Durability of Concrete Made with Different Types of Aggregate Available in Bangladesh - Chloride Ingress

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DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Professor Dr. Md. Tarek Uddin and this work has not been submitted elsewhere for any purpose (except for publication).

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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

Keywords: Rapid Chloride Penetration Test (RCPT), Chloride Ingress, Ultrasonic Pulse Velocity (UPV), compressive strength, tensile strength, coarse aggregate, water-cement ratio, recycled brick aggregate, slag etc.

In recent years, a good number of attempts are made in order to measure and test durability of concrete in various aspects. If such study and tests are properly performed, suitable materials along with their mix combination can be identified in order to make a durable concrete structure. Therefore, in this study, different types of binder materials and aggregates that are available in Bangladesh are tested in order to find proper aggregates for better durability.

To perform this investigation, four different types of coarse aggregate (Brick Aggregate, Recycled Brick Aggregate, Black Stone and Shingles) and eight types of cement [Ordinary Portland Cement (OPC), CEM Type II B-M, CEM Type II B-M-SL, 40% OPC – 60% SlagCEM IIIA, 80% OPC – 20% Slag(CEM II/A-S), 70% OPC – 30% Slag(CEM II/B-S), 30% OPC –70% Slag(CEM-IIIB), 15% OPC –85% Slag(CEM-IIIC)] have been used. Aggregates were collected and prepared according to grading requirements of ASTM C33-03. Several tests as specific gravity, absorption capacity, unit weight and abrasion resistance were performed for coarse aggregate. Cylindrical concrete specimens of diameter 100 mm and length 200 mm were made with different W/C ratio (0.45 and 0.5) and cement content (340 kg/m^3 and 400 kg/m^3). A total of 42 different cases were considered and a total of 546 concrete specimens were made for testing. The specimens were tested for compressive strength, stress-strain curve and Young's modulus at the age of 28 days and 60 days. Non-destructive test as Ultrasonic Pulse Velocity (UPV) were also performed. To conduct UPV test Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT) were used.

The major objective of this study was to investigate the influence of different types of aggregate and different types of binding materials on Chloride Penetration through concrete. Due to time constraint, the mechanical properties of concrete for different types of aggregate and binding materials could only be measured. The significance of those results is discussed here. The research will be continued and data will be collected by RCPT and Chloride Ingress Test for measuring Chloride penetration through concrete.

LIST OF SYMBOLS

W/C	Water to Cement ratio
s/a	Sand to total aggregate volumetric ratio
R^2	Pearson product moment correlation co-efficient
f'_c	Compressive strength of concrete
f_t	Tensile strength of concrete
E_c	Young's Modulus of concrete

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1. Introduction

1.1 General

This chapter covers the background of the study the importance of the project precisely. It also states the durability as another important factor that should be ensured aside of strength properties of concrete. Objectives, thesis outline and scope of the study are also mentioned in this chapter.

1.2 Background

The durability of concrete is considered as one of the most important properties of concrete. Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical action and abrasion while maintaining it's desired engineering properties. Designers of concrete structures have traditionally focused on the strength characteristics of the material. In recent years, the industry has started to adopt a more holistic approach by emphasizing the life-cycle cost of a structure.

According to World Corrosion Organization (WCO) worldwide annual loss due to corrosion is 2.2 trillion US $. This loss also includes loss due to durability of concrete structures. The durability of concrete is affected by corrosion of steel reinforcements inside concrete. Corrosion reduces the effective cross section of structural components. This will reduce the axial, and flexural strength of elements, and makes them structurally weak. Design strength of a structure is also affected for a long term due to durability issue.

In Bangladesh, structures located at coastal regions are susceptible to damage due to corrosion of steel reinforcements, which is a threat to the durability of the structures. Thus ensuring durability is as important as strength properties for safety structures located at these areas. A huge amount of money is expensed to build a cyclone shelter at the coastal regions. But they fail to give service for a long term due to durability issue. Both money and time can be saved, if durable structures can be provided in these areas. These structures will give service for a long time and will have strength enough to stand during natural calamities.

Building a structure at a certain place creates various types of environmental pollution in that area. It creates noise pollution. It also pollutes surface water of nearby water source by the run-off of effluents during the construction period. A huge amount of dust particles is formed during construction period and it has negative impact on the air quality of the area concerned. Destruction of an existing structure also have more or less same impacts on the environment. So destroying an existing structure due to lack of durability and re-constructing it will result in environmental and economic loss. Thus we can get environmental benefit, if a structure can provide service for a long period of time.

1.3 Rational

Construction of a concrete structure demands a huge amount of money. So if the structure can be made durable, it will be concluded in a good value of money. A good number of studies have been done and still going on the topic of durability of concrete. Different parameters and methodologies are used in different studies.

Durability of concrete is measured and tested in various aspects. But vast research on durability of concrete, using different types of course aggregate, measured by RCPT test and Chloride Ingress Test is still limited. Therefore experimenting with a large variation of binding materials and aggregates is necessary to ensure durability of concrete.

1.4. Objective

The major objective of this study is to create a comparative analysis of the different parameters durability of concrete using different types of aggregates and different types of binding materials. The specific objectives are:

i. To investigate the influence of different types of aggregate on Chloride Penetration through concrete.

ii. To investigate the influence of different types of binding materials on Chloride Penetration through concrete.

1.5 Methodology of the Study

The investigation was conducted to achieve concrete of higher durability using different aggregates and study the mechanical properties. The properties of concrete can be changed with the change of type of aggregate, water-cement ratio, sand-aggregate ratio and cement content. The chloride ingress, compressive strength as well as the splitting tensile strength, the modulus of elasticity, Ultra-sonic Pulse Velocity (UPV), workability of concrete, percentage of air were studied in our research. There were four types of coarse aggregate as brick aggregate, recycled brick aggregate, black stone and shingles. Each aggregate had 13 cases with the variation of binding materials (OPC, CEM Type II B-M, CEM Type II B-S, CEM Type II B-S(40% OPC – 60% Slag)), 40% OPC – 60% Slag(CEM-IIIA), 80% OPC – 20% Slag(CEM II/A-S), 70% OPC – 30% Slag(CEM II/B-S), 30% OPC –70% Slag(CEM-IIIB), 15% OPC –85% Slag(CEM-IIIC), W/C ratio (0.45, 0.50) and cement content (340 kg/m^3, 400 kg/m^3). For each cases 13 specimens were made. 3 specimens were tested for compressive strength and UPV test at 28 days, 2 specimens were tested for compressive strength and UPV test at 60 days, 2 specimens were tested for compressive strength and UPV test at 6 months, 1 specimen was tested for Split Tensile Strength Test by UTM machine at 28 days, 1 specimen was tested for Split Tensile Strength Test by UTM machine at 60 days and 1 specimen was tested for

Split Tensile Strength Test by UTM machine at 6 months, 1 specimen was gone through RCPT at 28 days, 1 specimen was tested for chloride ingress at 60 days, 1 specimen was tested for chloride ingress at 6 months. Total 42 cases were studied and 546 specimens were made.

1.6 Thesis Outline

The rest of the thesis chapters will be organized as follows:

Chapter 2: Literature Review; the chapter discusses about the past works on this subject, necessity and importance of the study, analysis of data on previous works.

Chapter 3 – Methodology; discusses the procedural steps of the study.

Chapter 4 – Comparative Data Analysis; it discusses the durability and strength of concrete by using different types of aggregates and for different types of mix deigns.

Chapter 5 – Conclusion and Summary; discusses about the effectiveness of the study.

Chapter 6- Future Plan; discusses about future works to be done.

2. Literature Review

2.1 General

This chapter discusses about effect on durability of concrete due to different size and grading of the coarse aggregate. The chapter also describes in brief the estimation of chloride permeability of concretes considering the effects of cement type, curing condition and age on the basis of past studies. It describes the effect of Aggregate fraction on the reliability of RCPT results. It also describes the durability performance of concrete made with fine recycled concrete aggregates from crushed concrete.

2.2 Effect of different size and grading of coarse aggregate

Reinforced concrete structures in marine and similar environmental conditions have to withstand severe exposures. Due to this, the mix design procedures have to be revised to include durability as a primary criterion along with strength and workability. If the proportion of larger size aggregate increases in the mix, the local porosity increases and the overall durability decreases. Reducing the average aggregate size in a mix improves the pore structure and enhances the durability of concrete (Basheer 2005) [1]. Most of the important properties of hardened concrete are related to the quantity and characteristics of various types of pores in the cement paste and aggregate components of the concrete. For example, the engineering properties of concrete, such as strength, durability, shrinkage and permeability, are directly influenced or controlled by the number, type and size of pores present. The total volume of pores, not their size or continuity affect the strength and elasticity of concrete, whereas concrete permeability is influenced by pore volume, size and continuity. It is believed that capillary voids larger than 50 micrometer , referred to as macro pores, are detrimental to strength and impermeability, whereas voids smaller than 50 micrometer, referred to as micro pores, are more related to drying shrinkage and creep. The movement of gases, liquids and ions through concrete is important because of their interactions with concrete constituents and the pore water which can alter the integrity of concrete directly and indirectly, leading to the deterioration of structures.

In reinforced concrete this deterioration is mainly due to the corrosion of reinforcement, freeze–thaw attack or chemical attack. In the recent past the cost of repair of structures due to such deterioration has been high. So durable concrete can be produced resorting to mixes with a low average aggregate size.

2.3 Effects of cement type, curing condition and age

Permeability is an important factor affecting the concrete durability. It controls the rate of entry of moisture that may contain aggressive chemicals. Concrete permeability depends largely on the volume and size of the interconnected capillary pores in the cement paste, and also on the intensity of micro-cracks at the aggregate–cement paste interface as well as within the paste itself. Low permeability of concrete can improve resistance to the movement of water, sulphate ions, chloride ions, alkali ions, and other causes of chemical attack. It is generally agreed that the ingress of chloride ions into concrete leads, in many structures, to long-term deterioration. In other words, the chloride permeability of concrete is such an intrinsic property of the concrete that needs to be assessed independently, especially in the design and construction of structures to be built in a salt-laden environment. When the chloride concentration of concrete exceeds a certain threshold value, de-passivation of the steel occurs and reinforcing bars start to corrode. It is a convenient way to use a pozzolanic material in the production of the concrete for improving its resistance to chloride penetration and eventually reducing chloride-induced corrosion initiation period of steel reinforcement. Blended (or pozzolanic) cements are being used worldwide to produce dense and impermeable concrete. They contain a blend of portland cement clinker and a variety of natural pozzolans and/or supplementary cementing materials such as blast furnace slag, fly ash, silica fume, etc. Curing condition, testing age, water–cement ratio, and using mineral admixture such as silica fume, flay ash, slag, etc. in the concrete production are the main factors governing the performance of the concretes against chloride ingress (Gneyisi, 2009)[2]. Concretes subjected to wet curing procedure resulted in higher resistance to chloride permeability in comparison to uncontrolled and controlled curing conditions.

The blended cement concretes exhibited higher resistance against chloride penetration than the plain concretes depending mainly on W/C ratio and curing procedure.

Among the blended cements, the use of blast furnace slag cement (CEM III/A) is very effective in reducing chloride permeability of concretes, especially under long-term proper curing condition. Cement type, W/C ratio, curing condition, and testing age is very effective on the chloride permeability of concretes.

2.4 Effect of Aggregate fraction on the reliability of RCPT results

The exposed surfaces of concrete structures are subjected to the attack of deleterious agents such as temperature, wind, sun, moisture, chlorides and atmospheric carbon dioxide. It is these deleterious agents that are instrumental in causing the rapid deterioration of concrete structures, sometimes leading to premature failure. Therefore, it is vital to focus attention on those properties of the concrete near the exposed surface, which allow the ingress of deleterious agents. The important properties of concrete present near the exposed surface which need attention are adsorption, gas diffusion and capillary absorption when the concrete is in an unsaturated state, and permeability and diffusion when the concrete is in a saturated or nearly saturated state. Submerged concrete structures are generally devoid of dissolved oxygen, and therefore, are free from chloride-induced corrosion of the reinforcing steel. However, in above-ground concrete structures, the exposed concrete surface will be subjected to drying action due to wind, temperature and sun. Thus, the concrete near the exposed surface will have non-uniform moisture distribution (or moisture gradients), and the moisture content generally will be lower than the saturation limit. As a result of the exposed concrete being in an unsaturated state, moisture (with chlorides and dissolved oxygen) will be absorbed into the concrete cover by capillary forces depending on the degree of saturation of the concrete, thereby sustain the chloride-induced corrosion of the reinforcing steel. The movement of moisture containing chloride and dissolved oxygen by capillary absorption is reported to be significantly faster, which demonstrates the significance of capillary absorption for long term durability of above-ground concrete structures. The RCPT results showed good correlation with the results of 90-day chloride ponding tests on companion slabs cast from the same concrete mix. The higher the total charge passed through the hardened cement matrix, the lower is its resistance to chloride penetration. In recent years, the RCPT is widely employed for the qualitative evaluation of chloride permeability of structural concrete although the technique has a few drawbacks. The main drawback of the RCPT according to Andrade is the possibility of other ions present in the pore solution of the hardened matrix conducting a part of the total current leading to an inaccurate estimation. The aggregates, depending on their volume fraction in the mix and type, may also influence the RCPT results (Wee, 1999)[3] .

For the plain cement concrete and mortar specimens, regardless of the w/b ratios (0.40, 0.50 and 0.60) and pre-curing duration (3, 7 and 28 days), the depths of chloride penetration increases with increasing period of immersion in salt solution (up to 90 days). For a given immersion period, the depths of chloride penetration through concrete and mortar decreases insignificantly with increasing pre-curing period, but the depths of chloride penetration increases significantly with increasing w/b ratios. The plain cement mortar specimens (0.4, 0.5 and 0.6 w/b ratio) of lower aggregate content (higher cement content) to be more resistant against chloride penetration compared to the plain cement concrete specimen of similar w/b ratios but with higher aggregate content (lower cement content). the RCPT demonstrated the plain cement mortar specimens (0.4, 0.5 and *0.6 w/b* ratios) of lower aggregate content (higher cement content) to be less resistant against chloride penetration than the corresponding plain cement concrete specimens of similar w/b ratio but with higher aggregate content (lower cement content), The measured electrical resistivities for the mortar specimens with and without silica fume (lower aggregate and higher cement content) are significantly lower than those for the concrete specimens (higher aggregate and lower cement content) with and without silica fume, which explain the reason for the passage of higher charge through the former during the RCPT. The lower aggregate fraction (higher cement fraction) in the plain cement mortar and the mortar blended with silica fume mislead the RCPT results. A higher cement fraction in the mortar mix with and without silica fume promotes the passage of greater charge as the resistivity of the cement paste is lower by several orders of magnitude compared to that of the aggregates (fine and coarse).

