide), process slag (produced in ladle refining furnace where CaO and other necessary ingredients are added to fix required chemical parameters of steel, it is produced in finer form and rich in calcium oxide, silicon oxide, magnesium oxide and iron oxide) and flue dust (collected from the smoke generated during melting of scrap and sponge in blast furnace, it is rich in carbon and zinc). The furnace slag can be used as coarse aggregate for making concrete as well as aggregate in asphalt paving roads. No investigation on utilization of furnace slag as coarse aggregate in concrete has been carried out yet in Bangladesh as a replacement of brick coarse aggregate. Literature review suggests, use of 50% slag with brick aggregates give the highest strength (Thangaselvi 2015). Therefore, this study has been planned to find out the suitability of utilization of the slag aggregates in concrete as coarse aggregate in Bangladesh.

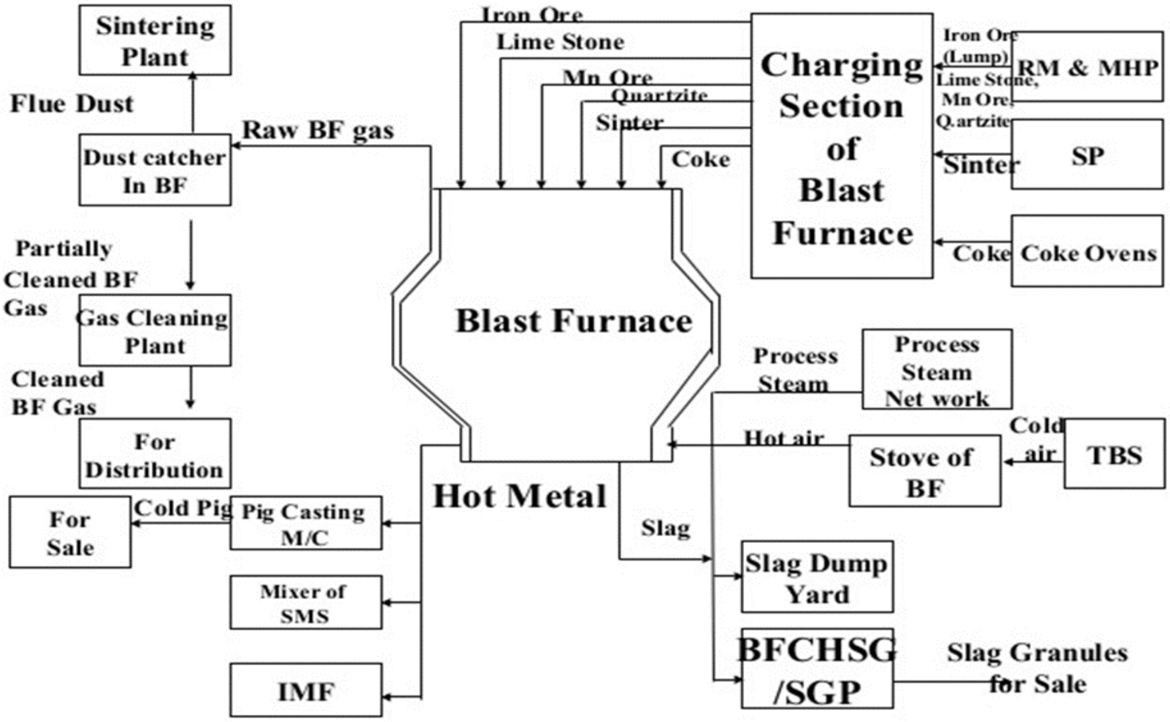


Fig 1.1: Material Flow Diagram for Blast Furnace

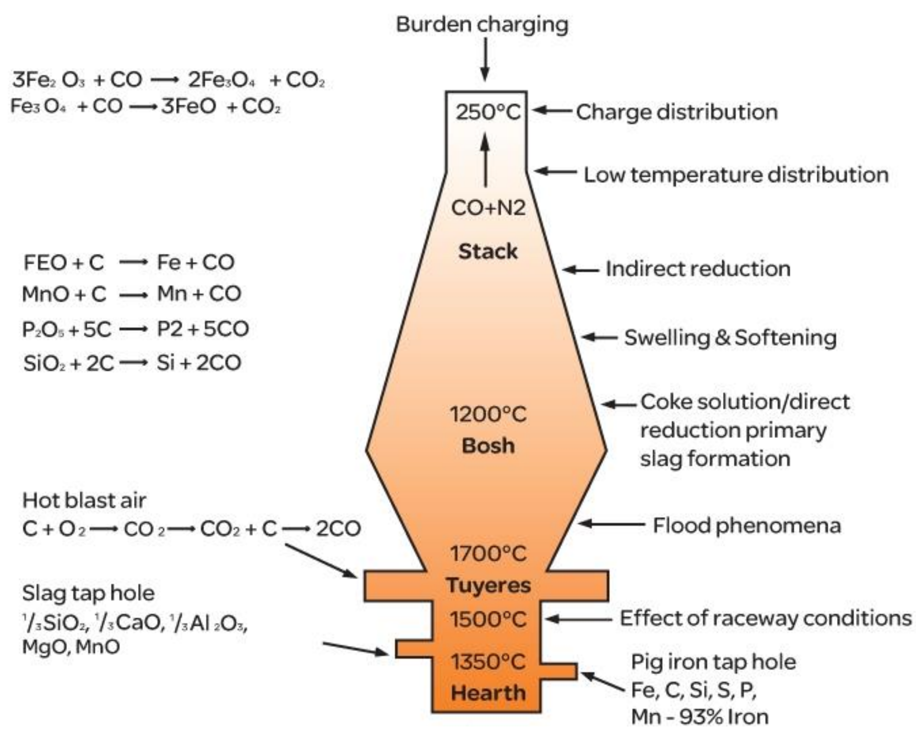


Fig 1.2: Steel slag formation in Blast Furnace

1.3 Objectives of the Study

The objectives of this study are as follows:

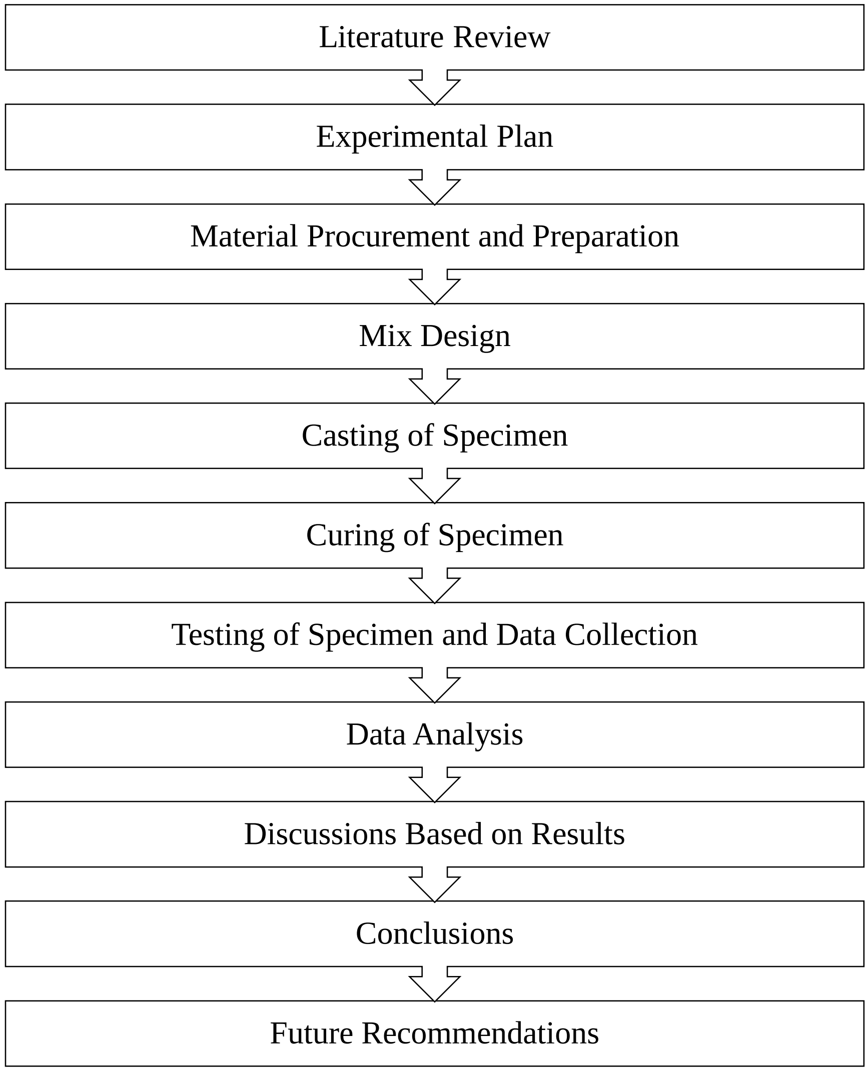
1. To find out the possibility of utilization of slag in concrete as partial replacement.
2. To study the fresh and hardened properties of concrete made with steel slag as coarse aggregate
3. To find out mechanical properties of concrete by partially replacing brick aggregate with steel slag as coarse aggregate
4. To compare mechanical properties of concrete made with brick aggregate and steel slag aggregate
5. To understand the effects of variation of sand to aggregate volume ratio (s/a) and water cement ratio (w/c) on properties of concrete

1.4 Methodology

This study investigated the effect of replacing coarse aggregate with iron slag on fresh and hardened properties of concrete. For investigation, first class bricks were collected from local market and steel slag were obtained from a local steel manufacturing company. It was found that some slag aggregate were light in weight with a lot of voids and some were heavier with a little or no voids. Therefore, the slag aggregates were termed as the mixed slag aggregate (SM). Brick were broken manually into maximum sizes of 4.75 mm, 9.5 mm, and 19.0 mm to comply with the grading requirements specified by ASTM C 33. The aggregates were tested for specific gravity, absorption capacity, abrasion resistance, and unit weight. CEM Type II/A-M cement (as per BDS EN 197–1:2000) was used. Tap water was used for mixing and curing of concrete. The mixture proportion was prepared with varying W/C ratios of 0.45, 0.50; s/a ratio of 0.40, 0.44 and 0.48; and cement contents of 340 kg/m^3.198 cylindrical concrete specimens of 100 mm diameter and 200 mm height were made. 11 cylinders were made for each case. 3 cylinders were used for 7 day, 28 day and 90 day compression tests each and 2 cylinders for 28 day tensile test.