2.5 Durability performance of recycled aggregates

Sustainable construction has become a great concern over construction practice at the expense of the future of our planet. This is due to the fact that the construction industry is a massive consumer of natural resources and a huge waste producer as well. High value of raw material consumption in the construction industry becomes one of the main factors that causes environmental damage and pollution to our mother earth and the depletion of natural and mineral resources. The resources such as coarse aggregates, sands and cements will be at a disadvantaged position, as these resources are not able to cope with the high demand in the construction industry. Therefore, utilizing the recycled aggregate may be one of the significant efforts in achieving a sustainable construction. The major difference between natural aggregate and recycled coarse aggregate (RCA) is the adhered mortar at the surface of the RCA. It is a porous material, exhibits lower bulk density and saturated surface dry density, 1290–1470 kg/m3 and 2310–2620 kg/m3 respectively. The bulk density of the RCA is comparable to that of the lightweight aggregate. The higher porosity of the RCA is due to the higher content of adhered mortar responsible for its low resistance towards mechanical and chemical actions. There were some works already carried out by researchers to explore the important properties of this RAC such as workability, compressive, flexural and tensile strength, elastic modulus and so on. Replacing natural coarse with the RCA in concrete requires 10% of extra water in order to achieve the same slump. The RCA content in the concrete is found to have an inverse relationship with its compressive strength. However, at low level of replacement, i.e. less than 20%, this effect is negligible. The increase in concrete porosity and the presence of weak interfacial bonding between aggregate and binder matrix are mainly attributed to this situation. The uniaxial tensile strength and modulus of elasticity have also exhibited the same changing profile as the compressive strength. The reduction effect in the uniaxial tensile strength is up to about 30% for elastic modulus, it is about 45% when the coarse aggregate of concrete is completely replaced with the RCA. However, for the concrete with cylinder compressive strengths staying in the range of 25–30 MPa, the modulus of elasticity of concrete containing the RCA is only 3% lower than that of the normal concrete. In terms of the flexural strength, it has been reported that the RCA content has insignificant influence on that. Increase of the

RCA content in concrete increase the shrinkage as well. A total of 50% increment on shrinkage is registered by the concrete when the coarse aggregate is completely superseded with the RCA. For air permeability, the permeability of concrete containing 60% of the RCA has increased drastically by 196% compared to that of the normal concrete. The concrete with 100% RCA as the coarse aggregate has been graded as ‘‘poor’’ in the oxygen permeability index (OPI). This phenomenon is mainly due to the cracks and fissures created within the micro and macro structures of the RCA during the crushing process. However, the permeability of the RAC is possible to be refined through a longer curing duration. These kinds of shortcomings of the RAC could also be enhanced by the incorporation of pozzolonic materials like fly ash and blast furnaces slag as in the conventional concrete , just only that the mindset of most practitioners are still dominated by negative effects of the RCA in concrete. Therefore, the application of the RAC is still not encouraging, especially in those countries where the sources of natural aggregate are still abundant. In addition, there are even few researchers who would recommend suitable mix design methods for the RAC. They seldom describe and examine the suitability of an individual mix design method for the RAC in specific way. In fact, most of them have simply shown the mix proportions of concrete mixtures in the experimental program. However, there are also some researchers who have recommended that adjustments like lowering the water cement ratio enable the RAC to achieve higher target strength when it is designed by the conventional way as in the normal concrete. For instance if a RAC can achieve the compressive strength of 25 MPa, the RAC is then deemed practical in many applications, e.g. concrete pavement, ground slab, drainage, load bearing wall, etc. As the replacement ratio increases, the compressive strength and elastic modulus decreases, and the drying shrinkage strain increases. However, by estimating the decrease in quality by the relative quality values and adjusting the replacement ratio, the quality required for the concrete can be ensured (Eguchi 2007)[4]. The replacement level of the natural coarse aggregate with the RCA would reduce the compressive strength of the concrete. However, the replacement up to 80% is still acceptable to achieve the target strength by employing the DoE mix design method (Kwan 2011)[5].

2.6 Quality of cement effects durability of concrete

Concrete construction works in Bangladesh is rapidly increasing due to the necessity of development of significant number of infrastructures as well as booming of real estate business not only in the capital city, Dhaka but also in other major cities, such as Chittagong, Sylhet, Cox-Bazar, Comilla, etc. Due to a huge demand of cement for making concrete structures, more than 60 national and international cement companies are producing cement and supplying it to the market with different brand names. The per capita per year cement consumption was 22 kg in 1999 but it is increased to 65 kg in 2009 (Banikbarta, 2011)[6]. It is expected that it will be increased by several times in the near future. At this critical stage of huge construction works in Bangladesh, it is necessary to take steps for ensuring sustainable construction works in Bangladesh so that the structures which are constructed today will be durable for a long service life and thereby will reduce the demand of ingredients for making concrete in future. This strategy will ensure availability of concrete ingredients for making homes and other structures for future generations to come. Based on this background, an integrated research project has been taken for sustainable construction works in Bangladesh. This integrated research project covers various vital issues related to the sustainable construction works, such as (i) common causes of deterioration of concrete structures in Bangladesh, (ii) common problems at construction sites that cause early deterioration of concrete structures in Bangladesh, (iii) mechanical properties of concrete made with different aggregates available in Bangladesh, (iv) investigation on different cement brands available in the market in Bangladesh, (v) recycling of demolished concrete as coarse aggregate for new construction works and making blocks. At 28 days, compared to CEM I cement, CEM II/A-M and CEM II/B-M show 30% lower strength, and CEM II/A-S and CEM II/A-L show 20% lower strength. Cement brands with more setting time (both initial and final) show lower strength (T. U. Mohammed, 2012) [7]**.** Relationships between the setting time and compressive strength of mortar are proposed and can be used to predict the compressive strength of cement from the data of setting time.

3. Methodology

3.1 General

In this experiment brick aggregate, recycled brick aggregate, black stone and shingles as coarse aggregate, Sylhet sand as fine aggregate, water, cement as binding material were used to make cylindrical concrete specimen. The chapter describes the full experimental procedure, material properties of both coarse and fine aggregate. Casting were performed according to different codes of ASTM. Specific ASTM standards for carrying out different test methods and the results from the tests are mentioned in this chapter.

3.2 Background of the Work

The following procedures was followed in the field work before making concrete specimen:

- Selecting coarse aggregate and grading them according to ASTM **C33**.

- Sylhet sand is used as fine aggregate after sieving and grading them according to ASTM **C33**.

- Using cement as binding material.

3.3 Material Properties

This section describes the properties of coarse aggregate, fine aggregate, binding material, water and chemical admixture with their dosage limits. The test were performed according to the following ASTM codes.

Tested Parameters	Test Method
Specific Gravity	ASTM C127
Absorption Capacity	ASTM C127
Unit Weight and Voids in aggregate	ASTM C29
Abrasion Test	ASTM C131
Fineness Modulus	ASTM C136

Table 3.1 ASTM Test Methods Followed

3.3.1 Binding Material

As a binding material Ordinary Portland Cement (OPC), CEM Type II B-M, CEM Type II B-S, CEM Type II B-S(40% OPC – 60% Slag),), 40% OPC – 60% Slag(CEM-IIIA), 80% OPC – 20% Slag(CEM II/A-S), 70% OPC – 30% Slag(CEM II/B-S), 30% OPC –70% Slag(CEM-IIIB), 15% OPC –85% Slag(CEM-IIIC) has been used in this research. CEM Type II B-M has about 65% -79% clinker, 21%-35% of fly ash, limestone and slag and 0.5% gypsum. Gypsum acts as a regulator preventing cement flash setting. CEM Type II B-S consists of clinker, blast furnace slag (approximately 25 %) and a mixture of calcium sulfate anhydrate and semi-hydrate as a retarder.

Fig 3.1: OPC

3.3.2 Aggregate

We used brick aggregate, recycled brick aggregate, black stone and shingles as coarse aggregate. We used Sylhet sand as fine aggregate which is commonly used in our country for construction works.

3.3.2.1 Coarse Aggregate

Coarse aggregates were collected from the local markets. For the ASTM requirements various tests like specific gravity, unit weight test, absorption test, Los Angeles Abrasion test and sieve analysis were done. Los Angeles Abrasion test was done according to ASTM **C131,** specific gravity and absorption test were done according to ASTM **C127** and unit weight test were done according to ASTM **C29**.

Fig 3.2: Recycle brick and brick aggregates

Fig 3.3: Shingles and black stones

Table 3.2: Specific Gravity of black stone

Mass of oven dry test sample in air, A	Mass of saturated surface dry test sample in air, B	Apparent mass of saturated test sample in water, C	Specific Gravity (SSD)	Avg. Sp.Gr. (SSD)
2387.8	2426.5	1563.7	2.81	
2219.3	2248.9	1453.5	2.83	2.82
1990.9	2020.6	1304.6	2.82	

Table 3.3: Specific Gravity of shingles

Mass of oven dry test sample in air, A	Mass of saturated surface dry test sample in air, B	Apparent mass of saturated test sample in water, C	Specific Gravity (SSD)	Avg. Sp.Gr. (SSD)
2284.5	2324.1	1423.6	2.65	
2410.7	2477.2	1496	2.65	2.65
2111.3	2156.8	1313.2	2.65	

Table 3.4: Specific Gravity of brick aggregate

Mass of oven dry test sample in air, A	Mass of saturated surface dry test sample in air, B	Apparent mass of saturated test sample in water, C	Specific Gravity (SSD)	Avg. Sp.Gr. (SSD)
1867	1921.6	926	1.98	
1818.5	1897.5	901.6	1.98	1.98
1765.1	1821.4	875.7	1.98	

Table 3.5: Specific Gravity of recycled brick aggregate

Mass of oven dry test sample in air, A	Mass of saturated surface dry test sample in air, B	Apparent mass of saturated test sample in water, C	Specific Gravity (SSD)	Avg. Sp.Gr. (SSD)
2571.3	2611.5	1370	2.14	
2282.6	2345.6	1219.5	2.15	2.14
2540.8	2677.3	1355.7	2.14	

Table 3.6: Absorption of black stone

Mass of oven dry test sample in air, A	Mass of saturated surface dry test sample in air, B	Apparent mass of saturated test sample in water, C	Absorption (%)	Avg. Absorption (%)
2387.8	2426.5	1563.7	1.62	
2219.3	2248.9	1453.5	1.33	1.5
1990.9	2020.6	1304.6	1.49	

Table 3.7: Absorption of shingles

Mass of oven dry test sample in air, A	Mass of saturated surface dry test sample in air, B	Apparent mass of saturated test sample in water, C	Absorption (%)	Avg. Absorption (%)
2284.5	2324.1	1423.6	1.3	
2410.7	2477.2	1496	1.1	1.1
2111.3	2156.8	1313.2	.9	

Table 3.8: Absorption of brick aggregate

Mass of oven dry test sample in air, A	Mass of saturated surface dry test sample in air, B	Apparent mass of saturated test sample in water, C	Absorption (%)	Avg. Absorption (%)
1867	2346.2	926	10.7	
1818.5	2444.5	901.6	10.15	10.32
1765.1	1999.4	875.7	10.11	

Table 3.9: Absorption of recycled brick aggregate

Mass of oven dry test sample in air, A	Mass of saturated surface dry test sample in air, B	Apparent mass of saturated test sample in water, C	Absorption (%)	Avg. Absorption (%)
2571.3	2866.7	1370	22.5	
2282.6	2657.2	1219.5	22.6	22.4
2540.8	2887.4	1355.7	22.2	

Table 3.10: % Abrasion Wear of Black stone

Mass of sample before test (g)	Mass retained on sieve size 1.70 mm (g)	Mass passing on sieve size 1.70 mm (g)	% wear	Avg. % wear
5000	4316	638	13.6	13.55
5000	4322	632	13.5	

Table 3.11: % Abrasion Wear of Shingles

Mass of sample before test (g)	Mass retained on sieve size 1.70 mm (g)	Mass passing on sieve size 1.70 mm (g)	% wear	Avg. % wear
5000	3670	1330	26.6	26.65
5000	3650	1350	26.7	

Table 3.12: % Abrasion Wear of brick aggregate

Mass of sample before test (g)	Mass retained on sieve size 1.70 mm (g)	Mass passing on sieve size 1.70 mm (g)	% wear	Avg. % wear
5000	3027	1973	39.5	39.5
5000	3020	1980	39.5	

Table3.13: % Abrasion Wear of recycled brick aggregate

Mass of sample before test (g)	Mass retained on sieve size 1.70 mm (g)	Mass passing on sieve size 1.70 mm (g)	% wear	Avg. % wear
5000	2874	2126	43	43
5000	2880	2120	42.9	

Fig 3.4: Los Angeles Abrasion test

Table 3.14: Unit weight of Black stone

Mass of mold (kg)	**Mass mold and aggregate (kg)**	**Unit weight** (kg)	**Avg. unit weight (kg)**	**SSD unit weight (kg)**
6.6	26.43	1513		
6.6	26.75	1538	1528	1551
6.6	26.67	1532		

Table 3.15: Unit weight of Shingles

Mass of mold (kg)	**Mass mold and aggregate (kg)**	**Unit weight** (kg)	**Avg. unit weight (kg)**	**SSD unit weight (kg)**
6.6	28.27	1654		
6.6	28.32	1656	1656	1674
6.6	28.30	1658		

Table 3.16: Unit weight of brick aggregate

Mass of mold (kg)	**Mass mold and aggregate (kg)**	**Unit weight** (kg)	**Avg. unit weight (kg)**	**SSD unit weight (kg)**
6.6	18.10	877		
6.6	18.42	902	892	1076
6.6	18.35	896		

Table 3.17: Unit weight of recycles brick aggregate

Mass of mold (kg)	**Mass mold and aggregate (kg)**	**Unit weight** (kg)	**Avg. unit weight (kg)**	**SSD unit weight (kg)**
6.6	20.6	821		
6.6	21.1	829	825	1004
6.6	20.8	825		

Fig 3.5: Unit Weight test

3.3.2.2 Fine Aggregate

Fine aggregates were collected from the local markets. For the ASTM requirements various tests like specific gravity, unit weight test, absorption test, Los Angeles Abrasion test and sieve analysis were done. Fineness Modulus test was done according to ASTM **C136,** specific gravity and absorption test were done according to ASTM **C127** and unit weight test were done according to ASTM **C29**.

Table 3.18: Specific Gravity of fine aggregate

Mass of pycnometer	Mass of pycnometer + saturated surface dry sand	Mass of pycnometer + saturated surface dry sand+water	Weight of pycnometer+ water	Specific gravity (SSD)	Avg. specific gravity (SSD)
233	751.7	1546.4	1237	2.47	
283	791.4	1578	1276	2.46	2.46
288	832	1600	1280	2.43	

Table 3.19: Absorption of fine aggregate

Mass of pycnometer	Mass of pycnometer + saturated surface dry sand	Weight of SSD sand	Weight of oven dry sand	Absorption (%)	Avg. Absorption (%)
233	751.7	1546.4	1237	3.06	
283	791.4	1578	1276	3.13	3.00
288	832	1600	1280	2.86	

Table 3.20: Unit weight of fine aggregate

Mass of mold (kg)	**Mass mold and aggregate (kg)**	**Unit weight** (kg)	**Avg. unit weight (kg)**	**SSD unit weight (kg)**
2.81	7.32	1526		
2.81	7.33	1527	1528	1574
2.81	7.34	1528		

Gradation of Fine Aggregate

Sieve analysis of fine aggregate (Sylhet sand) was within the upper and lower limit set by ASTM **C33** shown in figure 3.6.

Fig 3.6: Sieve Analysis

Table 3.21: Sieve Analysis

Sieve No.	Sieve opening mm	Materials Retained gm	% Materials Retained	Cumulative % Retained	% Finer
#4	4.75	0	0.0	0.0	100.0
#8	2.36	7.7	1.5	1.5	98.5
#16	1.19	65.9	13.2	14.7	85.3
#30	0.59	211.1	42.3	57.0	43.0
#50	0.3	138.5	27.7	84.8	15.2
#100	0.15	74.5	14.9	99.7	0.3
Pan		1.5	0.3	100.0	0.0
Total		499.2	100		

Fineness Modulus of Fine Aggregate = 2.58

Fig 3.7: Gradation Curve for Fine Aggregate

3.3.3 Overall results of materials testing

Type of Aggregate		Specific gravity	% Absorption	Unit weight (oven dry) Kg/m^3	Unit weight (SSD) Kg/m^3	%Wear
Fine Aggregate	**Sand**	**2.46**	**3%**	**1528**	**1574**	
Coarse Aggregate	**Black stone**	**2.82**	**1.5%**	**1528**	**1551**	**14%**
	Shingles	**2.65**	**1.1%**	**1656**	**1674**	**27%**
	Recycled aggregate	**2.14**	**22.4%**	**825**	**1004**	**43%**
	Brick chips	**1.98**	**10.32%**	**892**	**1076**	**39.5%**

Table 3.22: Aggregate Testing Results

3.4 Materials estimation

Cement: 400 Kg/m^3 x 676 x 0.00157 m^3 x 1.5 = (14 bags)

Fine Aggregate: 895 Kg/m^3 x 676 x 0.00157 m^3 x 1.5 = (50 cft)

Coarse Aggregate:

FB : 924 Kg/m^3 x 676 x 0.00157 m^3 x 1.5 = 50 cft (735 Nos)

RBA: 936 Kg/m^3 x 676 x 0.00157 m^3 x 1.5 = 50 cft

CS : 1064 Kg/m^3 x 676 x 0.00157 m^3 x 1.5 = 50 cft

SG : 1044 Kg/m^3 x 676 x 0.00157 m^3 x 1.5 = 50 cft

3.5 EXPERIMENTAL SETUP

3.5.1 Preparation of Fine Aggregate

Fine aggregates was collected from local market. We used Sylhet sand for our experiment procedure. The aggregates were cleaned to avoid impurities. They were sieved by ASTM **C33-93** standard. The aggregates passing 4.75 mm sieve were selected for the test procedure. Before casting the aggregates were prepared in SSD condition.