Prior to compressive strength test (ASTM C109), 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 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. Then compression strength test was done on the cylinders. UPV was not conducted on the 28 day tensile testing (ASTM C109) cylinders. They were directly splitted with the UTM machine.

1.5 Research Flow Diagram



1.6 Layout of the Thesis

Chapter 1 thoroughly discusses the background and objectives of this study. **Chapter 2** discusses the possibility of utilization of steel slag as a partial replacement of brick aggregate based on literature review. It also discusses non-destructive tests of concrete based on findings of recent researches. **Chapter 3** presents information on the development of methods used to design a concrete mixture, as well as the cases investigated in this study. In addition, it outlines the actual mix designs studied. It also includes background information on the key components of concrete and their respective properties. The chapter concludes with information pertaining to the test methods and procedures followed in this study. **Chapter 4** presents the results of the tests performed on specimens in both fresh and hardened state. The test results from the experimentation program in the fresh state and hardened state are discussed separately. The workability, compressive strength, splitting tensile strength, and Young's modulus of specimens are analyzed and discussed. In addition, several relationships between concrete properties are also presented in this chapter. **Chapter 5** presents a summary of the conclusions drawn from the results of this research and also suggests recommendations for future works.

CHAPTER 2: LITERATURE REVIEW

2.1 General

This Chapter elaborates the increasing demand of coarse aggregates and represents the facts that are responsible for the search of alternative materials. This chapter discusses the possibilities of using steel slag as a replacement of brick aggregate. Here a brief comparison is being carried out between steel slag and brick aggregate by doing partial replacement of these constituents in concrete and see if coarse aggregate can be replaced by steel slag based on literature review. Literature review on some non-destructive tests is also being presented in this chapter.

2.2 Aggregate in Concrete as an Ingredient

Concrete is an artificial, stone like, composite material used for various structural purposes and which is made by mixing cement as well as coarse and fine aggregate as an important constituent. Sand, pebbles, gravel or shale is also available in this mixture which is being hardened in the presence of sufficient amount of water. Other constituents such as admixtures, pigments, fibers, polymers and reinforcement can be incorporated to modify the properties of hardened concrete. The properties of the plastic and hardened concrete are determined by the combination of constituents used. Concrete Mix design is the name for the procedure for choosing a particular combination of constituents.

Since aggregates occupy 70-80 percent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable.(Malathy 2014)

Because of the effects of urbanization, the usages of coarse aggregate in concrete which dictates a major part in determining the characteristic of a certain structure is increasing day by day. Hence to sustain this increasing demand it is imperative to look for the alternative material in order to ascertain the existing situation.

2.3 Alternative Materials for Coarse Aggregate

As the demand for coarse aggregate in the making of cement concrete is increasing day by day the search for alternative material has become a crying need. Brick is the most widely used coarse aggregate in Bangladesh and the continuous spreading of the brick industries are hampering the environment to a great extent. Moreover the price of brick aggregate is also going higher as its demand gets higher. Stone can be used as a replacement of brick aggregate but it has low availability and higher price. In this existing condition the waste materials such as steel slag can be considered as a possibility which can be used instead of conventional coarse aggregates.

The mechanical strength of steel slag concrete is acceptable; though slightly lower flexural strength than that of conventional concrete. The expansion induced form steel slag using as coarse aggregates in concrete may lower the shrinkage and expansion to a certain extent (Liu et al. 2011).

2.4 What is Steel Slag?

Steel slag is an industrial by-product obtained from the steel manufacturing industry. It is produced in large quantities during the steel-making operations which utilize Electric Arc Furnaces (EAF). Steel slag can also be produced by melting iron ore in the Basic Oxygen Furnace (BOF). Steel slag is currently used as aggregate in concrete mix slab applications, but there is a need for some additional work to determine the feasibility of utilizing this industrial by-product more wisely as a replacement for coarse aggregates in a conventional concrete mixture. Concrete mix volume is up to 75% of aggregates.

Replacing all or some portion of natural aggregates by steel slag would lead to considerable strength and environmental benefits.(Dieu 2015)

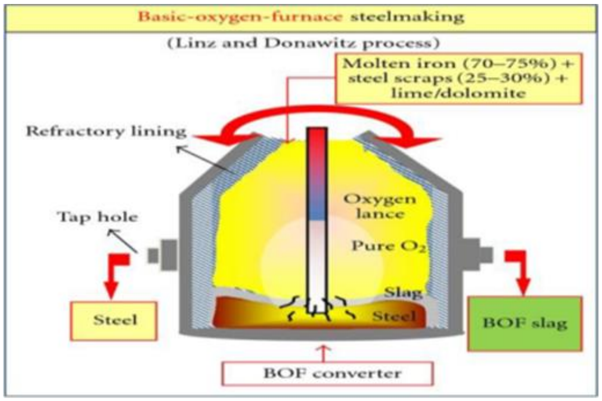


Fig 2.1. Manufacturing process of BOF slag

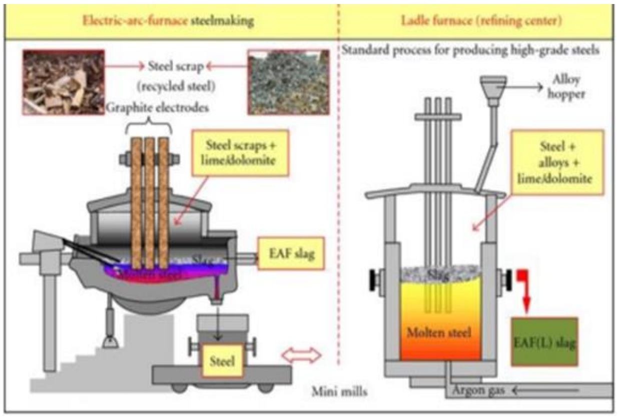


Fig 2.2. Manufacturing process of EAF slag

Fig 2.3. Steel Slag

2.5 Why this is Promising?

Steelmaking residues are defined as by-products obtained from the conversion process of iron to steel. In particular, steel slag represents a significant proportion of these by-products.

For instance, the production of 3 tons of stainless steel is estimated to generate about 1 ton of stainless steel slag. Consequently, a large amount of steel slag is yearly produced in the world which is around fifty million tons per year.(Ferreira et al. 2015)

So there is two different sight of the situation. One is our natural resources of the coarse aggregate is depleting day by day because of the increasing demand and the other sight is this large amount of industrial by–products should not be allowed to go as a complete waste. Hence the purpose of our study is to somehow correlate these two factors and find a suitable replacement of coarse aggregate from the waste particles in this case steel slag.

2.6 Scopes of Using Steel Slag as Aggregate

The production of steel making slag around the world is increasing over time, despite the onset of the economic crisis. It is, therefore, essential to conduct research into applications for this by-product, to reduce its dumping in landfill sites and the production of excessive volumes of waste. By doing so, there would be less extraction of the natural resources that are necessary in those applications, which may otherwise be substituted by slag.

In general, the use of these slag (EAFS and LFS) when applied as aggregates in hydraulic mixes has been relatively successful. Several research groups the EU (from Greece, Italy, Belgium, Germanyand Spain) are in contact with the intention of establishing some preliminary rules for the use of these two slag types (EAFS and LFS) in mortar, concrete and bituminous mixes, including particular mixes as self-compacting concrete (EAFS), sprayed concrete (shot Crete) and self-leveling mortar (LFS).

But in Bangladesh there is hardly any research work an alternative materials for coarse aggregates which relates steel slag whereas around 8 million steel is being produced per anum in Bangladesh and from which we can get around 1,20,000-1,60,000 metric ton per anum of iron making slag. So to utilize this large amount of slag in Bangladesh, it is necessary to investigate the possibility of using this by product as coarse aggregate.

The compressive strength of 78 MPa was reached with a mix employing EAF slag as aggregate; this compressive strength is promising comparing with the conventional aggregate. The stiffness of the mixes containing slag were, in general, lower than the stiffness of the natural aggregate mixes of similar strength.(Marcos et al 2016)

The partial replacement of natural stone aggregate by modified slag aggregate was found to be most optimal for 25% replacement in terms of compressive strength for the grades of concrete tested in this study. Splitting tensile results indicate that 25% replacement by slag aggregates is found to be greater for all the grades of concrete.(Sabapathy et al. 2016)

According to technical specifications for road and bridge works in Spain, black slag can be used as coarse aggregate in hot bituminous mixtures in the type of base layer for the T2 and T3 heavy traffic categories. Moreover, the black slag can be also used in the type of surface course layer in the T3 and T4 categories.(Ferreira et al. 2015)

The use of ladle furnace slag in masonry mortars is an affordable application for this by-product. The LFS-mortar mixes show useful properties for building sector applications; they constitute a contribution to global sustainability by partially substituting the consumption of cement and proportionally reducing greenhouse gas emissions.(Herrero et al. 2016)

So, under the lights of the previous study we can easily deduce that the further study of this steel making by product, slag; needs to be continued and hence their lies the possibility of finding suitable alternatives of conventional concrete technology and make a sustainable world which is the objective of our investigation.

2.7 Types of Aggregate

Aggregates can be classified into two parts such as coarse aggregates which includes brick chips, crushed stones, jhama bricks, shingles etc.s

Many studies have shown the effects of aggregate interfaces on the mechanical and fracture properties of concrete. (Torrijos, Giaccio & Zerbin (2013) concluded that the failure mechanisms under loading are affected by the characteristics of the coarse aggregates, specially their surface texture and shape and on the strength differences between aggregates and matrix in the case of high strength concretes.

Level(1998) stated that aggregate surface texture is one of the most important factors affecting bond strength; rough surfaces usually have a higher bond than sawn surfaces. But it is much more difficult to study the interfaces with concrete, as new phenomena such as different stress concentration, microcracks, etc., that do not always exist in composite specimens (i.e., microcracks due to drying shrinkage or thermal changes) appear.

Torrijos et al. (2013) stated that concretes with weaker aggregates, such as limestone, yield lower compressive strengths than concrete with stronger coarse aggregate.

2.8 Strength of Aggregate

The water and cementious material is an important factor affecting the strength of concrete. The size of the aggregates, shape, surface texture, grading and mineralogy are known to affect concrete strength in varying degrees. Also the strength of concrete depends on the type of aggregate used. So it is a mere obligatory approach to find out suitable composition of aggregate in order to attain desired concrete strength. Generally inn Bangladesh frequently two types of coarse aggregates are being used in construction work. One of them is brick aggregate and other is stone chips. Amongst them generally stone chips give higher strength than brick aggregates. As the availability of stone chips in Bangladesh is very less in number compare to the huge demand, the investigators find it imperative to look forward to enhance the concrete strength by finding and utilizing alternative sources and also try different partial replacement with the brick aggregates. Again some investigators have found some progressive results while using slag as an alternative material of brick aggregates at different ratios which influence our search for finding the suitable alternative material in slag.

Use of readymade fine slag accelerates the rate of gain in compressive strength at the early age of concrete which is a very good sign as it gives desired strength even before the probable time period estimated. Again the problem of steel slag utilization is not confined to Bangladesh alone but is being experienced all over the world. But this problem is particularly acute in Bangladesh as it doesn't get enough attention. The rate of iron slag utilization in the world is about 16 percent(Dieu 2015),where Bangladesh is lagging a long way behind.

Celik Sola & Sayin (2016) concluded that higher compressive strength is being found while using ground slag in manufacturing briquettes.

So we can clearly see that the compressive strength of aggregate is being dictated to a great extent by the nature of aggregate and hence finding a suitable alternative of coarse aggregate in the form of slag has become more essential. Since the testing of crushing strength measurement of individual aggregate particle is very difficult, the desired information has to be obtained from indirect test like crushing value of bulk aggregate or resistance to abrasion.

Concluded that for both light weight structural concrete and conventional concrete mixtures, regardless of the water cement ratio ,the compressive strength increases over time but as a result of a longer hydration period, as the matrix strength increases, the aggregate characteristics begin to play an important role in determining the maximum concrete strength that can be reached.

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.

Again, the strength and the Young's modulus of aggregate depend on its composition, texture and structure. Young's modulus of concrete is generally higher for higher Young's modulus and also it affects the magnitude of creep and shrinkage of concrete, Hence in determining the strength of concrete the proper measurement of Young's modulus is a must.

2.9 Sand to Aggregate Volume Ratio

The strength of concrete is related to the composition of sands used in concrete mix. Hence, the content and type of clay, percentage of feldspar and mica in the aggregates should always be determined before they are used in the concrete mix. The presence of clay in the natural sand reduces the concrete strength by nearly 10 MPa (Hasdemir et al. 2016).

(Hasdemir et al. 2016) also stated that an important constituent of concrete is natural sand, which makes up about (25%-28%) of the volume of aggregate used in the construction industry. Aggregates containing material such as coatings, reactive silica, sulfate, clay, feldspar and mica can potentially cause damage to the short and long-term performance of the concrete.

The technical literature gives quite contradictory data on the effect of sand to aggregate volume ratio (s/a) on strength of concrete. However, Sizov (1997) stated that, an excessive amount of sand compared with the optimal causes a high consumption of cement and it's too low content leads to segregation and bleeding of concrete (Sizov 1997). 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.

Literature review also shows that the compressive strength of concrete fluctuates with the increase or decrease of s/a ratio rather than specific types of sand. Long-term compressive strength for concrete with manufactured sand is similar with the ordinary concrete

But again we get some contradictory reviews regarding the sand type affecting the compressive strength as (Khouadjia et al. 2015)

Stated that the behavior of concrete is influenced by sand type. It depends on the rate of fines and particle shape. Concrete with few fine particles has better performance if mineral additions and dune sand are used as a crushed sand replacement to fill granular voids. In the other side, concrete with a high rate of fine particles may have better performance if river sand is used as a crushed sand replacement to reduce percent finer.

Yoo, Zi, Kang, & Yoon(2015) stated that, the s/a ratio is an important parameter and rheological properties such as, the compressive and tensile strength of concrete increase with an increase in the s/a ratio.

2.10 Water to cement ratio

The water-cement ratio is the ratio of the weight of water to the weight of cement used in a concrete mix. A lower ratio leads to higher strength and durability, but may make the mix difficult to work with and form. Workability can be resolved with the use of plasticizers or super-plasticizers.

Mindess et al. (2003) proposed that the strength of concrete decreases with an increase in W/C ratio and proposed a relationship between compressive strength and W/C ratio as shown in **Fig. 2.4.** Similar conclusion was also drawn by Wassermann et al. (2009), Dhir et al. (2004), Schulze (1999), Mehta and Monteiro (1993). Popovics (1990) suggested that to increase the concrete strength, it is more efficient and economical to reduce the water content than to use more cement.

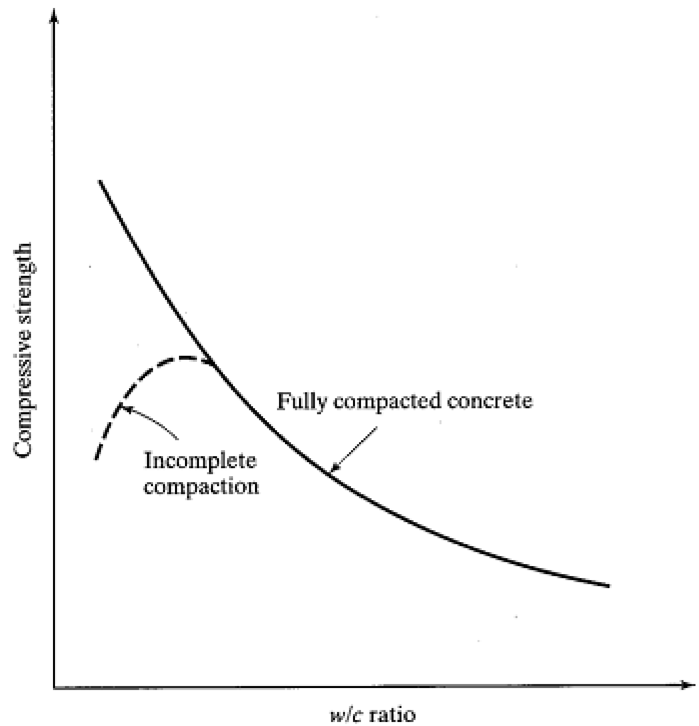


Fig 2.4: Relationship between compressive strength and W/C ratio (Mindess et al., 2003)

A well-established fact in the cement industry speaks that an excessive water content leads to reduction in strength in the cement mortar, but insufficient water content incurs a poor workability. Hence, a method for determining the optimum water content and influence of w/c ratio on cement mortar is obviously desirable.(Singh et al. 2015)

In case of concrete, it has been shown that compressive strength varies inversely with the w/c ratio through the Abram's law developed for strength of concrete is given below:

$$\text{Strength}, f_c = \frac{K_1}{K_2^{w/c}}$$

Where, w/c represents the W/C ratio of the concrete mix, and K_1 and K_2 are empirical constants.

Haach, Vasconcelos, & Lourenço(2011) investigated the influence of aggregate grading and w/c ratio on the workability and compressive strength of mortar. Authors observed that increase in w/c ratio has reduced the value of mechanical properties and increased the workability.

Zhou et al.(2013) observed that dynamic compressive strength of cement mortar increased with decrease in water content. The dynamic compressive strength of saturated specimen was 23% lower than that of totally dry specimen.