Fig 3.8: Sand Before Sieved

Fig 3.9: Sand after Sieved and in SSD condition

3.5.2 Preparation of Coarse Aggregate

Coarse aggregates were collected from the local markets. They were sieved and the particles retained on 19 mm sieve, 12.5 mm sieve, 9.5 mm sieve and 4.75 mm sieve were collected for the mix design. The aggregates were cleaned very carefully to avoid dust and any kind of harmful materials. Before casting the aggregates were prepared to SSD condition.

Fig 3.10: Coarse Aggregate before Condition SSD

Fig 3.11: Coarse Aggregate after SSD Condition

3.5.3 Preparation of Cement

For casting we used Ordinary Portland Cement (OPC), CEM Type II B-M, CEM Type II B-S, CEM Type II B-S(40% OPC – 60% Slag),), 40% OPC – 60% Slag(CEM-IIIA), 80% OPC – 20% Slag(CEM II/A-S), 70% OPC – 30% Slag(CEM II/B-S), 30% OPC –70% Slag(CEM-IIIB), 15% OPC –85% Slag(CEM-IIIC). The cement content for each test procedure was weighted very carefully.

3.5.4 Preparation of Water

Water that we used in the concrete casting and for the curing of the concrete specimen was normal tap water which unit weight was about 1000 kg/m3.

3.6 Mix Design

3.6.1 Entire Mix proportion

Case No.	Type of Cement	Type of aggregate	W/C	s/a	Cement Content
1			0.45		340
2		Brick Aggregate	0.50		340
3			0.45		400
4			0.50		400
5			0.45		340
6		Recycled Brick Aggregate	0.50		340
7	OPC		0.45		400
8			0.50		400
9			0.45		340
10		Black Stone	0.50	0.44	340
11			0.45		400
12			0.50		400
13			0.45		340
14	OPC	Shingles	0.50		340
15			0.45		400
16			0.50		400
17		Brick Aggregate	0.45	0.44	
18			0.50		
19		Recycled Brick Aggregate	0.45		
20	CEM Type II B-M		0.50		400
21		Black Stone	0.45		
22			0.50		
23		Shingles	0.45		
24			0.50		
25		Brick Aggregate	0.45		
26	CEM Type II B-SL		0.50	0.44	400
27		Recycled Brick Aggregate	0.45		
28			0.50		

29		Black Stone	0.45		
30			0.50		
31		Shingles	0.45		
32			0.50		
33	40% OPC – 60% Slag(CEM-IIIA)	Brick Aggregate	0.45		400
34			0.50		
35		Recycled Brick Aggregate	0.45		
36			0.50		
37		Black Stone	0.45		
38			0.50		
39	80% OPC – 20% Slag(CEM II/A-S)	Black Stone	0.45		
40	70% OPC – 30% Slag(CEM II/B-S)	Black stone	.45	.44	400
41	30% OPC – 70% Slag(CEM-IIIB)				
42	15% OPC – 85% Slag(CEM-IIIC)				

3.6.2 Specimen Plan

Age	**Plain Specimens**			
	Comp. Strength & UPV	Split Tensile	RCPT	Chloride Ingress
28d	3	1	1	-
60d	2	1	-	1
6m	2	1	-	1
Total	7	3	1	2

Table 3.23: Specimen plan

Specimens per case = 7+3+1+2 = 13 Nos

Total number of cases = 42

Total number of specimens

= Total cases x Specimen per cases

= 42 x 13

= 546 Nos

3.7 Workability Measurement

The workability of the concrete was tested by taking the slump value and void test.

3.7.1 Slump test

The concrete **slump test** measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. It can also be used as an indicator of an improperly mixed batch. The concrete slump test is used for the measurement of a property of fresh concrete. The test is an empirical test that measures the workability of fresh concrete. More specifically, it measures consistency between batches. The slump cone has a base of 200mm (8"), a smaller opening at top of 100mm (4") and a height of 300mm (12"). While performing the slump test, all three types of slumps are noticed. For collapse slump and true slump one reading is taken and for shear slump average reading is taken. To carry out the slump test, standard procedure is adopted from ASTM C143.

Fig 3.12: Slump test

3.7.2 Percentage Air Entrancement

It in measured by Pressure Type "B" Meter. This device measures the air content of fresh concrete based on the pressure-to-volume relationship of Boyles Law. Pressure is applied to the sample to compress the entrained air in the pores. The Press-Ur-Meter uses the change in known volume of air to determine the air content of the mix. Readings are not affected by changes in barometric pressure. This method is faster to use than the volumetric method.

The Press-Ur-Meter is made from corrosion resistant aluminum alloy with a heavy duty pump and built in pressure gauge. The base has a volume of 0.25 cubic feet (7000 cubic cm) and can also be used for unit weight measurements. Instructions include a chart for using the meter to determine the specific gravity of aggregates. Wood and plastic cases are available. Applicable Standards: ASTM C 231 AASHTO T-152.

Fig 3.13: Percentage air entrancement test

3.8 Sample Making

3.8.1 Mold Preparation

The size of the cylindrical mold was 4 inch in diameter and 8 inch in height. The cylinder was prepared very carefully. They were tightened and the inside surface was polished with lubricant. For lubrication grease was used.

3.8.2 Materials preparation

Materials were weighted carefully as mix design and coarse aggregates were soaked for 24 hours before casting. Before casting the aggregates were prepared to SSD condition.

3.8.3 Casting

For the casting of concrete of specimens, ASTM C31 is followed for standard procedure. We used mixture machine for casting of cylindrical specimen. Here the mixing procedure was slightly different than the normal procedure followed in Bangladesh. In Bangladesh all cement, sand and water put together in the mixing machine. But we followed the right procedure of mixing. At first 50% of the fine aggregate was poured in the mixing machine. Then all the cement was poured and then rest of the sand was poured for each case. After that they were mixed for about 30 second in the mixing machine. Then water was poured and again mixed for 30 second. After that coarse aggregate was poured in the mixing machine. Then it was mixed well for about 3-4 minutes. Then the concrete mixed was poured down and slump was measured. All necessary precautions were taken as-

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, then capping with a thick mortar after half an hour of casting 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 or bottom part of the specimen.

Fig 3.14: Casting of concrete

3.8.4 Compaction of Specimens

Concrete mixtures of the specimens were properly compacted and scaled along the perimeter. Each specimens were compacted by two layers. In each layer 25 blows as per ASTM specification were given for compaction. After compaction, scaling and hammering were done properly to avoid air voids and to get a smooth surface of the specimens.

Fig 3.15: pouring and scaling of concrete

Fig 3.16: Scaling and hammering

Fig 3.17: smoothing surface of cylinder

3.8.5 Curing of the Specimens

3.8.5.1 Initial Curing

Specimen were covered for first 24 hours with moist cloth and polythene to prevent water evaporation. After 24 hours, the specimen were demolded and placed in the water tub for final curing.

Fig3.18: Initial curing

Fig 3.19: Final curing

3.8.5.2 Final Curing

After demolding, the concrete cylinders were completely immersed in water in curing tub until the day of testing (28 days,60 days) according to ASTM C 31.

3.9 Testing

3.9.1 Non Destructive Test

Ultrasonic Pulse Velocity (UPV) test was done on 28th day and 60th day. It is seen that with the increase of the strength the Velocity increases. Ultrasonic pulse velocity (UPV) was measured on unloaded wet specimens by using Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT) according to ASTM C 597–02. 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. A thin couplant (solid vaseline) was used in between the transducers and concrete to ensure good contact between the specimen surface and the receiver.

Fig 3.20 : UPV Test

3.9.2 Destructive Tests

3.9.2.1 Compressive Strength test

The compressive strength of concrete was measured at 28th and 60th day using compressive strength testing machine according to ASTM C 39. Before destructive tests capping was done properly to get a smooth surface for concentrated loading. The strain of concrete specimens was measured by a strain measurement setup of 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.

Fig 3.21: Compressive Strength Test

3.9.9.2 Split Tensile Strength

The split tensile strength of concrete was tested at 28 days according to ASTM C496. The Universal Testing machine was used to perform this test. The failure surfaces of broken concrete specimens were also checked carefully after crushing of the concrete cylinders to corroborate the findings of
this investigation.

Fig 3.22: Split Tensile strength test by UTM

4. Comparative Data Analysis

4.1 General

In order to establish the relationship between various mechanical properties of concrete, different cases are investigated in this study. Different commonly available aggregates are tested for establishing the relationship so that structural health monitoring system can be introduced As from the previous chapter of *Methodology*, the study has fixed some definite key parameters to run a thorough investigation. Different s/a ratios, W/C ratios, cement content variations and all constant volumetric content (m^3) for materials irrespective of their types are considered to have a broad insight into the study. So, in order to state the results and findings of the study and to discuss them, it is necessary to fix some key parameters.

In this chapter, the results of the study conducted will be quantified. It will be discussed elaborately in order to establish the relationship and analyze different between various mechanical properties of concrete. Variations in slump values, effect for water content variations, effect for cement content variations, effect for different s/a ratios, effect of curing period, comparative tensile strength and young's modulus etc. is discussed in this chapter. Finally, some relationships are proposed regarding the different mixing parameters and type of materials being used. These relationships can be used to measure the strength of concrete up to a certain degree of accuracy. Different aspects of these relationships will be discussed and also the degree of accuracy will also be determined and discussed at the end of this chapter.

4.2 Result at a glance

The overall result for 28 days of curing in shown below:

Case No	Type of aggregate	W/C	Slump value (mm)	%entrapped air	compressive strength-28 days (psi)	*ft* 28 days (psi)	Young's Mod 28 days (psi)	UPV (m/s)	Unit Weight (kg/cu.m)
1	Brick Aggregate	0.45	2.50	2.20	4163.44	405.36	2762758	3826.74	2135.43
2	Brick Aggregate	0.50	7.70	2.20	4086.61	376.50	2078091	3756.12	2129.71
5	Recycled Brick Aggregate	0.45	1.00	2.40	3804.14	387.47	3079298	3945.34	2174.72
6	Recycled Brick Aggregate	0.50	5.75	1.90	3495.51	350.14	2379461	3940.97	2141.07
9	Black Stone	0.45	1.05	2.50	4698.42	439.58	4891315	4690.64	2419.83
10	Black Stone	0.50	16.80	2.10	3973.62	383.63	4110661	4673.68	2476.34
13	Shingles	0.45	3.50	2.45	4392.66	420.70	4281185	4509.91	2368.24
14	Shingles	0.50	18.90	1.95	4151.64	383.70	3739134	4489.42	2359.93

Table 4.1: Results for OPC binder, cement content 340 kg/ cu.m and s/a ratio 0.44.

Case No	Type of aggregate	W/C	Slump value (mm)	%entrapped air	compressive strength -28 days (psi)	*ft* 28 days (psi)	Young's Mod 28 days (psi)	UPV (m/s)	Unit Weight (kg/cu.m)
3	Brick Aggregate	0.45	3.50	2.00	4772.0247	476.6629	2939623	3876.488	2140.462
4	Brick Aggregate	0.50	14.25	1.90	4404.9243	412.3226	2810433	3835.576	2135.253
7	Recycled Brick Agg.	0.45	3.20	2.10	4345.2188	452.0585	3202416	3884.273	2154.157
8	Recycled Brick Aggregate	0.50	13.29	2.00	3990.3309	388.5757	3095898	3957.582	2176.168
11	Black Stone	0.45	7.30	1.70	5088.9235	513.51	5368860	4709.821	2359.932
12	Black Stone	0.50	17.25	1.90	4860.4901	437.9803	4603644	4704.539	2385.657
15	Shingles	0.45	19.15	2.00	4982.6656	508.1207	4315446	4839.193	2380.958
16	Shingles	0.50	23.00	2.00	4590.0966	412.6066	3948436	4748.506	2362.719

Table 4.2: Result for OPC binder, cement content 400 kg/ cu.m and s/a ratio 0.44.

Case No	Type of aggregate	W/C	Slump value (mm)	%entrapped air	compressive strength-28 days (psi)	*ft* 28 days (psi)	Young's Mod 28 days (psi)	UPV (m/s)	Unit Weight (kg/cu.m)
17	Brick Aggregate	0.45	9.39	1.80	3780.6512	387.0859	2427777	3913.284	2111.344
18	Brick Aggregate	0.50	18.37	1.80	3377.3042	348.7368	2315633	3814.098	2104.705
19	Recycled Brick Aggregate	0.45	7.50	2.10	3570.1132	391.0068	2958146	3966.463	2156.327
20	Recycled Brick Aggregate	0.50	16.50	1.80	3269.5208	347.2429	2715462	3929.618	2143.789
21	Black Stone	0.45	15.00	1.50	4386.1996	437.7326	4484159	4829.612	2414.59
22	Black Stone	0.50	22.50	1.45	3641.8267	373.9839	3410278	4753.393	2409.829
23	Shingles	0.45	19.50	1.70	3833.8059	400.3591	3806113	4630.038	2366.103
24	Shingles	0.50	22.50	1.50	3439.4459	357.1116	328347.4	4521.347	2353.394

Table 4.3: Result for CEM type-II BM binder, cement content 400 kg/ cu.m and s/a ratio 0.44.

Case No	Type of Cement	Type of aggregate	W/C	Slump value (mm)	%entrapped air
25	CEM Type II B-M-SL	Brick Aggregate	0.45	17.00	2.40
26	CEM Type II B-M-SL	Brick Aggregate	0.50	24.00	2.30
27	CEM Type II B-M-SL	Recycled Brick Aggregate	0.45	17.50	1.90
28	CEM Type II B-M-SL	Recycled Brick Aggregate	0.50	22.00	1.50
29	CEM Type II B-M-SL	Black Stone	0.45	16.50	2.10
30	CEM Type II B-M-SL	Black Stone	0.50	18.00	1.60
31	CEM Type II B-M-SL	Shingles	0.45	21.95	2.20
32	CEM Type II B-M-SL	Shingles	0.50	24.20	1.60
33	40% OPC – 60% Slag(CEM-IIIA)	Brick Aggregate	0.45	22.80	2.20
34	40% OPC – 60% Slag(CEM-IIIA)	Brick Aggregate	0.50	23.50	2.00
35	40% OPC – 60% Slag(CEM-IIIA)	Recycled Brick Aggregate	0.45	9.50	2.20
36	40% OPC – 60% Slag(CEM-IIIA)	Recycled Brick Aggregate	0.50	20.00	2.10
37	40% OPC – 60% Slag(CEM-IIIA)	Black Stone	0.45	16.00	1.50
38	40% OPC – 60% Slag(CEM-IIIA)	Black Stone	0.50	21.50	1.50
39	80% OPC – 20% Slag(CEM II/A-S)	Black Stone	0.45	18.25	1.80
40	70% OPC – 30% Slag(CEM II/B-S)	Black Stone	0.45	15.75	1.60
41	30% OPC –70% Slag(CEM-IIIB)	Black Stone	0.45	20.25	1.50
42	15% OPC –85% Slag(CEM-IIIC)	Black Stone	0.45	10.00	1.60

Table 4.4: Result for cement content 400 kg/ cu.m and s/a ratio 0.44.