They observed that fracture behavior of low w/c ratio mortar is more brittle than that of mortar with high w/c ratio.

The compressive strength of cement mortar is considered to be one of the most important aspects of masonry structures. The compressive strength of cement mortar at the age of 28 days has decreased with an increase in cement-to-sand proportions. The decrease in cement content requires more water for making mortar workable.(Singh et al. 2015)

2.11 Ultrasonic Pulse Velocity

An ultrasonic pulse velocity test is an in-situ, nondestructive test to check the quality of concrete and natural rocks. In this test, the strength and quality of concrete or rock is assessed by measuring the velocity of an ultrasonic pulse passing through a concrete structure or natural rock formation. This test is conducted by passing a pulse of ultrasonic wave through concrete to be tested and measuring the time taken by pulse to get through the structure. Higher velocities indicate good quality and continuity of the material, while slower velocities may indicate concrete with many cracks or voids.

Assessments of concrete structures using non-destructive techniques have interested engineers all over the world; thus many non-destructive techniqueshave been adopted evaluate concrete performance(Bungey 1980). Several nondestructive 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.

UPV measurements are conducted on concrete specimens to gauge the internal structure of the specimen. The test is used to assess existence of any damages/cracks, material discontinuities and the level of deterioration for a given exposure time. The measurements are obtained by measuring the travel time of the ultrasonic pulse between transducers on opposite ends of the given material (direct method). With the length between the transducers and the travel time known, the pulse velocity is easily determined to be the length divided by the travel time. Higher or faster levels of velocity indicate higher density, integrity, and quality of the material.(Abdi et al. 2015). Hence the equation becomes as;

$$Vc(x,t) = \frac{x}{t}$$

Where, the UPV value is Vc(x, t), which is a function of the distance (x) and the transit time (t).

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

An exponential relationship between UPV and compressive strength before and after exposure to elevate temperatures provided an adequate approximation to compare the two, with R 2 values in the range of 95-98%.(Abdi et al. 2015).

CHAPTER 3: EXPERIMENTAL METHOD

3.1 Introduction

As the study has a wide insight on a variety of aspects, different methods were adopted in order to achieve the objective of this study properly. 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, 0.44, and 0.48); W/C ratio (0.45 and 0.50), and cement content (340 kg/m^3). Mixed slag and bricks were used using aggregate sizes of 4.75mm, 9.5mm and 19mm. With these aggregates, concrete is to be made and hence the main approach is to build a relationship between their compressive strength and different mixing proportions of slag. A total of 18 independent cases and 198 cylindrical specimens were investigated; the case plan of all 18 cases are summarized in **Table 3.1** and the mixture proportion is summarized in **Table 3.2**. For each different mixture proportions of 0%, 50% and 100%, 66 cylinders were casted.

Cylinder per case = 3 × 3 (compressive strength at 7 days , 28 days, and 90 days) + 2(tensile test at 28 days)

.

Table 3.1. Case Plan

Coarse Aggregate	Fine aggregate	Cement content (kg/m^3)	s/a	W/C	No. of cylinders
100% slag + 0% brick	100% Natural Sand	340	0.40	0.45	18*11 = 198
				0.50	
			0.44	0.45	
				0.50	
			0.48	0.45	
				0.50	
50% slag + 50% brick			0.40	0.45	
				0.50	
			0.44	0.45	
				0.50	
			0.48	0.45	
				0.50	
0% slag + 100% brick			0.40	0.45	
				0.50	
			0.44	0.45	
				0.50	
			0.48	0.45	
				0.50	

Table 3.2. Mixture Proportion of Concrete

% Replacement of Coarse Aggregate	Cement content (kg/ m^3)	s/a	W/C	Unit Content,(kg/m^3)				
				Cement	Fine Aggregate	Water	Coarse Aggregate	
							Slag	Brick
100% slag + 0% brick	340	0.40	0.45	340	735	153	1129	0
			0.50	340	718	170	1101	0
		0.44	0.45	340	808.84	153	1053	0
			0.50	340	789.46	170	1028	0
		0.48	0.45	340	882.3	153	978	0
			0.50	340	861.23	170	954.6	0

50% slag + 50% brick	340	0.40	0.45	340	735	153	564	455.7
			0.50	340	718	170	550.7	444.8
		0.44	0.45	340	808.84	153	526.6	425.3
			0.50	340	789.46	170	514	415.1
		0.48	0.45	340	882.3	153	489	394.9
			0.50	340	861.23	170	477.3	385.5
0% slag + 100% brick	340	0.40	0.45	340	735	153	0	911.3
			0.50	340	718	170	0	889.5
		0.44	0.45	340	808.84	153	0	850.6
			0.50	340	789.46	170	0	830.2
		0.48	0.45	340	882.3	153	0	789.8
			0.50	340	861.23	170	0	770.09

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:

$$\frac{C}{G_c\gamma_w} + \frac{S}{G_s\gamma_w} + \frac{A}{G_A\gamma_w} + \frac{W}{G_w\gamma_w} + \frac{Air\ (\%)}{100} = 1 \qquad (3.1)$$

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 Properties of Materials

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 3.3**.

Table 3.3. 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

3.3.1 Coarse Aggregate

To study the effects of partial replacement of mixed slag with natural aggregates, three different aggregate sizes were used in this study – 4.75mm, 12.5 mm, and 19.0 mm. First class bricks were procured from local market, and manually broken into pieces of desired size. The gradation was controlled as per ASTM C 33 (2003). The gradation followed in this study is shown in **Table3.4**. The slag aggregate was collected from a local steel manufacturing company. It was found that some slag aggregate were light in weight with a lot of voids and some were heavier with a little or no voids. Therefore, the slag aggregates were termed as the mixed slag aggregate (SM).

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 3.5** and the gradation shown in **Figure 3.1**.

Table 3.4. Gradation of coarse aggregate (according to ASTM C 33)

Aggregate Size	**Percentage according to ASTM C33**
25 mm to 20 mm	5%
20 mm to 12.5 mm	65%
12.5 mm to 9.5 mm	30%
Total	100%

Table 3.5. Properties of coarse aggregate

Aggregate Type	Specific Gravity	Absorption Capacity (%)	Abrasion (%)	SSD Unit Weight (kg/m^3)	Fineness Modulus
Brick Coarse Aggregate	2.14	19	38.88	1211	Controlled as per ASTM C 33 – 03
Iron slag	2.65	12.33	37.40	1349	-

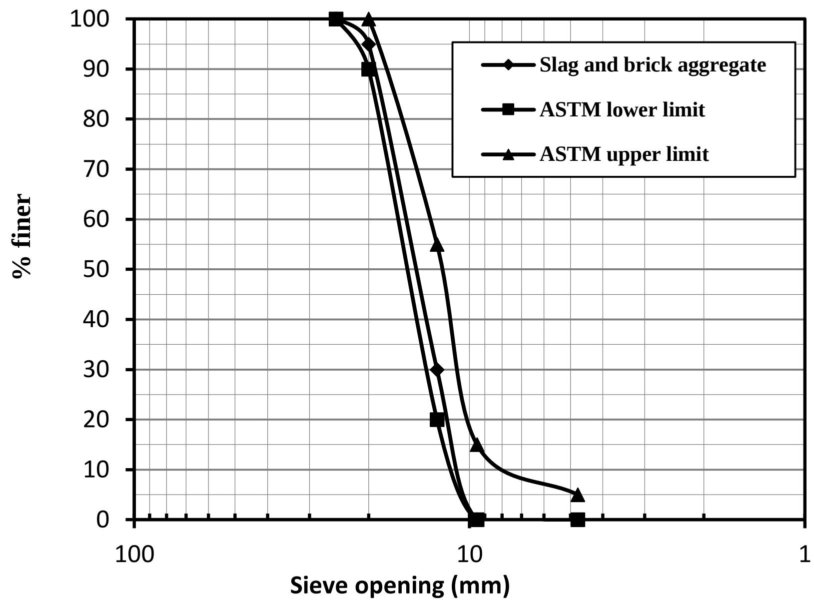


Fig. 3.1. Gradation of coarse aggregate

3.3.2 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 3.6**.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**.

Table 3.6. Properties of fine aggregate

Aggregate Type	Specific Gravity	Absorption Capacity (%)	Abrasion (%)	SSD Unit Weight (kg/m3)	Fineness Modulus

Sylhet Sand	2.59	1.50	-	1520	2.52

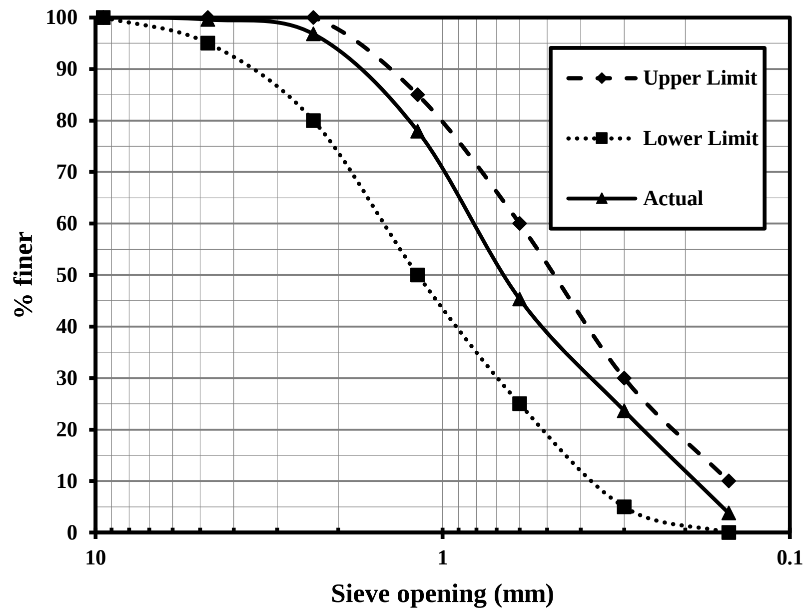


Fig. 3.2. Gradation of fine aggregate

3.3.3 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 3.7** (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.