4.3 Split Tensile Strength

The tensile strength is one of the basic and important properties of the concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The cracking is a form of tension failure.

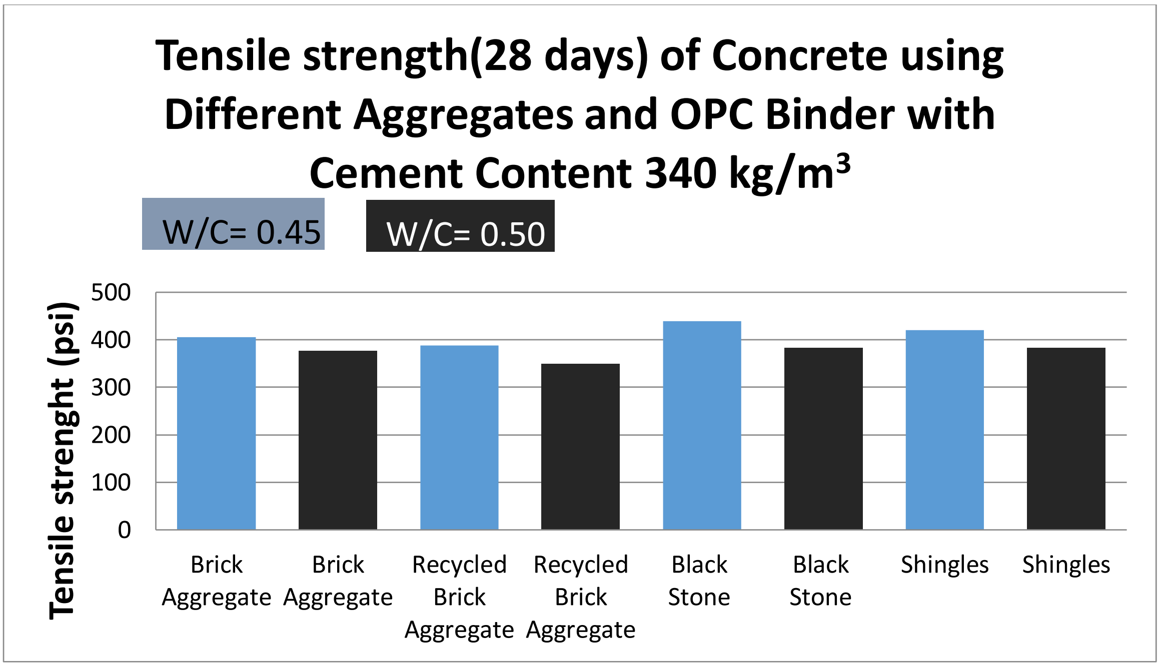


Fig 4.1 : Split Tensile Strength for different types of aggregates

From the figure we can see the Tensile strength of concrete using different aggregates and OPC binder with cement content 340 kg/m^3 for two different types of w/c ratio. Tensile strength increases with decrease of w/c ratio and for black stone the tensile strength is maximum. . The reason is that the interlocking properties of black stone aggregate, higher compaction and less bleeding.

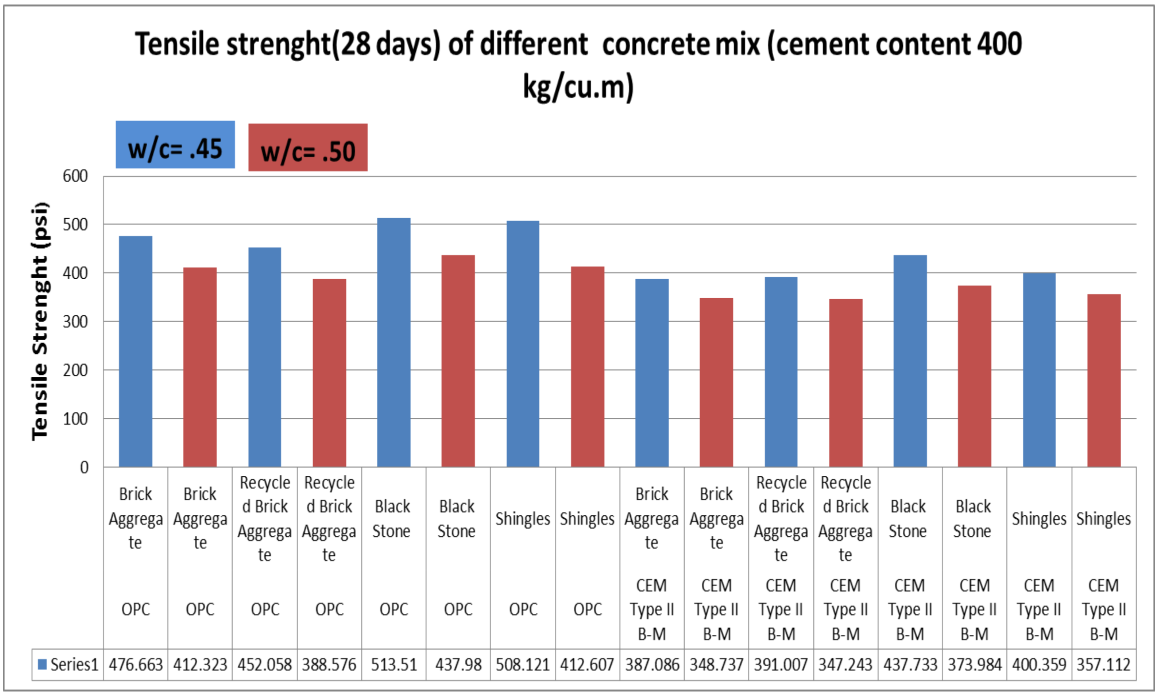


Fig 4.2: Split Tensile Strength for different types of aggregates and binders

From the figure we can see the Tensile strength of concrete using different aggregates and binders with cement content 400 kg/m^3 for two different types of w/c ratio. Tensile strength increases with decrease of w/c ratio and for black stone the tensile strength is maximum. For CEM type-II BM tensile strength was found lower for all types of aggregate comparing to OPC cement.

Tensile strength also increases with the increase of cement content. But for black stone tensile strength of concrete was found always higher for any case.

4.4 UPV

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.

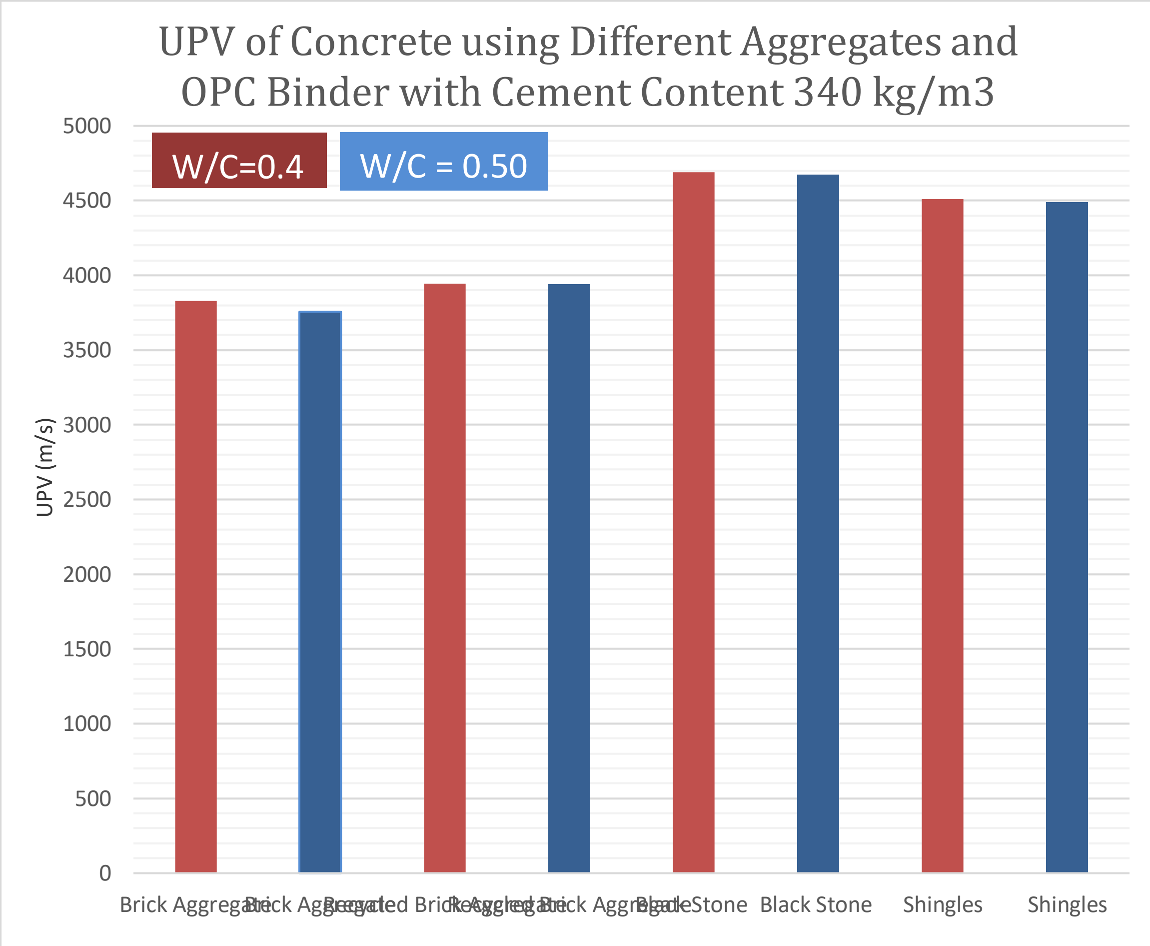


Fig 4.3: UPV for different types of aggregates

From the figure we can see the UPV of Concrete using different Aggregates and OPC Binder with Cement Content 340 kg/m^3 for two different types of w/c ratio. UPV increases with decrease of w/c ratio and for black stone the UPV is maximum which means the concrete mix containing black stone will be less corrosion prone than others.

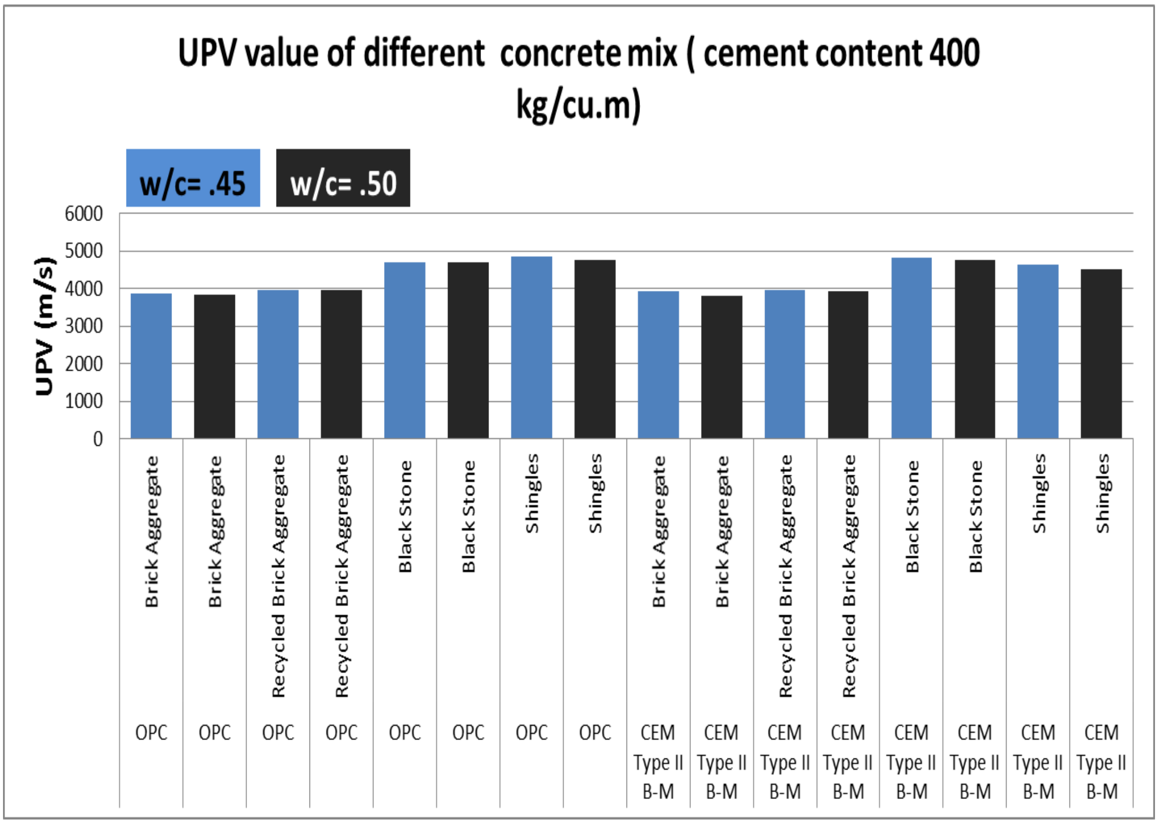


Fig 4.4: UPV for different types of aggregates and binders

From the figure we can see the UPV of concrete using different aggregates and binders with cement content 400 kg/m^3 for two different types of w/c ratio. UPV increases with decrease of w/c ratio and for black stone and shingles the UPV is maximum. For CEM type-II BM UPV was found almost same comparing to OPC cement for all types of aggregate. UPV increases with the increase of cement content. By using black stone and shingles we got higher UPV than brick and recycle brick as aggregates.

4.5 Compressive Strength

Strength of hardened concrete measured by the compression test. The compression strength of concrete is a measure of the concrete's ability to resist loads which tend to compress it. Compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of concrete material, quality control during production of concrete etc.