Table 3.7. Composition of cement

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

3.3.4 Water

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

3.4 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, coarse 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.

First class bricks were broken manually. Prior to casting, these coarse aggregates were sieved separately to satisfy ASTM C 33 (2003) and mixed according to proportion. 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.

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.

3.5 Experimental Setup

After casting of concrete specimens, they were cured initially for 24 hours by covering the cylindrical molds with wet clothes 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).

3.6 Sample Preparation

3.6.1 Mold Preparation

For studying the effects of partial replacement of coarse aggregate with slag, cylindrical molds of diameter 100 mm and height 200 mm were used. 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 the casting of concrete of specimens, ASTM C31 was followed for standard procedure. Coarse aggregates were brought up to surface saturated dry (SSD) condition before casting.

Following precautions were observed:

a) Prevention of drying of the bed on which casting is to be done.

b) Dampening of the sheet on which slump is to be taken is also prevented.

c) To prevent mortar attack and mixing, the sheets and wall of mixing machine are washed every time before a batch is mixed and casted

d) Made sure that grease is applied to the wall of all cylindrical molds.

e) Made sure that proper distribution of paste and aggregate is done in casting all specimens.

f) The top surface of specimens must have a smooth surface, if that is not possible during casting, ten capping with a thick mortar after half an hour of cating is provided.

g) It is mandatory to cast a specimen with a proper distribution of materials, such as, the top must get as much aggregate as the middle and bottom part of the specimen.

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

The concrete slump test is used for the measurement of a property of fresh concrete. Slump is a term used to describe how consistent a concrete sample is. The test is an empirical test and 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.

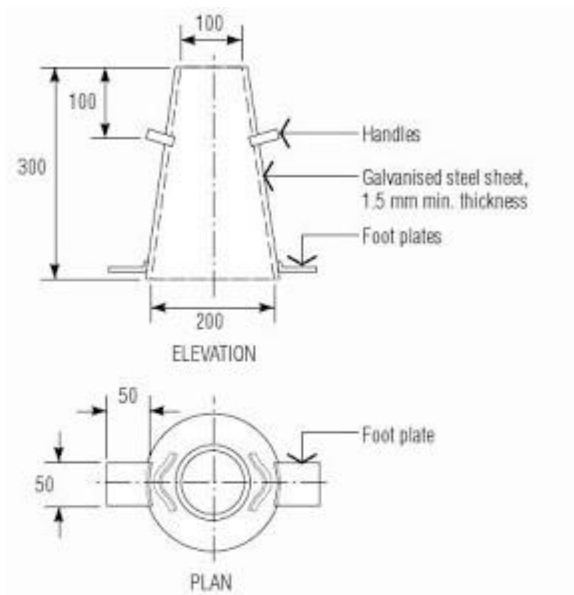


Fig. 3.3. Typical cone for slump test

3.6.4 Casting of Concrete Samples

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

The specification of the tamping rod, and the number of times the layer is tamped/rodded is summarized in **Table 3.8**.

Table 3.8. Differences between 100 mm diameter and 150 mm diameter concrete cylinder specimens

	100 mm diameter and 200 mm height
Tamping rod diameter	10 mm
Length of tamping rod	300 mm
No. of concrete layers in the mold to be tamped	2
No. of tamping	25 times

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). For the curing of specimens, a preliminary curing is done and followed by underwater curing. To prevent the evaporation of water from the unhardened concrete, each specimen was immediately covered with 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 and Young's modulus. 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.

3.7.1 Destructive Test

3.7.1.1 Compressive Strength

The compressive strength of concrete in this study was determined according to ASTM C 39 (2003). Crushing test is done in the semi-auto crushing machine as shown in **Fig. 3.4**. In this method, compressive axial load was applied to molded cylinders at a rate which is within a prescribed range of 0.15 to 0.35 MPa/s, until failure occurred. The compressive strength of the specimen was then calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen. The diameter and length of each cylinder specimen were measured using a Vernier caliper, and the cross-section was calculated. To determine the compressive strength of a particular batch of concrete on a particular age, the average compressive strength of three specimens was taken.

The compressive strength of concrete was measured at 7 days, 28 days, and 90 days using compressive strength testing machine according to ASTM C 39 (2003).

The following precautions were observed:

a) The top surface must be smooth, if not, capping is provided.

b) A base plate and top plate is applied to ensure uniform load distribution.

c) Load rate adopted from the standard (0.023MPa/s) is to be maintained throughout the crushing.

d) After each test the base plate of the machine is to be wiped for crushed particles.

Fig 3.4 Compressive failure

3.7.1.2 Splitting Tensile Strength

The splitting tensile strength of concrete was determined according to ASTM C 496 (2003), by applying a diametral compressive force along the length of cylindrical concrete specimens, until failure as shown in **Fig 3.5**. Tensile strength tests are performed at 28-day. Tests are performed in universal testing machine (UTM). The rate of loading was 0.7 to 1.4 MPa/min. This loading induces tensile stresses on the plane containing the applied load and relatively high compressive stresses in the area immediately around the applied load. Tensile failure occurs rather than compressive failure because the areas of load application are in a state of triaxial compression, thereby allowing them to withstand much higher compressive stresses than would be indicated by a uniaxial compressive strength test result. The maximum load sustained by a specimen is divided by appropriate geometrical factors to obtain the splitting tensile strength as shown in equation.

$T = 2P/\pi ld$

Where,

T = splitting tensile strength (MPa)

P = maximum applied load indicated by the testing machine (N)

l = length (mm)

d = diameter (mm)

Before placing the specimen in the testing machine (Universal Testing Machine, UTM), diameter of each specimen was determined by averaging three diameters measured near the ends and the middle of the specimen. Diametral lines were drawn on each end of the specimen using a marker to ensure that they are in the same axial plane. The specimen was placed in between the UTM bearing plates and aligned so that the lines marked on the ends of the specimen are vertical and centered.

Following precautions were adopted:

a) The side of the cylindrical specimen needs to be smooth.

b) The specimens need to be placed in the center position of base plate carefully.

c) Load rate adopted from the standard is to be maintained throughout the test.

d) After each test the base plate of the machine is to be wiped for crushed particles.

Fig 3.5. Tensile failure

3.7.1.3 Young's Modulus

The Young's modulus of each specimen was measured according to ASTM C 469 (2003), during compressive strength test of the specimen. In order to find out the young modulus of concrete specimens, an extensometer is applied to all the specimens during performing crushing test. The extensometer has two identical dial gauges. Readings are taken from the two gauges and average values are used to find the stress-strain plot and young's modulus. Readings from the extensometer are taken in every 5KN interval of crushing load applied. The dial gauge readings are averaged and multiplied by 0.01 to get deformation value in mm. From there strain value is calculated for each of the loads applied. Young's modulus is calculated at a strain of 0.0005 by dividing the corresponding stress to 0.0005. Young's modulus is calculated in Psi. Following precautions were adopted-

a) The extensometer needs to be properly set on the specimen, the spikes needs to be gripped tightly to the specimen.

b) All the fastening bolts need to be loosened to make sure that the spikes holding the specimen is not jammed, because otherwise gauge will not give deformation.

c) The dial gauges needs to be calibrated to zero before each test.

d) While handling the specimen from one place to another, the specimen should not be held gripping on the extensometer, because this way the spikes may slip.

e) While calculating strain, the length is to be considered is the distance between upper and lower spikes.

3.7.2 Non-destructive Test

3.7.2.1 Ultrasonic Pulse Velocity

The ultrasonic pulse velocity (UPV) through wet concrete specimen was measured using a PUNDIT apparatus, prior to compressive strength test. It has a transducer and receiver. The transducer generates pulse where the receiver receives the pulse. A coupling media (gel) is applied to the ends of a cylindrical specimen in order to provide a proper condition for transducing and receiving. The frequency of the pulse is kept at 54 kHz

The specimen dimensions were measured using Vernier calipers. The equipment was verified to operate properly by performing a zero-time adjustment. For this adjustment, coupling agent was applied to the ends of the reference bar provided by the manufacturer, and the transducers were pressed firmly against the ends of the bar until a stable transit time was displayed. The zero reference was adjusted until the displayed transit time agreed with the value marked on the bar.

Once the reference was adjusted, appropriate coupling agent (grease) was applied to the transducer faces and then the transducers were placed on opposite sides of the cylinder. The faces of the transducers were pressed firmly against the concrete surfaces until a suitable transit time was displayed. The transit time was recorded for further calculation using the flowing equation:

$$UPV = L/T$$

Where, *UPV* is the pulse velocity in m/s, *L* is the specimen length through which the pulse travelled in m, and *T* is the transit time in s.

The standards are adopted from ASTM C597 to carry out the test.

3.8 Conclusion

In this chapter, different methods adopted to achieve the objectives of the study are thoroughly discussed. Different testing parameters are explained in order to relate it to the study result. Experimental method is important in order to set out the scope the study. So, the methodology is followed by result and discussion in the next chapter.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 General

In this chapter the results that we got throughout this investigation have been summarized and discussed. The effect of partial replacement of steel slag on compressive strength, splitting tensile strength, Young's modulus and UPV are discussed. The effect of s/a on compressive strength, splitting tensile strength, Young's modulus and UPV are discussed. Moreover, for different replacement of steel slag and s/a, the stress-strain relationship of concrete, relationships between compressive strength and Young's modulus, compressive strength and tensile strength, UPV and compressive strength, UPV and Young's modulus are also discussed.

4.2 Effect of steel slag replacement and s/a

4.2.1 Workability of Concrete

The effect of steel slag as a partial replacement of brick aggregate on workability of concrete for different s/a ratio and W/C ratio is shown in **Fig. 4.1**. The workability of concrete increases with an increase in the replacement of steel slag and s/a. The workability of concrete as slump (in cm) is shown in Figure 4.1 for W/C 0.45 and 0.50. It is found that W/C of 0.50 shows better slump than the W/C ratio of 0.45. On the other hand, with the increase of replacement ratio of steel slag the workability increases. It is clearly found that concrete made with a 100% slag aggregate shows maximum workability. This is expected due to the less water absorption capacity of slag aggregate compared to the brick aggregate.

It is also found that with the increase of s/a ratio, workability is reduced. It is clearly revealed that the concrete made with slag aggregate has better workability compared to the similar concrete made with brick aggregate. Thangaselvi (2015) also concluded that the use of steel slag as replacement of coarse aggregate in concrete is beneficial for the better workability and strength up to 50% replacement level**.**

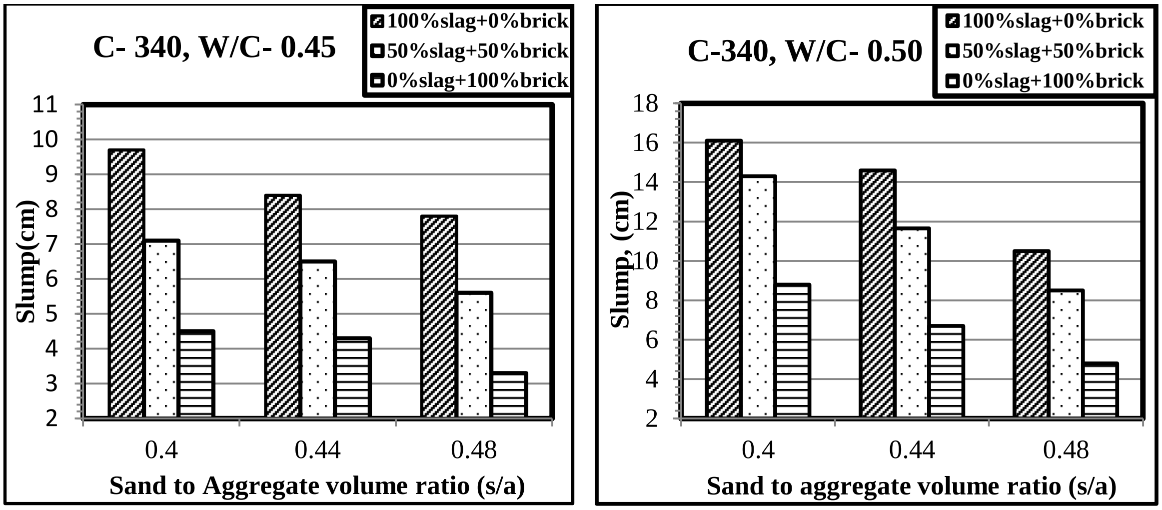


Figure 4.1: Workability of concrete

4.2.2 Compressive Strength of Concrete

The effect of replacement of steel slag on 28 days compressive strength of concrete is shown in **Fig.4.2**. 28 days compressive strengths of concrete cylinders for 0%, 50% and 100% replacement ratios of steel slag are shown in **Fig 4.2**. From the Figure **4.2**, it is found that 50% replacement of steel slag the strength is increases but after that the strength decreases for 50% replacement ratio of steel slag, the compressive strength of concrete is found at 26 Mpa and 22 Mpa for W/C 0.45 and 0.50 respectively. This indicates, with the increase of W/C ratio the compressive strength tends to decrease. Another observation is that, with the increase of s/a ratio the compressive strength of concrete is increased. It is found that the compressive strength is highest at 50% replacement of steel slag for each s/a ratio. The improvement in strength may be due to shape, size and surface texture of steel slag aggregates, which provide better bonding between the particles and cement paste (Thangaselvi 2015).

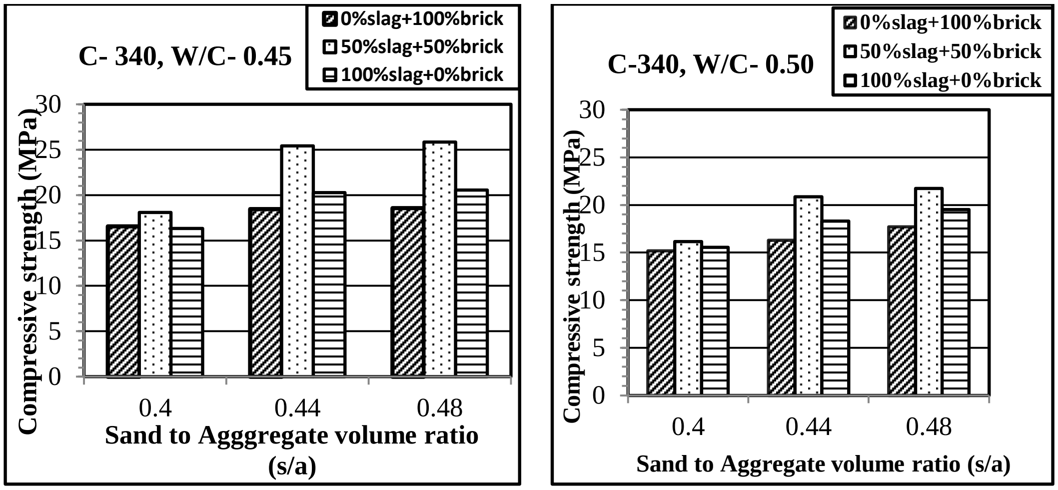
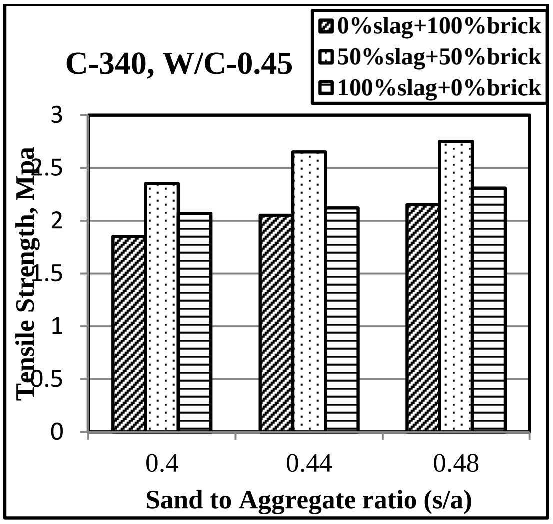


Figure 4.2: Compressive Strength of concrete

4.2.3 Splitting Tensile Strength of Concrete

The effect of replacement of steel slag and s/a on 28 days splitting tensile strength is shown in **Fig. 4.3**. It shows the split tensile strength of concrete using steel slag at 28 days. The results show that the split tensile strength is increased up to 50% replacement of coarse aggregate with steel slag, beyond that the split tensile strength is decreases. The replacement of coarse aggregate with steel slag has increased the compressive strength, split tensile strength of concrete (Thangaselvi 2015). It is also observed that the tensile strength follows the trend of compressive strength as described earlier. The replacement of coarse aggregate with steel slag has increased the compressive strength and split tensile strength of concrete (Thangaselvi 2015). It is also observed that the tensile strength follows the trend of compressive strength as described earlier.



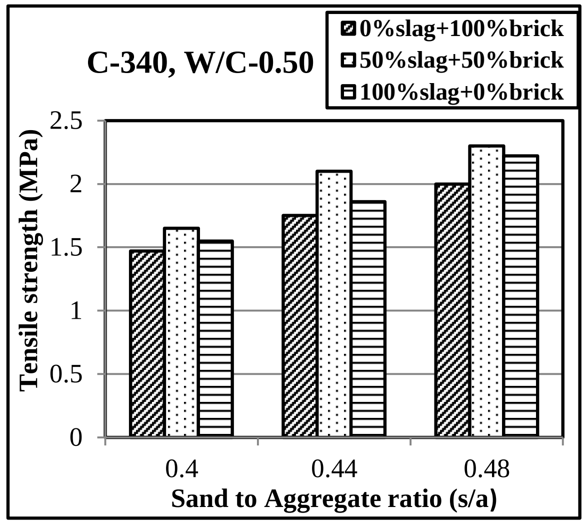


Figure 4.3: Tensile Strength of concrete

4.2.4 Ultrasonic Pulse Velocity

The effect of replacement of steel slag and s/a on 28 days splitting tensile strength is shown in **Fig. 4.4.** The variation of UPV with the change of different s/a ratio, W/C ratio and other parameters is shown in Figure. It is observed that lower W/C ratio gives better pulse velocity than a higher W/C ratio. The concrete strength is inversely proportional to water to cement ratio (Bogas et al. 2013). So that with the increase of w/c the UPV of concrete tends to decrease.