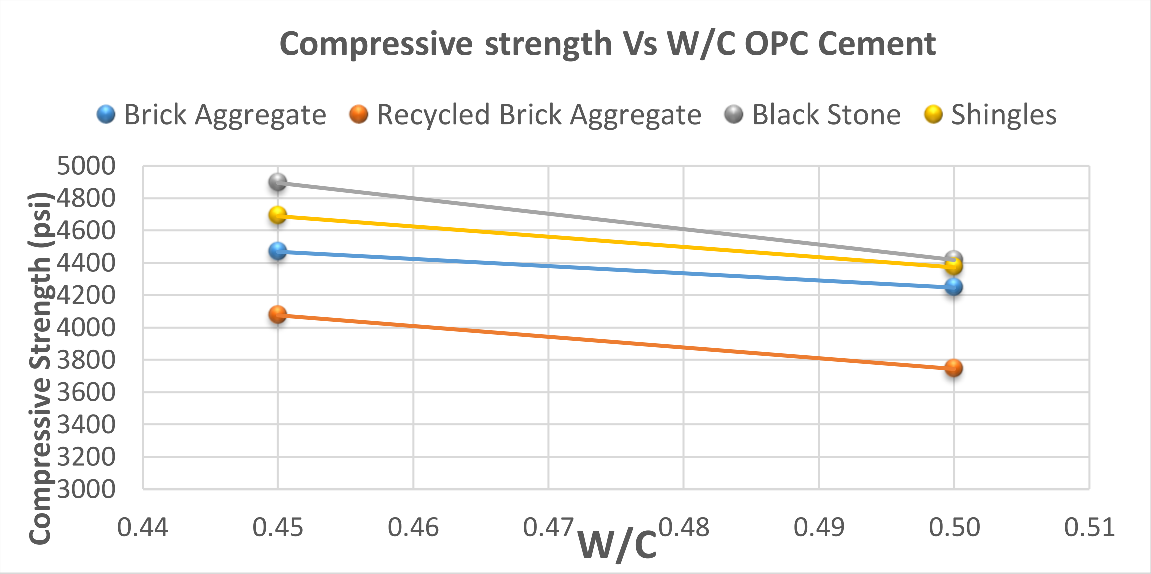


Fig 4.5: Compressive Strenght vs W/C for different aggregates

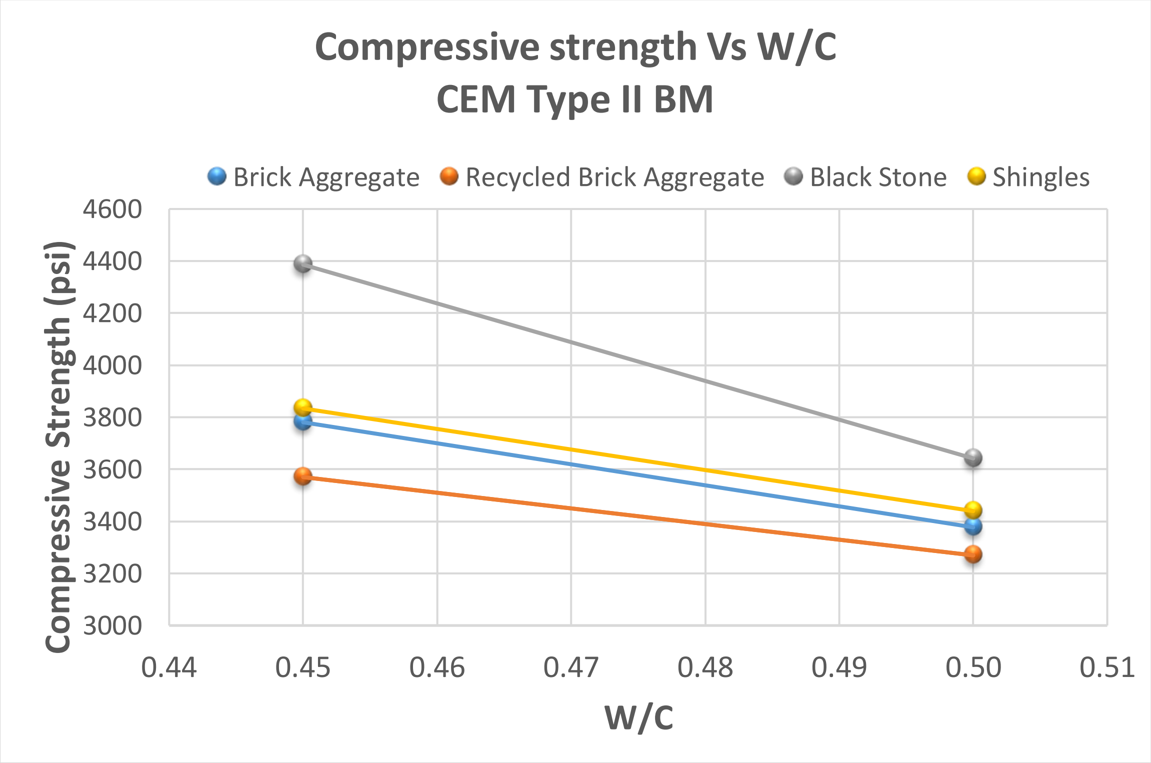


Fig 4.6: Compressive Strenght vs W/C for different aggregates

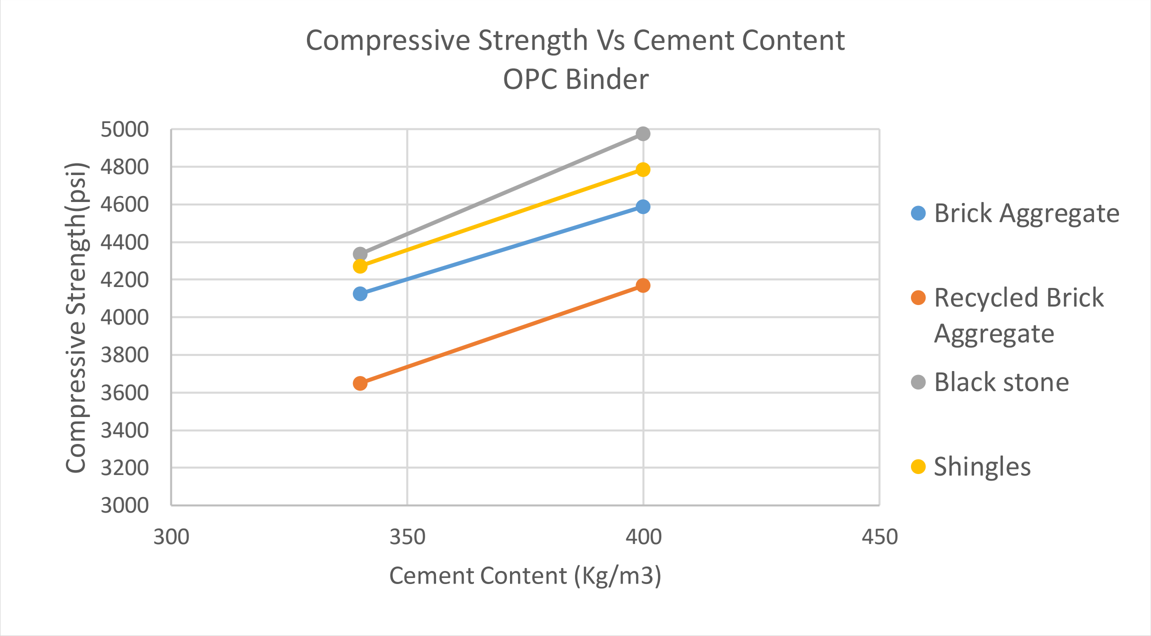


Fig 4.7: Compressive Strenght vs W/C for different aggregates

From the graphs we can see the compressive strength vs w/c ration of concrete using different aggregates and binders. Compressive strength increases with decrease of w/c ratio and for black stone the compressive strength is maximum for both OPC and CEM type-II BM. For CEM type-II BM compressive strength was found lower for all types of aggregate comparing to OPC cement.

Compressive strength also increases with the increase of cement content. But for black stone compressive strength of concrete was found always higher for any case.

4.6 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.

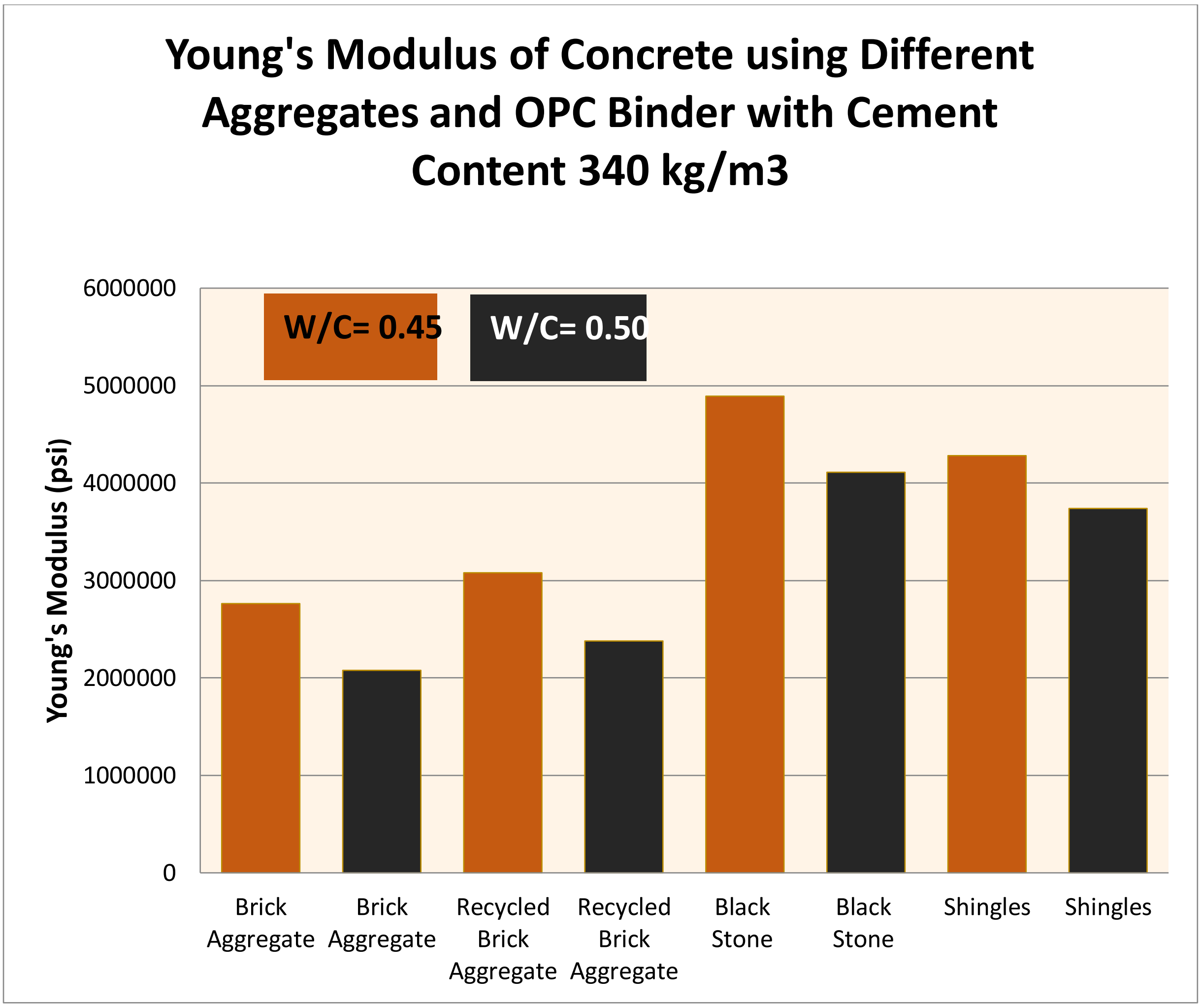


Fig 4.8: Young's Modulus for different aggregates

From the figure we can see the Young's modulus of concrete using different aggregates and OPC binder with cement content 340 kg/m^3 for two different types of w/c ratio. Young's modulus increases with decrease of w/c ratio and for black stone the Young's modulus is maximum.

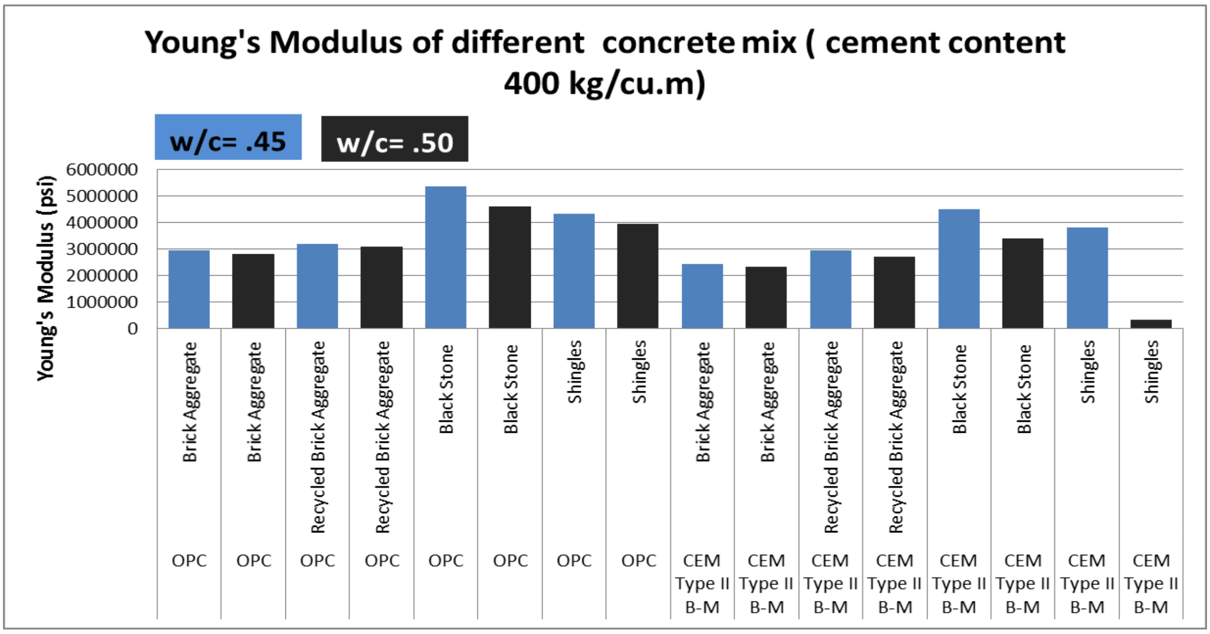


Fig 4.9: Young's Modulus for different aggregates and binders

From the figure we can see the Young's modulus of concrete using different aggregates and binders with cement content 400 kg/m^3 for two different types of w/c ratio Young's modulus increases with decrease of w/c ratio and for black stone Young's modulus is maximum. For CEM type-II BM Young's modulus was found less comparing to OPC cement for all types of aggregate. Young's modulus increases with the increase of cement content. By using black stone we got higher Young's modulus than brick and recycle brick as aggregates for any types of case.

4.7 Unit weight

The unit weight of concrete is primarily affected by the unit weight of the aggregate, which varies by geographical location and increases with concrete compressive strength depending on the added pozzolans. Variations in unit weights are mainly because of greater specific gravity of one aggregate than the others. Highest variation in unit weight of similar concrete for aggregate to aggregate variation is observed in 28 days when the concrete ted to achieve almost 80%-85% of its strength indicating most of the hydration is done within this time (28 days).

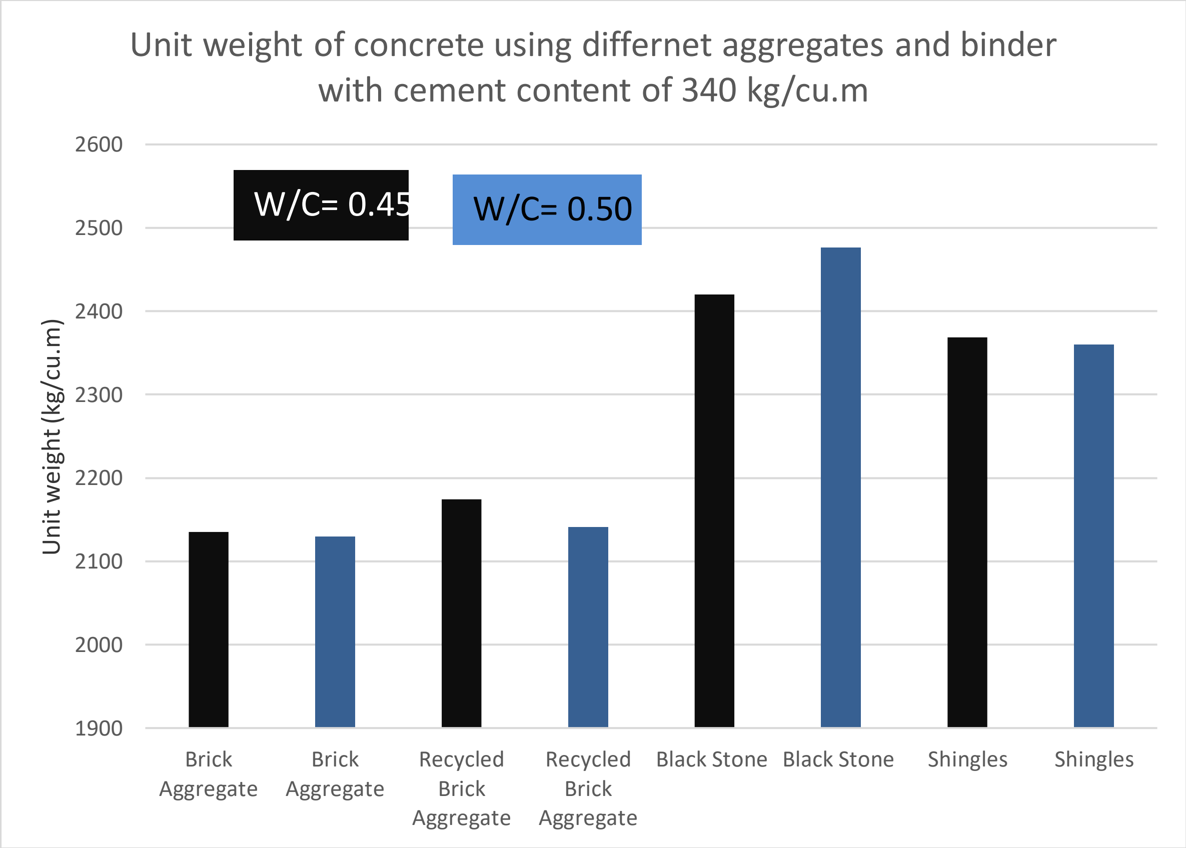


Fig 4.10: Unit weight for different aggregates

From the figure we can see the Unit weight of concrete using different aggregates and OPC binder with cement content 340 kg/m^3 for two different types of w/c ratio. Unit weight increases with decrease of w/c ratio for recycled brick aggregate and for black stone unit weight increases with increase of w/c ratio and for other no change found. Unit weight is maximum for black stone concrete specimen than others.