But with increasing s/a ratio, the strength tends to increase despite the UPV of concrete decreasing. On the other hand, with the increase of partial replacement of brick chips by steel slag the UPV also increases. This is because steel slag has high iron content making the ultrasonic pulse travel faster than anticipated.

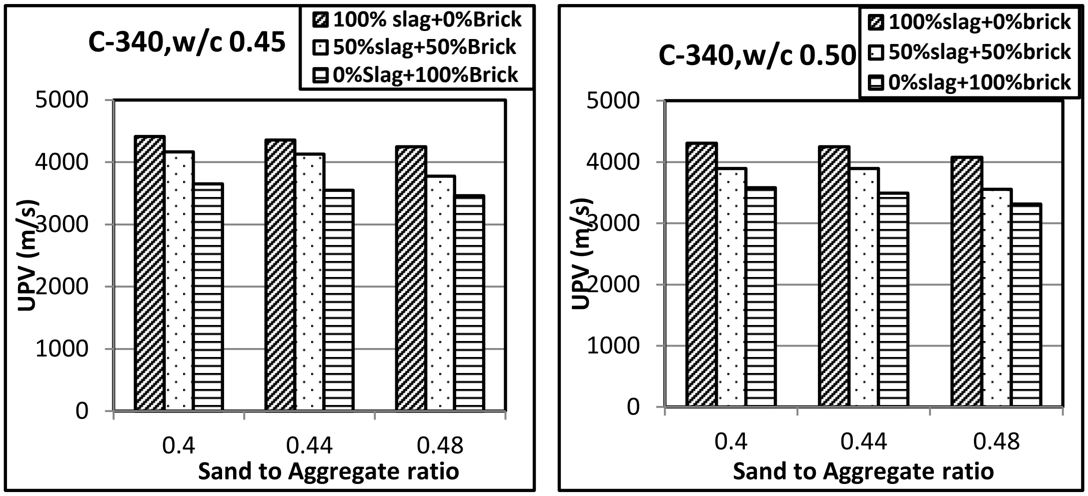


Figure 4.4: Ultrasonic pulse velocity

4.3 Relationship between Compressive Strength and Splitting Tensile Strength

The relationship between compressive strength and Young's modulus for different percent replacement of brick aggregate is shown in **Fig. 4.5**. Based on the experimental data in **Fig. 4.5**, the tensile strength of concrete can be correlated with compressive strength

$f_t\,(100\%slag) = 0.55\sqrt{f'c}$; $R^2 = 0.87$

$f_t\,(50\%\ slag) = 0.57\sqrt{f'c}$; $R^2 = 0.92$

$f_t\,(0\%\ slag) = 0.54\sqrt{f'c}$; $R^2 = 0.80$

by the following equations:

Where, *f*t is the splitting tensile strength in MPa and *f*c' is the compressive strength of concrete in MPa.

Concrete made with 50% replacement of steel slag exhibits the maximum splitting tensile strength for a given compressive strength.

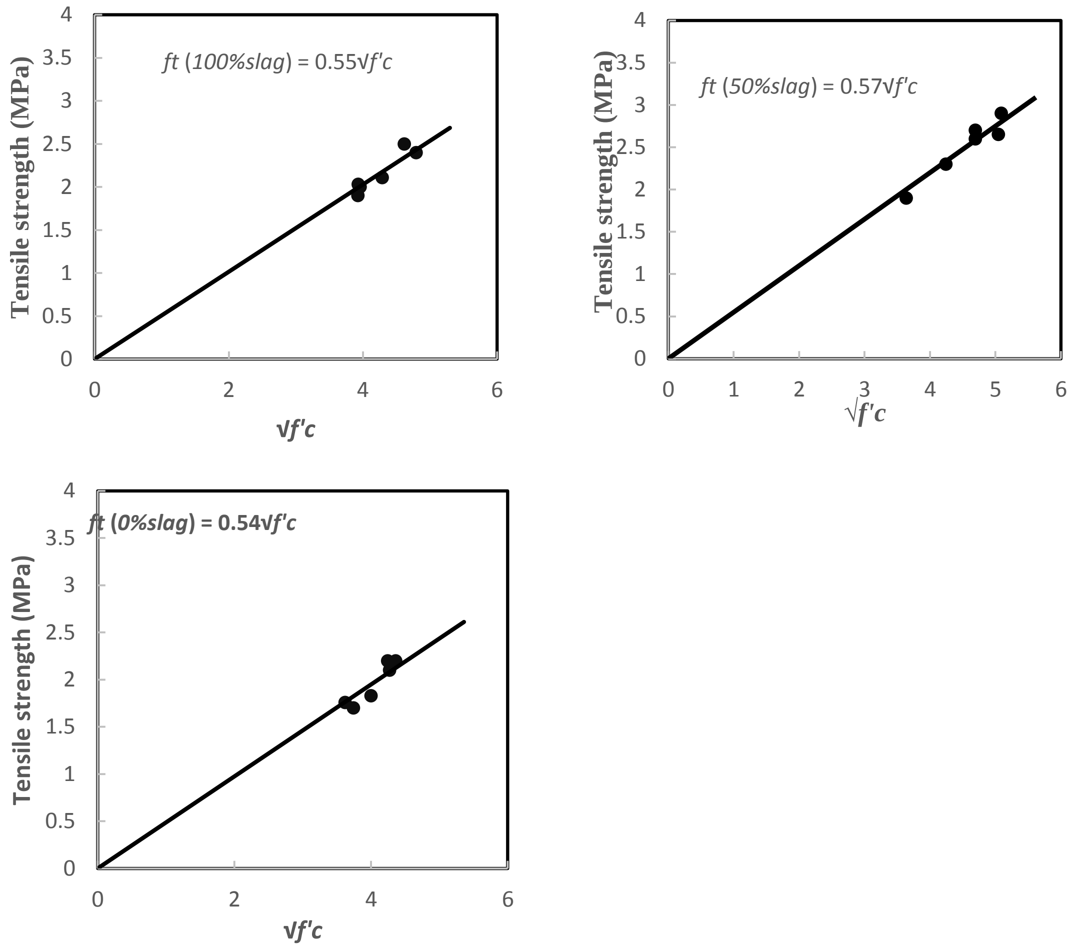


Fig. 4.5 Relationship between compressive strength and tensile strength

4.4 Relationship between Compressive Strength and Young's modulus

Young's modulus has been found out for concrete specimen made with each of the aggregate tested in order to analyze their behavior under applied stress. As young's modulus is an indicator of how elastic the concrete is, thus it very important in order to understand the behavior of concrete made with particular type of aggregate. From following figures it can be observed that concrete made with 50% replacement of steel slag has the highest recorded Young's modulus. The relationship between compressive strength and Young's modulus for different percent replacement of brick aggregate is shown in **Fig. 4.6**. Based on the experimental data in **Fig. 4.6**, the tensile strength of concrete can be correlated with compressive strength by the following equations:

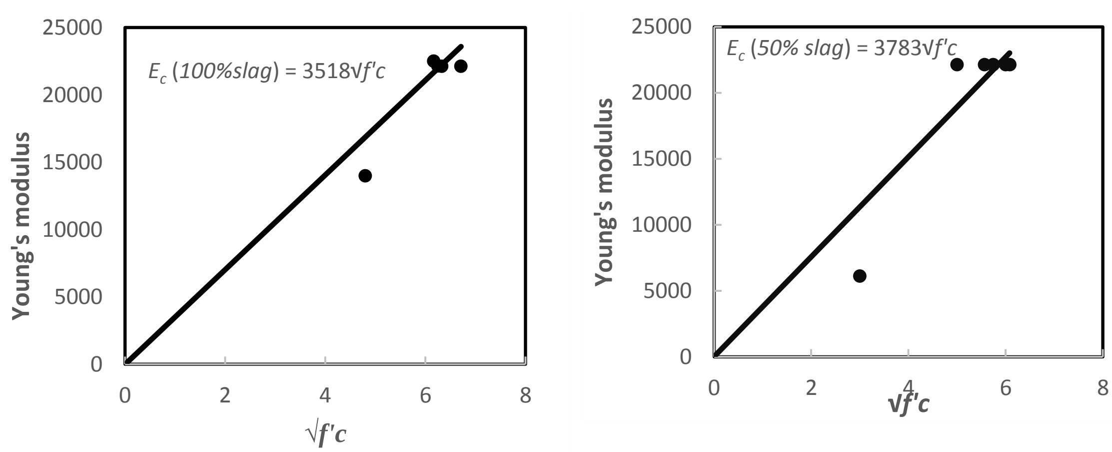
E_c (*100%slag*) = 3518√*f'c* ; $R^2 = 0.74$

E_c (*50% slag*) = 3783√*f'c* ; $R^2 = 0.81$

E_c (*0% slag*) = 3472√*f'c* ; $R^2 = 0.67$

Where, E_c is the splitting tensile strength in MPa and *f*c' is the compressive strength of concrete in MPa.