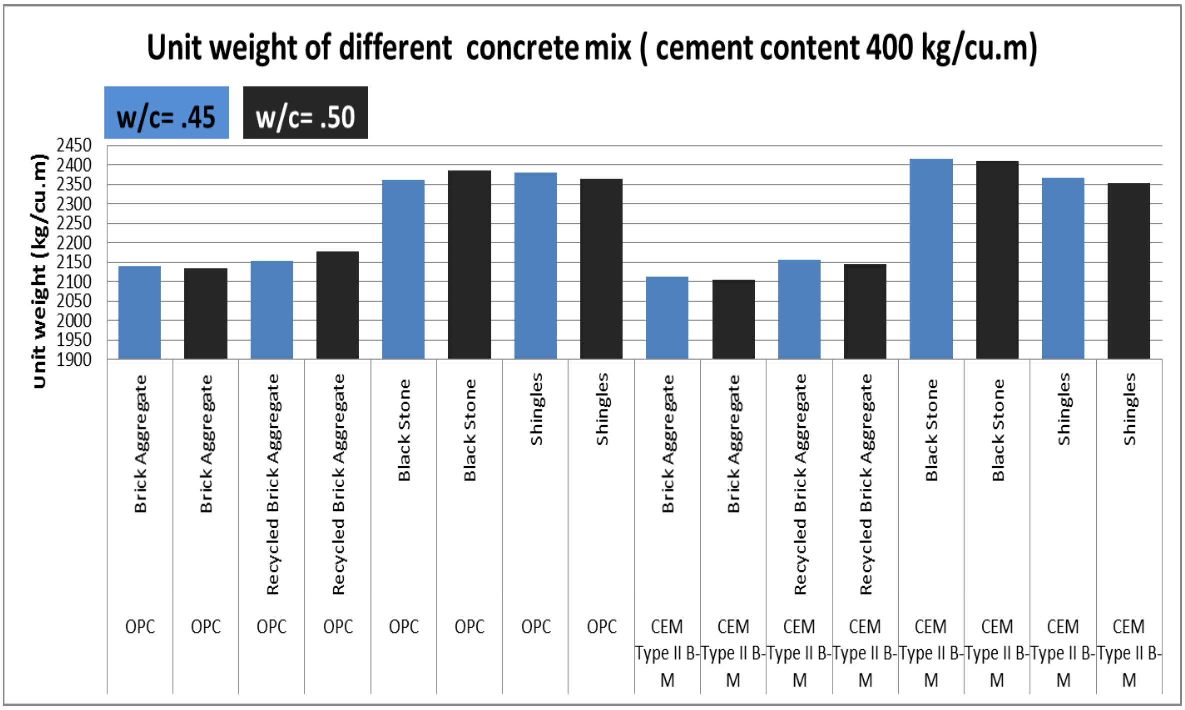


Fig 4.11: Unit Weight for different aggregates and binders

From the figure we can see the Unit weight of concrete using different aggregates and binders with cement content 400 kg/m^3 for two different types of w/c ratio. Unit weight increases with decrease of w/c ratio and for black stone Unit weight is maximum. For CEM type-II BM Unit weight was found less comparing to OPC cement for all types of aggregate. Unit weight almost remains same with the increase of cement content. By using black stone we got higher Unit weight than brick and recycle brick as aggregates for any types of case.

4.8 Workability

It is customary to know how much workable the concrete will be prior to casting. As many times it presents a problem during casting in congested areas like beam-column joints, a preliminary idea is necessary about the workability of concrete. W/C ratio plays a important role in this regard but aggregates has the most significant effect.

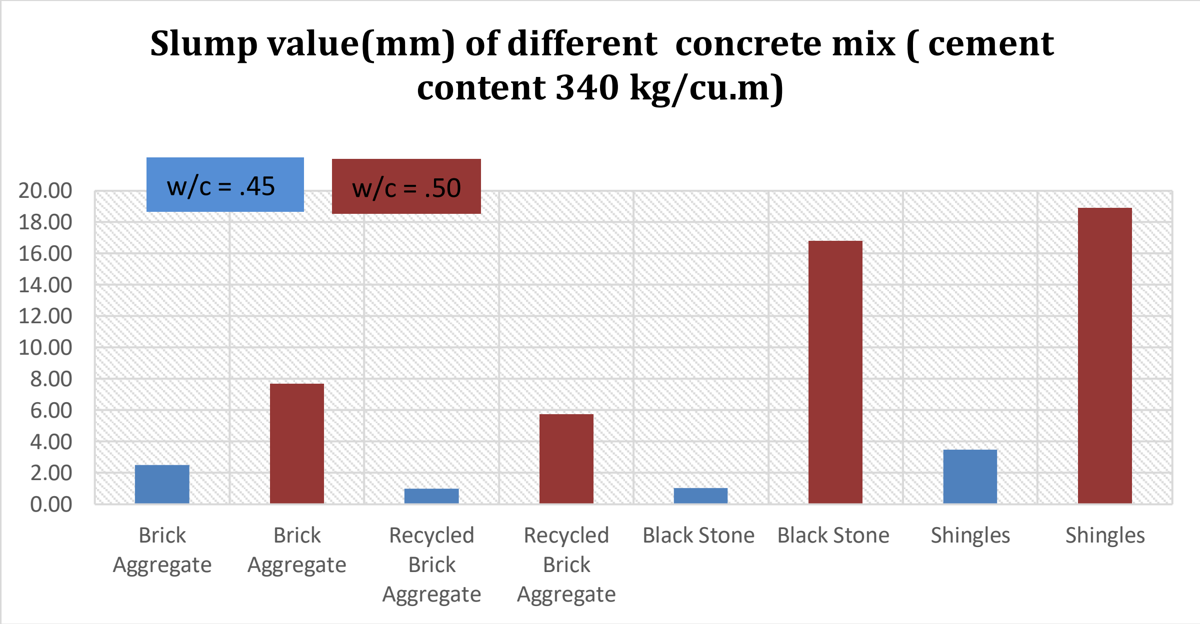


Fig 4.12: Slump value for different aggregates

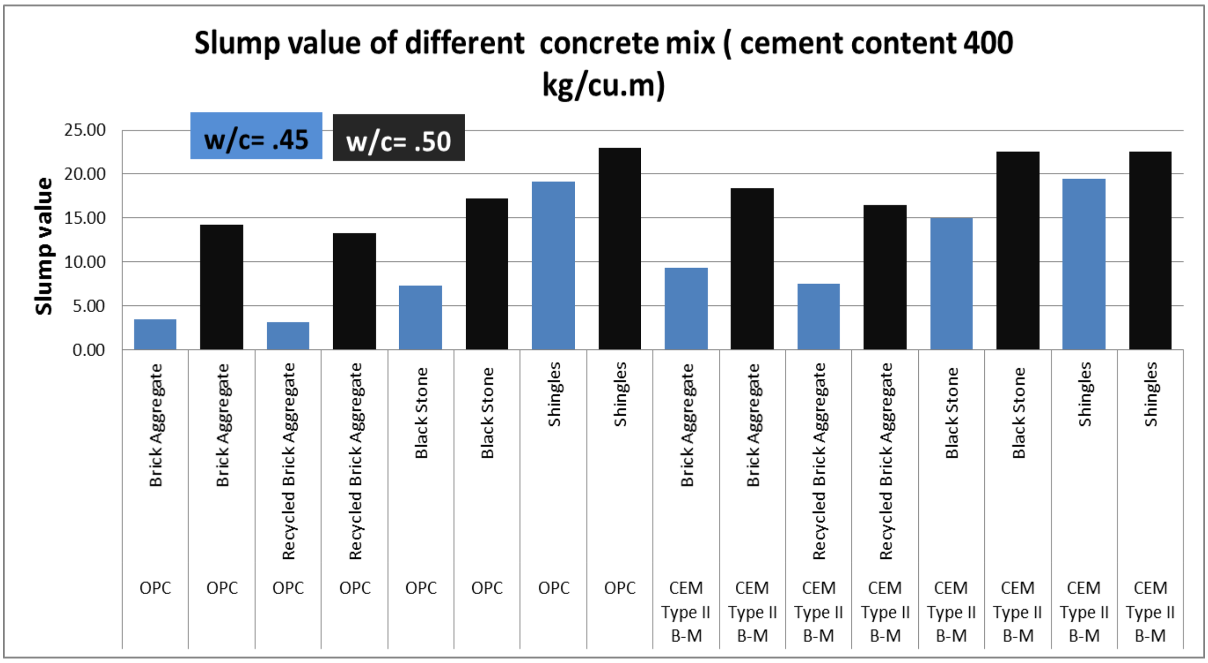


Fig 4.13: Slump value for different aggregates and binders

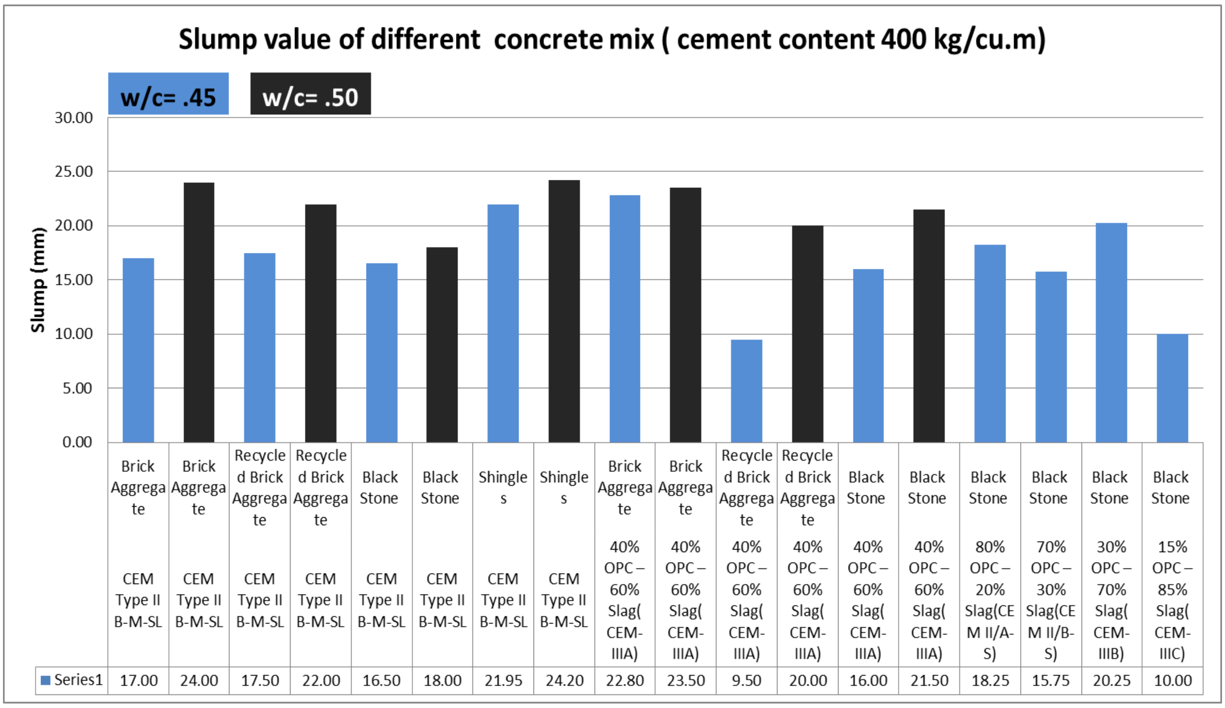


Fig 4.14: Slump value for different aggregates and binders

From the figure we can see the workability of concrete using different aggregates and binders with cement content 400 kg/m^3 and 340 kg/m^3 for two different types of w/c ratio. Workability increases with increase of w/c ratio and for shingles workability is maximum. For CEM type-II BM workability was found high comparing to OPC cement for all types of aggregate. Workability increases with the increase of cement content. By using shingles we got higher workability than brick and recycle brick as aggregates for any types of case.

4.9 Air entrainment

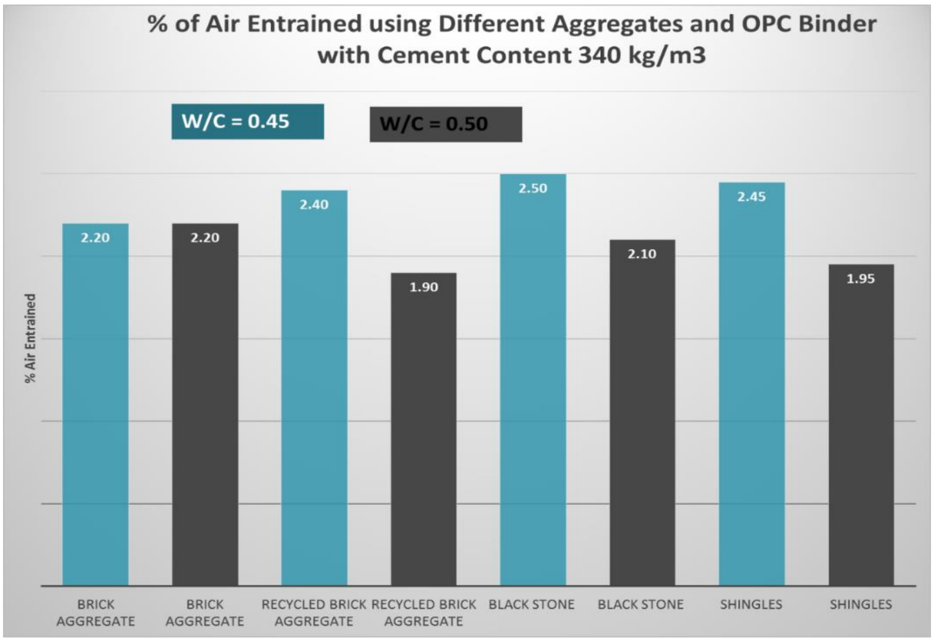


Fig 4.15: Percentage air entranment for different aggregates

The air-void system created by using air-entraining agents in concrete is also influenced by concrete materials and construction practice. Concrete materials such as cement, sand, aggregates, and other admixtures play an important role in maintaining the air-void system in concrete. Fine aggregate serves as a three-dimensional screen and traps the air; the more median sand there is in the total aggregate, the greater the air content of the concrete will be. Mineral admixtures such as fly ash and silica fume also affect the formation of void systems in concrete. From the figure we can see the percentage of air entrained in concrete using different aggregates and OPC binder with cement content 340 kg/m^3 for two different types of w/c ratio. Percentage air entrainment decreases with increase of w/c ratio and for black stone the percentage air entrainment is maximum.

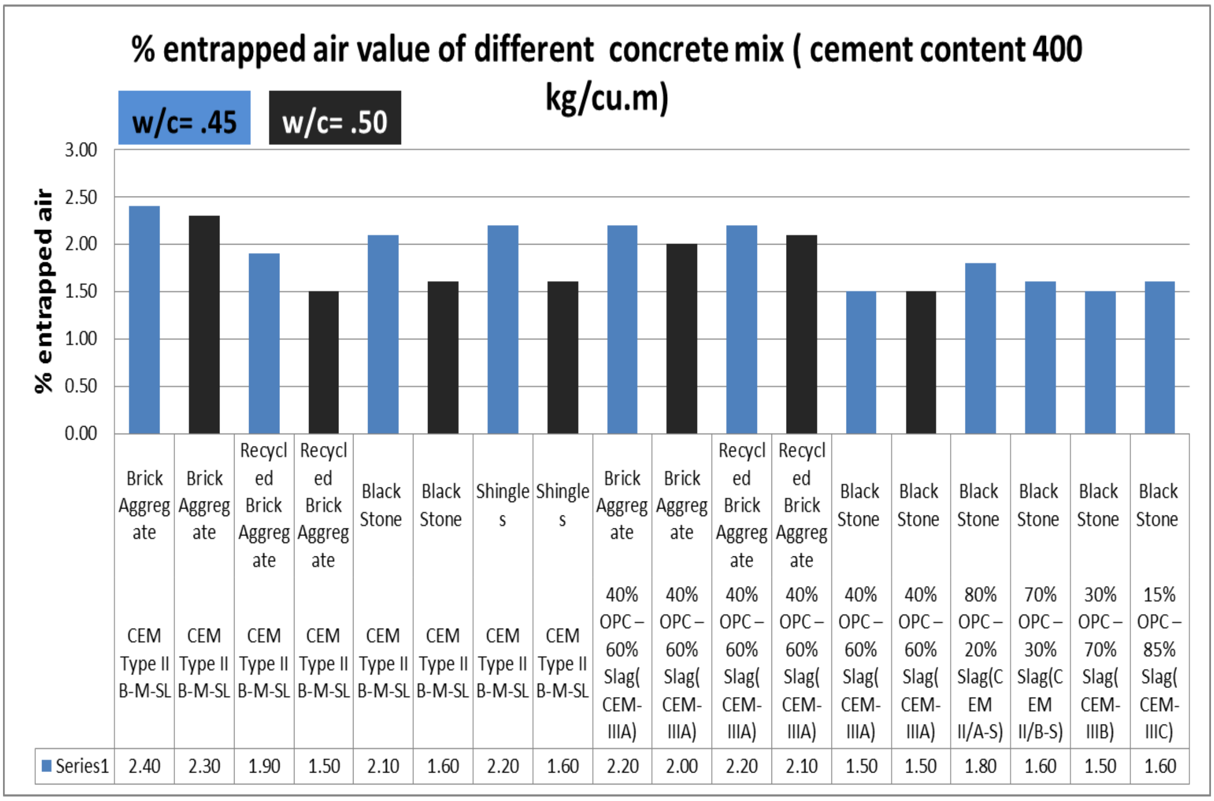


Fig 4.16: Slump value for different aggregates and binders

From the figure we can see the percentage air entrainment of concrete using different aggregates and binders with cement content 400 kg/m^3 for two different types of w/c ratio. Percentage air entrainment increases with decrease of w/c ratio and for brick aggregate percentage air entrainment is maximum for CEM type-II BM. For CEM type-II BM percentage air entrainment was found high comparing to OPC cement for brick aggregate. Percentage air entrainment decreases with the increase of cement content.

4.10 Regression Analysis

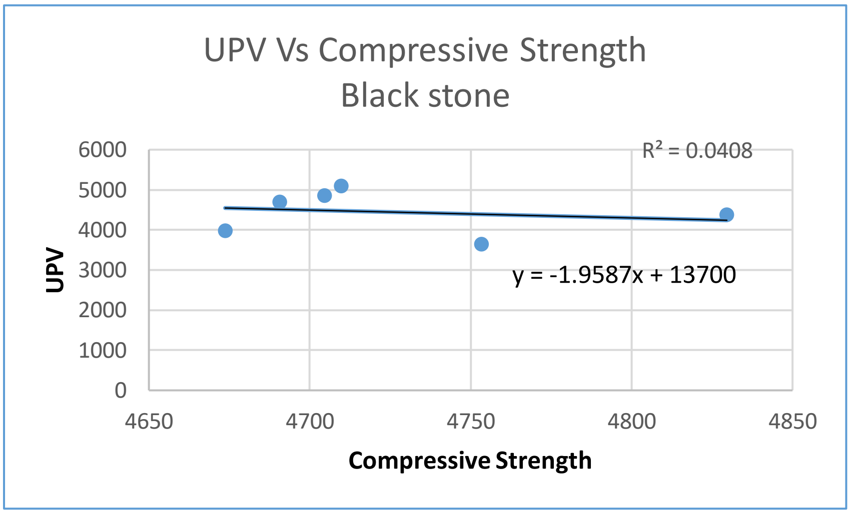


Fig 4.17: UPV vs Compressive Strength

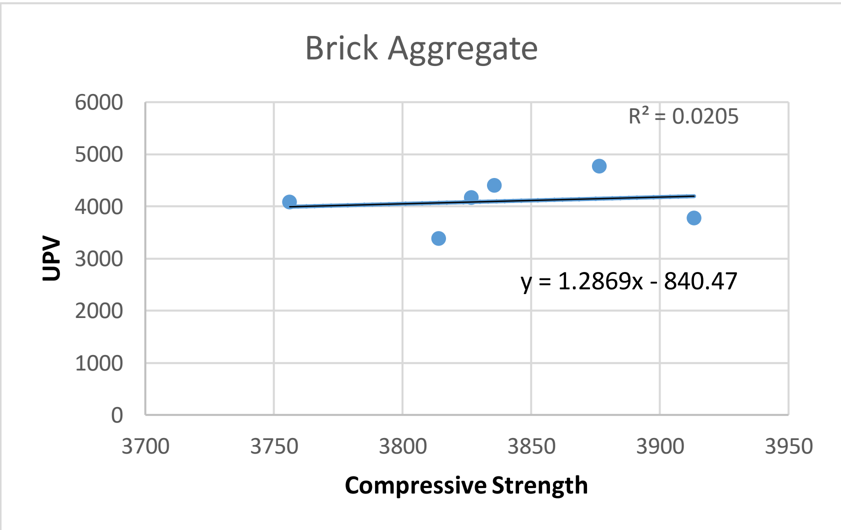


Fig 4.18: UPV vs Compressive Strength

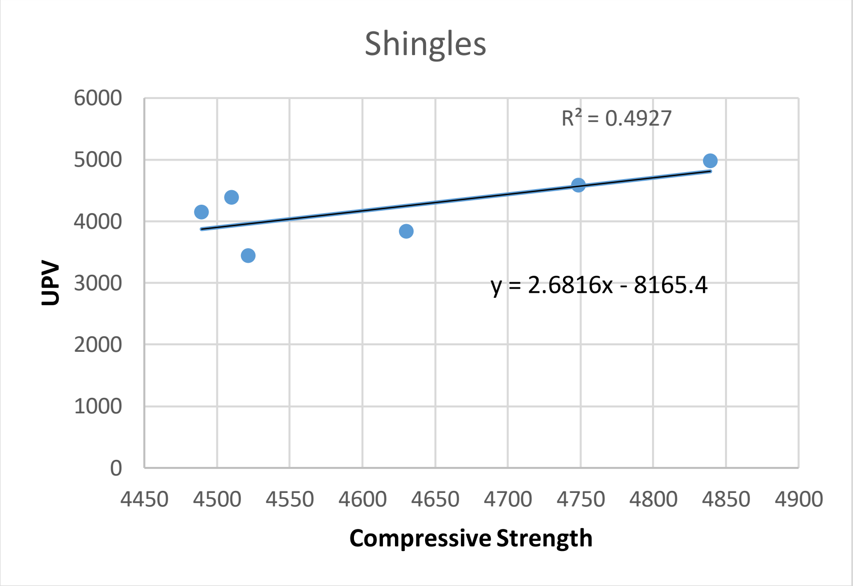


Fig 4.19: UPV vs Compressive Strength

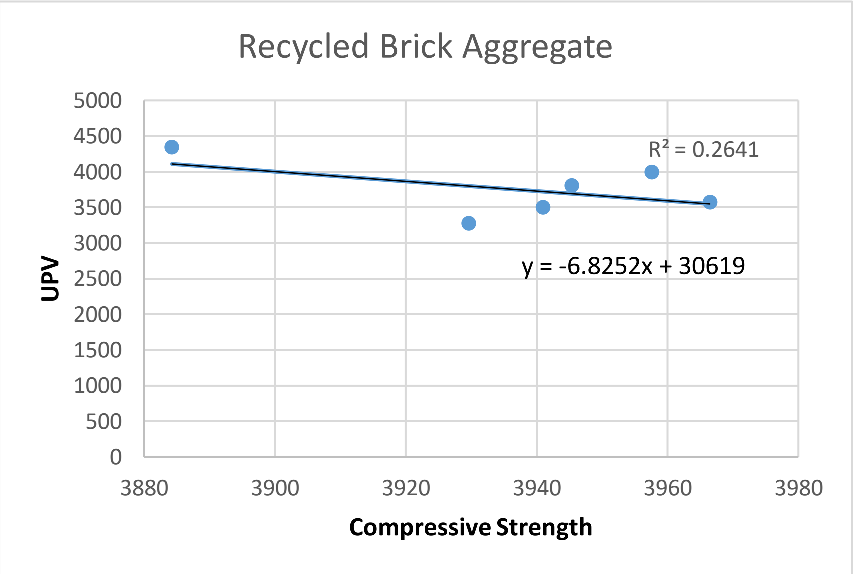


Fig 4.20: UPV vs Compressive Strength

From the UPV vs Compressive strength graphs we can see how compressive strength of concrete and ultrasonic pulse response behavior of concrete is related to each other and also we can observe different behavior for different types of aggregates. R^2 indicates how close the data are to the fitted regression line. From all the graphs we can see that for shingles we got the higher value of R^2 which means for shingles the UPV vs compressive strength points are most closer to linear line than other aggregates. Higher UPV value means higher elastic modulus, density and integrity of the concrete. Higher compressive strength value means higher resistance to compressive load. Both high value of these two are expectable for a sound concrete. Shingle give the best combination of high UPV as well as high compressive strength to the concrete in comparison to others. For brick we can observe to most worst case. So shingles has the most higher significance.

Fig 4.21: Young's modulus vs Compressive Strength

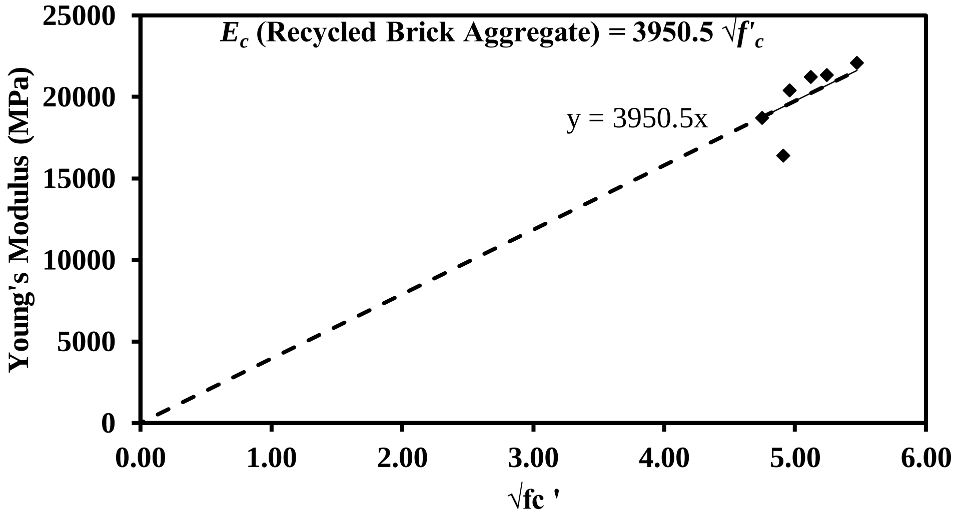
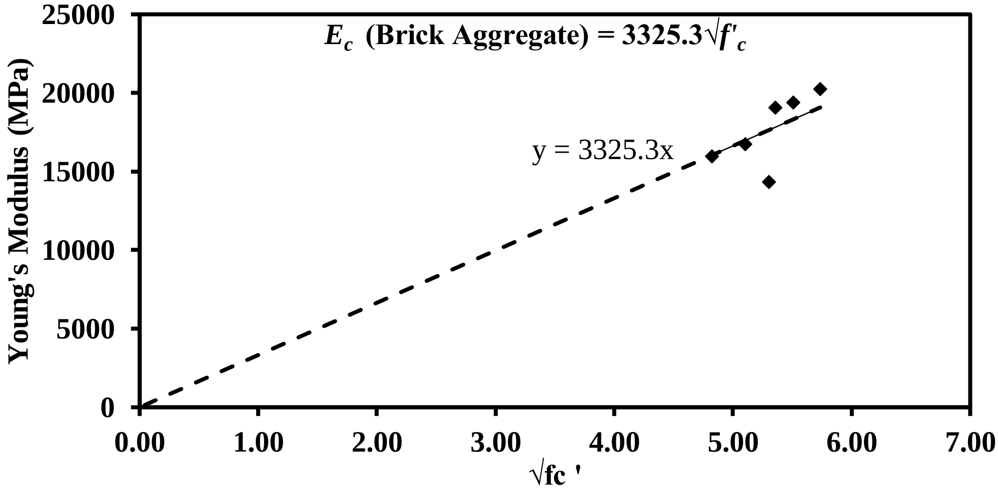


Fig 4.22: Young's modulus vs Compressive Strength



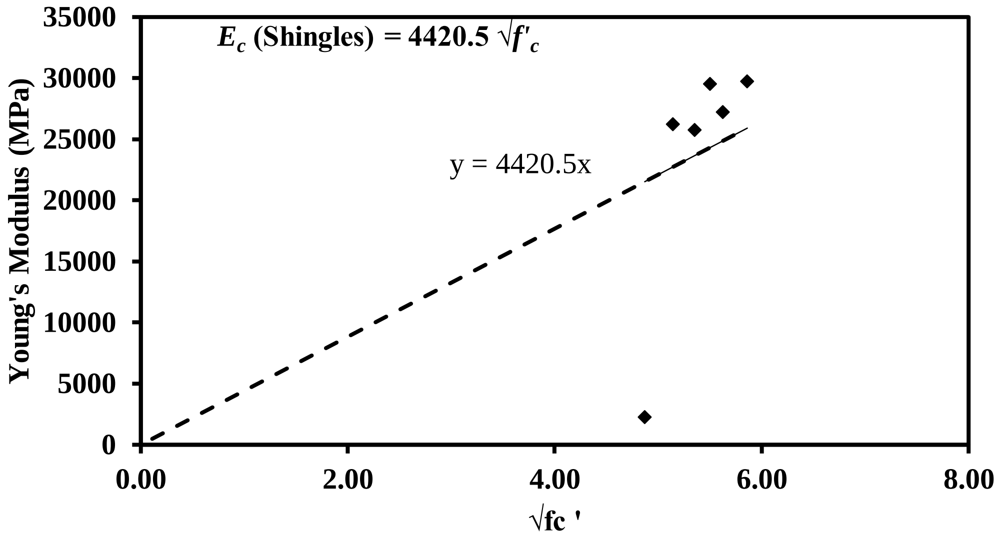


Fig 4.23: Young's modulus vs Compressive Strength

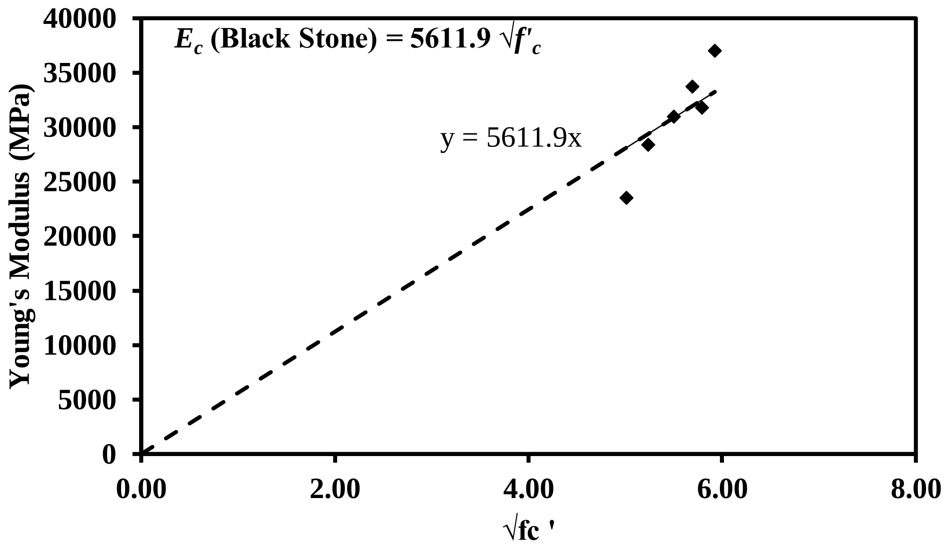


Fig 4.24: Young's modulus vs Compressive Strength

From the Young's modulus vs Compressive strength graphs we can see how compressive strength of concrete and Young's modulus of concrete is related to each other and also we can observe different behavior for different types of aggregates. R^2 indicates how close the data are to the fitted regression line. From all the graphs we can see that for black stone we got the higher value of R^2 which means for black stone the Young's modulus vs compressive strength points are most closer to linear line than other aggregates. Higher Young's modulus means higher the ability of a material to withstand changes in length when under lengthwise tension or compression. Higher compressive strength value means higher resistance to compressive load. Both high value of these two are expectable for a sound concrete. Black stone give the best combination of high Young's modulus as well as high compressive strength to the concrete in comparison to others. For brick we can observe to most worst case.