Concrete made with 50% replacement of steel slag exhibits the maximum Young's modulus for a given compressive strength.



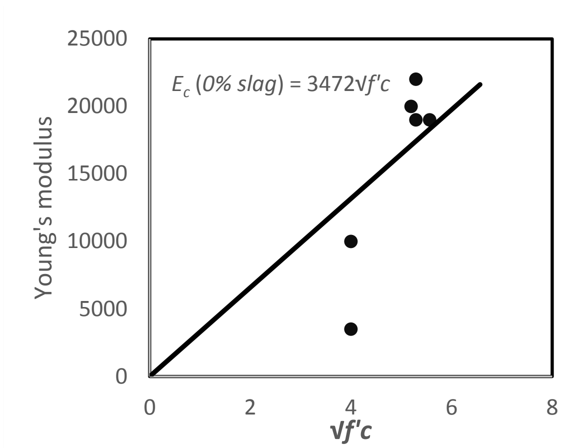


Fig. 4.6 Relationship between Compressive Strength and Young's modulus

4.5 Relationship between Compressive Strength and UPV

The relationship between compressive strength and UPV for different percent replacement of brick aggregate is shown in **Fig.4.7**. Based on the experimental data, the following relationships are proposed:

$E_{c=}$ *(100% slag)* = $1.837e^{0.1865x}$; $R^2 = 0.663$

$E_{c=}$ *(50% slag)* = $1.948e^{0.1906x}$; $R^2 = 0.7328$

$E_{c=}$ *(0% slag)* = $1.7272e^{0.1641x}$; $R^2 = 0.7197$

Where, *f*c' is the compressive strength of concrete in MPa and *UPV* is the Ultrasonic Pulse Velocity in km/s.

So we can see that for 50% slag replacement we got the higher strength.

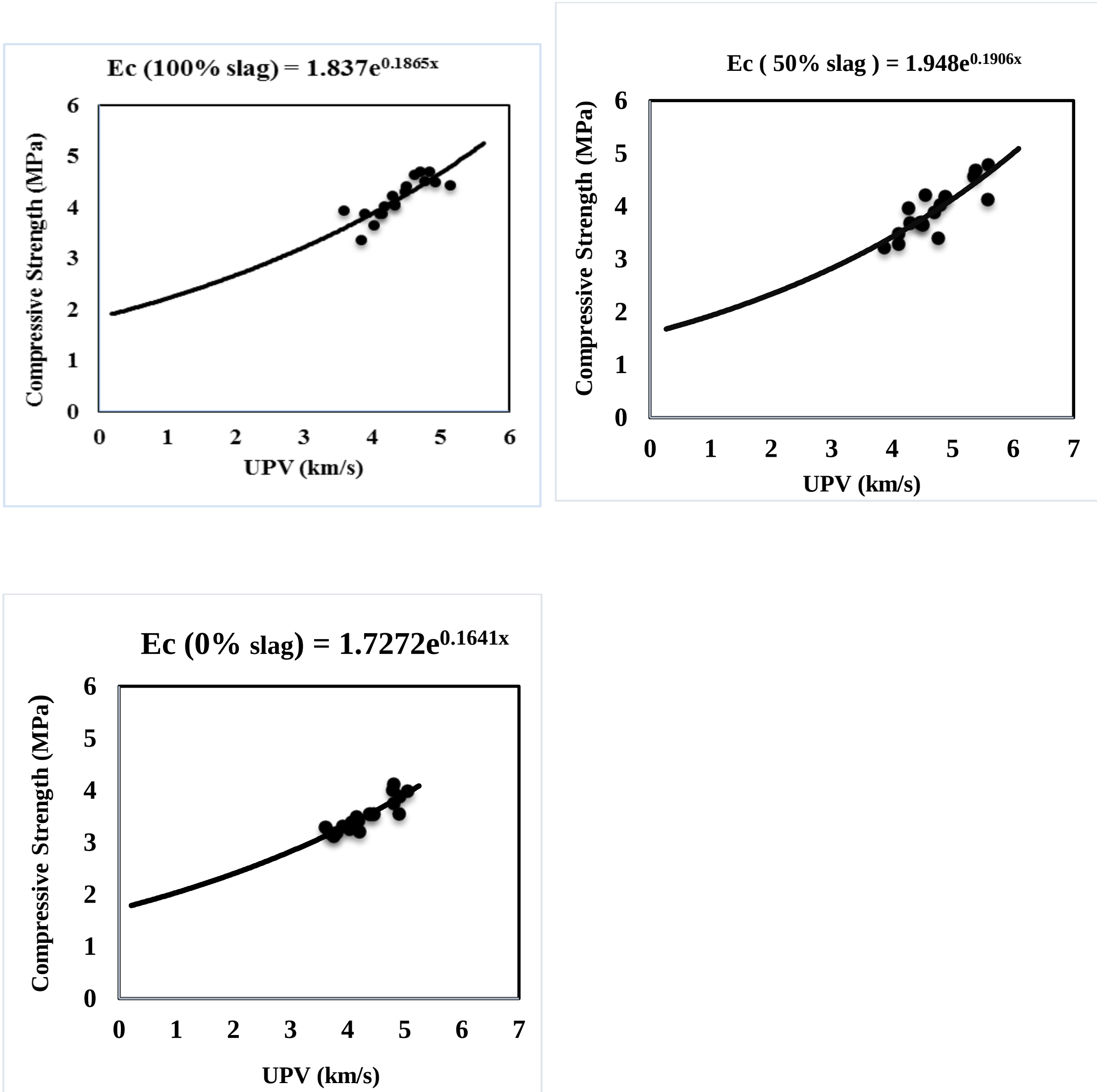


Fig. 4.7 Relationship between Compressive Strength and UPV

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 General

This chapter describes the summary of the research findings based on the results and discussions in chapter 4. Moreover, recommendation and future works related to this investigation are also mentioned in this chapter.

5.2 Conclusions

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

1. It was observed that at 50% replacement of brick aggregate with slag, we found the maximum workability. But with the increase of the percent replacement beyond 50% the workability tends to follow a decreasing manner.

2. We found the maximum compressive strength of concrete at 50% replacement of brick aggregate with slag aggregate.

3. We also observed reaching the maximum tensile strength at 50% replacement of brick aggregate with slag aggregate.

4. For all the variations of sand to aggregate ratios we found that the maximum compressive strength at 50% replacement of brick aggregate with slag

5. The relationship between Young's modulus and compressive strength; UPV and compressive strength; compressive strength and tensile strength were proposed.

6. We observed that UPV tends to increase with the increase of the amount of steel slag present in the concrete mixture. That means we found the maximum UPV value at 100% replacement of brick aggregate with slag aggregate.

7. From the relationship drawn between compressive strength and UPV we observed maximum compressive strength at 50% replacement of brick aggregate with slag whereas; for 0% replacement of brick aggregate we found minimum compressive strength.

8. From the relationship drawn between compressive strength and young's modulus we observed maximum compressive strength at 50% replacement of brick aggregate with slag whereas; for 0% replacement of brick aggregate we found minimum compressive strength.

9. From the relationship drawn between compressive strength and tensile strength we observed maximum compressive strength at 50% replacement of brick aggregate with slag whereas; for 0% replacement of brick aggregate we found minimum compressive strength.

10. We observed maximum compressive strength at 50% replacement of brick aggregate with steel slag for both of the W/C ratios. (0.45 and 0.5)

5.3 Recommendations

From this study, this is evident that at a cement content of 340 kg/m^3, construction engineers can go for 50% replacement of brick aggregate with steel slag without causing any decrease in the compressive strength compared to the using of conventional coarse aggregate in concrete mixture. But for 100% replacement of brick aggregate with steel slag, the compressive strength tends to decrease for all the variations of W/C ratios. While studying the variation of s/a ratios we found that maximum compressive strength occurs at s/a ratio of 0.44 at 50% replacement of brick aggregate with steel slag.

Moreover, non-destructive tests on structural members made with various percent replacements of brick aggregate can be conducted and results can be used to evaluate the pattern of increase or decrease of compressive strength.

5.4 Limitations and Future Work

Though this study has been primarily planned to study the scope of using steel slag as a percent replacement of brick aggregate, the scope was not limited to the effect of using steel slag only. This study also investigates the effect of variation of s/a ratio (0.40, 0.44 and 0.48) and W/C ratio (0.45atnd 0.50) on compressive strength of concrete. A total of three different percent replacements were studied, but there were no variation of cement content. Future works can be planned to study the effects of cement content variations to find an optimum s/a ratio and cement content for different percent replacement of brick aggregate with steel slag. Also this experiment could be broadened by studying the effect of using stone chips as a percent replacement of brick aggregate.

Though this study discusses the effect of percent replacement of brick aggregate with steel slag on major concrete properties like compressive strength, splitting tensile strength, stress-strain curve, and Young's modulus; the scope of the research can be expanded to study the effect of percent replacement on modulus of rupture of concrete, flexural and shear behavior of concrete under load as well.

Moreover, XRD test and SEM analysis is recommended for better understanding of the behavior of concrete specimens.

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