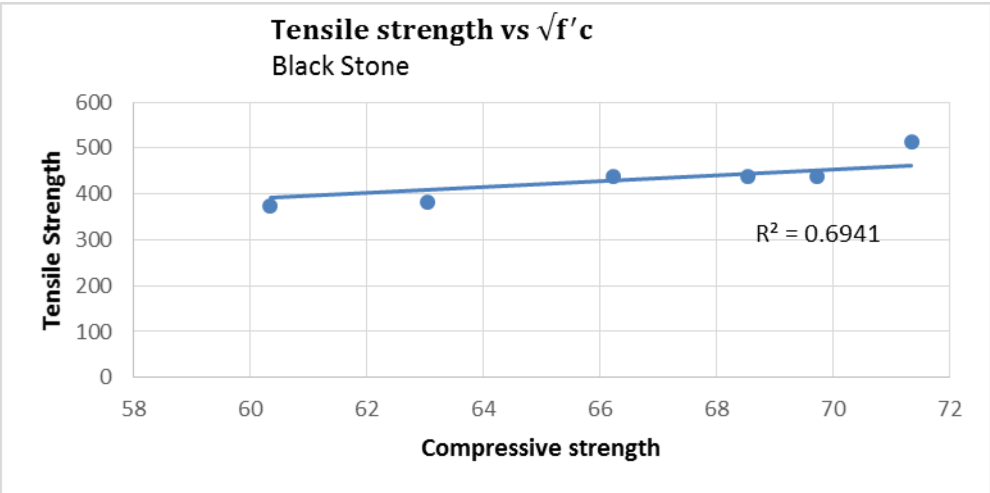


Fig 4.25: Tensile Strength vs Compressive Strength

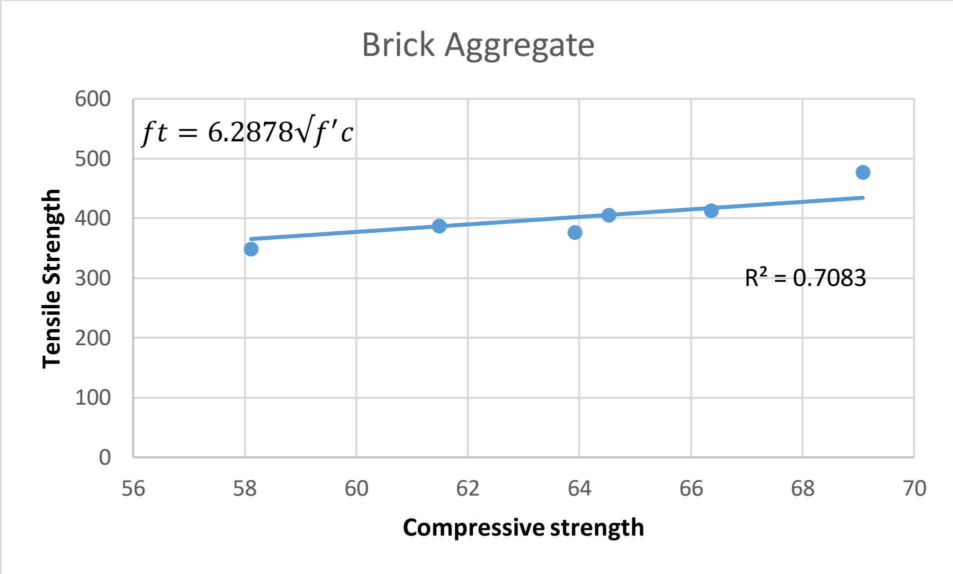


Fig 4.26: Tensile Strength vs Compressive Strength

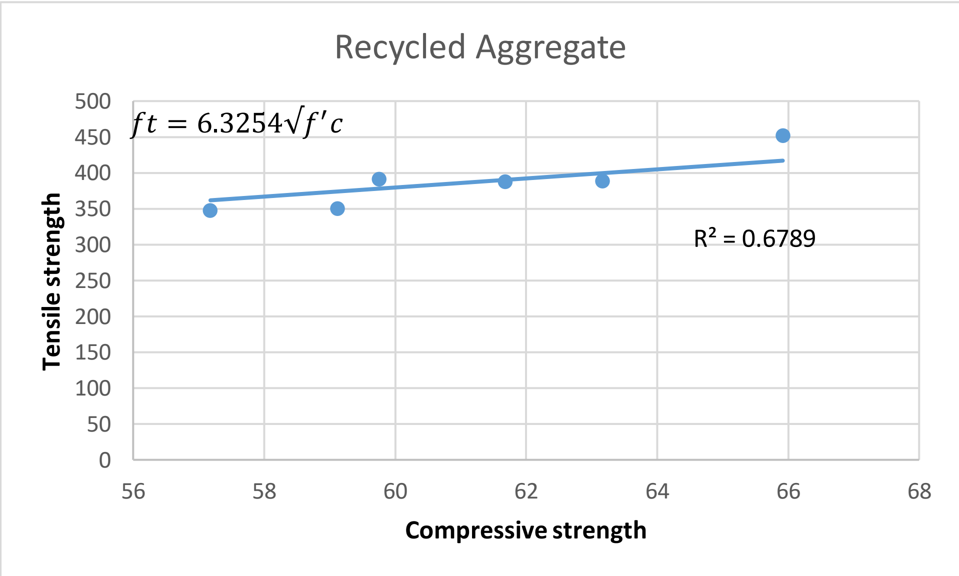


Fig 4.27: Tensile Strength vs Compressive Strength

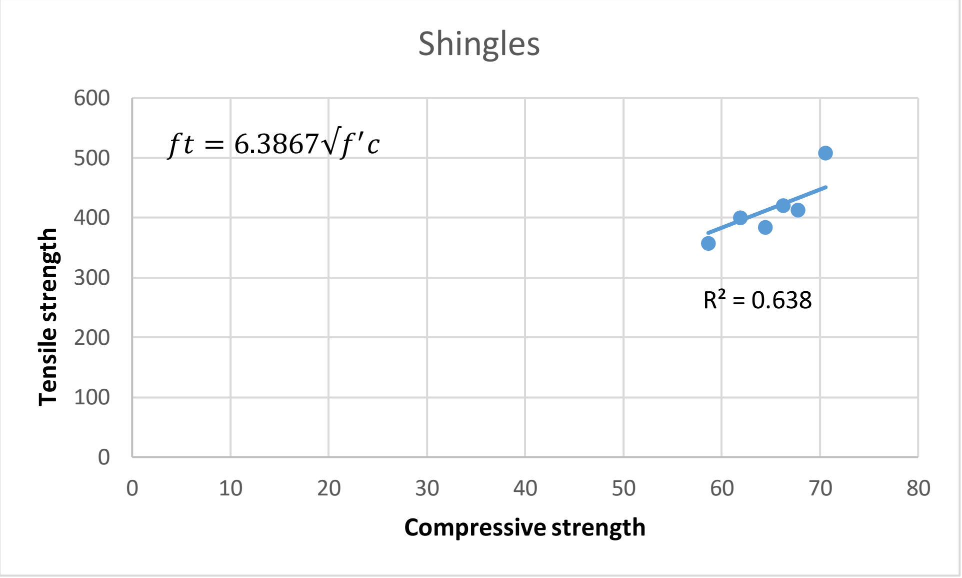


Fig 4.28: Tensile Strength vs Compressive Strength

From the Tensile strength vs Compressive strength graphs we can see how compressive strength of concrete and Tensile strength of concrete is related to each other and also we can observe different behavior for different types of aggregates. R^2 indicates how close the data are to the fitted regression line. From all the graphs we can see that for brick aggregate we got the higher value of R^2 which means for brick aggregate the Tensile strength vs compressive strength points are most closer to linear line than other aggregates. Higher Tensile strength means higher the ability of a material to resist breaking under tension. Higher compressive strength value means higher resistance to compressive load. Both high value of these two are expectable for a sound concrete. Brick aggregate give the best combination of high Tensile strength as well as high compressive strength to the concrete in comparison to others. For shingles we can observe to most worst case.

4.11 Conclusion

The primary goal of this study was to find out and establish relationship between various mechanical properties of concrete. Comprehensive study among concrete made with different types of aggregate and binders are made in order to have a better understanding.

5. Conclusion and Summary

5.1 Reviews on Completed Research Work

The major objective of this study was to create a comparative analysis of the different parameters related to durability of concrete using different types of aggregates and different types of binding materials. The major objective was to investigate the influence of different types of aggregate on Chloride Penetration through concrete. And also to investigate the influence of different types of binding materials on Chloride Penetration through concrete.

But due to time constraint we could only measured the mechanical properties of concrete for different types of aggregate and binding materials. The significance of those results were discussed here. The research will continue and data will be collected for Chloride penetration through concrete.

5.2 Summary and Conclusion

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

- From the test results, specific gravity of black stone is higher than shingles. So, black stone are more dense than shingles.
- As the value of %wear of shingles is greater than that of black stone, it can be said that shingles are harder than black stone.
- Abrasion value of Recycled Brick Aggregate is the highest, which means it is the weakest of the aggregates investigated.
- Slump value increases with increase in W/C ratio of mix for any type of aggregate.

- Percentage air entrainment in concrete decreases with increase in W/C ratio for any type of concrete. For brick aggregate the percentage air entrainment is maximum.
- UPV of concrete specimen made with brick aggregate and recycled brick aggregate appears to be lower than that of concrete made with shingles and black stone.
- Split Tensile Strength is found higher for concrete made with OPC and it increases with decrease in W/C ratio.
- Black stone give the best combination of high Young's modulus as well as high compressive strength to the concrete in comparison to others.
- Shingle give the best combination of high UPV as well as high compressive strength to the concrete in comparison to others. For brick we can observe to most worse case.
- Young's modulus and compressive strength of concrete increases with decrease of w/c ratio for any type of aggregate and increases with increase of cement content.

Unit weight increases with decrease of w/c ratio and for black stone Unit weight is maximum. For CEM type-II BM Unit weight was found less comparing to OPC cement for all types of aggregate. Unit weight almost remains same with the increase of cement content.

6. Future Plan

6.1 General

Testing of specimen for 28 days of curing for the remaining cases and 60 days of curing and 6 months of curing for all the cases. RCPT test of specimen for 28 days of curing and Chloride ingress test for 60 days and 6 months of curing.

6.2 RCPT Test

A direct current (DC) of 60+0.10 V will be applied across the specimen and the resulting current will be recorded at 5-min interval covering a total period of 6 hr.

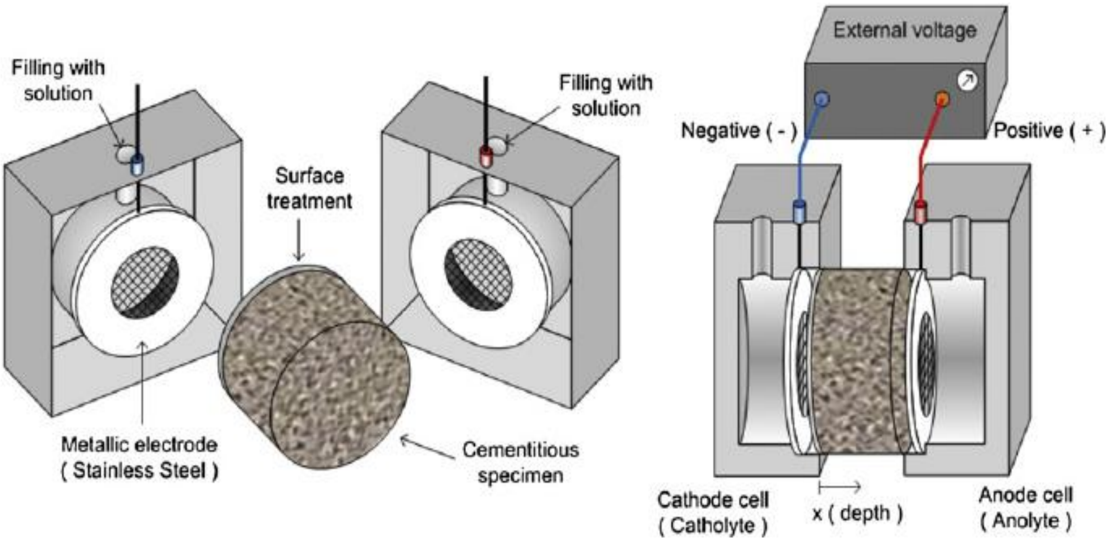


Fig 4.29: RCPT Test

Calculating the total charge, the chloride permeability will be determined using the chart given:

Chloride permeability of concrete based on charge passed [18, 20, 30, 31, 33]

Charge [Coulombs]	Chloride permeability	Type of concrete
> 4,000	high	high water-to-cement ratio (> 0.5) conventional Portland cement concrete
2,000–4,000	moderate	moderate water-to-cement ratio (0.4–0.5) conventional Portland cement concrete
1,000–2,000	low	low water-to-cement ratio (< 0.4) conventional Portland cement concrete
100–1,000	very low	latex-modified concrete, internally sealed concrete
< 100	negligible	polymer-impregnated concrete, polymer concrete

Fig 4.30: RCPT Test

6.3 Chloride Ingress Test

Chloride ingress in reinforced concrete induces corrosion and consequent spilling and structural weakness, and it occurs world-wide and imposes an enormous cost. Resistance of Concrete to Chloride Ingress sets out current understanding of chloride transport mechanisms, test methods and prediction models. It describes basic mechanisms and theories, and classifies the commonly used parameters and their units which expressing chloride and its transport properties in concrete. Some concrete specimens will be exposed to an accelerated environment of 3% NaCl solution in 40 C temperature prior to perform chloride ingress test. The specimens will be splited at different ages (60 days and 6 months) to measure the depth of chloride ingress in the direction of diameter. The more is the penetration, the worse is the condition.

6.4 Conclusion

By the following two test method we will get the value of RCPT and chloride ingress in concrete. We will investigate the influence of different types of aggregate on Chloride Penetration through concrete and also will investigate the influence of different types of binding materials on Chloride Penetration through concrete. Then we will use those results to perform a comparative analysis of the different parameters related to durability of concrete using different types of aggregates and different types of binding materials.

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