THE EFFECT OF DIFFERENT TYPES OF AGGREGATE ON THE DURABILITY OF CONCRETE : CARBONATION

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Declaration of Candidate

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

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Dedication

We would like to dedicate this thesis to our beloved parents

Acknowledgements

"*In the name of Allah, Most Gracious, Most Merciful*"

All praises to Almighty Allah for giving us opportunity to conduct this thesis work and helping us in solving difficulties during our project work.

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Abstract

Highly desirable durability requirement for concrete is not always achieved in practice due to various environmental factors. Corrosion of reinforcement in concrete is a common cause of deterioration in many RC structures. One of the main cause of corrosion of reinforcement in concrete is Carbonation, which is the result of the chemical reaction between carbon dioxide gases in the atmosphere and alkaline hydroxides in the concrete. This paper investigates the durability of concrete specimens made with different locally available coarse aggregate through carbonation testing in accelerated condition using a carbonation chamber. To investigate the fresh and hardened properties of concrete, four different coarse aggregates such as black stone (a type of crushed stone), shingles (round shaped stone), brick aggregate and recycled brick aggregates were used. Several tests such 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 sand to total aggregate volume ratio (s/a) (0.44), W/C ratio (0.45, 0.50). OPC, PCC Type II B-M, PCC Type II B-S, PCC Type II B-S (40% OPC – 60 % Slag) are the four different binder types used with cement content (340 kg/m^3 and 400 kg/m^3). A total of 42 different cases were considered and a total of 672 concrete specimens were made for testing. The specimens have been tested for compressive strength, split tensile strength test at 28 days and 2 months. Non-destructive tests such as Ultrasonic Pulse Velocity (UPV) was also performed.

The results have revealed that black stone and OPC are the two aggregate and cement type that produced highest compressive and tensile strength for the concrete specimens at 28 days. UPV test showed higher values for stone aggregates compare to brick and recycled brick aggregates. Besides, correlation between compressive strength with other properties like young’s modulus, tensile strength and UPV were also explored .Our main goal was to find the effect of different aggregates types and the mechanical properties they produced on the durability of concrete by assessing the carbonation depth found in the specimens. But due to time limitation the carbonation testing could not be completed. Further analysis based on the data collected and carbonation depth will be made as soon as the data are available. This analysis will help us to reach a conclusion on how different aggregates and cement types affect the carbonation process in concrete.

Keywords: Carbonation, different coarse aggregate, different cement binders, compressive strength, Tensile strength, UPV, cement content. W/C ratio.

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UPV	Ultrasonic Pulse Velocity
W/C	Water to Cement ratio
s/a	Sand to total aggregate volumetric ratio
U	Unit weight of Concrete
R^2	Pearson product moment correlation co-efficient
f’c	Compressive strength of concrete
ft	Tensile strength of concrete
Ec	Young’s Modulus of concrete

CHAPTER 1: INTRODUCTION

1.1 General

For a long time, concrete was considered very durable material requiring a little or no maintenance. The assumption is largely true, except when it is subjected to highly aggressive environments. We build concrete structures in highly polluted urban and industrial areas, aggressive marine environments, harmful sub-soil water in coastal area and many other hostile conditions where other materials of construction are found to be non-durable. Since the use of concrete in recent years, have spread to highly harsh and hostile conditions, the earlier impression that concrete is a very durable material is being threatened, particularly on account of premature failures of number of structures in the recent past. One of the main reasons for deterioration of concrete in the past, is that too much emphasis is placed on concrete compressive strength. As a matter of fact, advancement in concrete technology has been generally on the strength of concrete. It is now recognized that strength of concrete alone is not sufficient, the degree of harshness of the environmental condition to which concrete is exposed over its entire life is equally important. Therefore, both strength and durability have to be considered explicitly at the design stage.

According to ACI 201.2R-08 “Durability of hydraulic-cement concrete is determined by its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration”. Reinforced concrete structures have the potential to be very durable and capable of withstanding a variety of adverse environmental conditions. However, failures in the structures do still occur as a result of premature reinforcement corrosion which are Durability problems related to environmental causes. Some common causes of deterioration related to durability of concrete structures in Bangladesh are:

(A) Carbonation induced corrosion of steel bar,

(B) Chloride induced corrosion,

(C) Sulphate attack.

Carbonation induced corrosion of steel bar is a process by which CO_2 from the air penetrates into concrete and reacts with calcium hydroxide to form calcium carbonates in presence of water. Thus reduce pH value, finally breaking the passivation film of concrete which leads to corrosion of steel.

- The first reaction is in the pores where carbon dioxide (CO_2) and water (H_2O) react to form carbonic acid (H_2CO_3):

$$CO_2 + H_2O \longrightarrow H2CO_3$$

- carbonic acid then reacts with the calcium phases:

$$H_2CO_3 + Ca\,(OH)_2 \longrightarrow CaCO_3 + 2\bullet H_2O$$

Once the $Ca(OH)_2$ has converted and is missing from the cement paste, hydrated CSH (Calcium Silicate Hydrate - $CaO\bullet SiO_2\bullet H_2O$) will liberate CaO which will then also produce carbonate:

$$H_2CO_3 + CaO \longrightarrow CaCO_3 + H_2O$$

H_2C0_3 reacts with $Ca(OH)_2$ and carbonation of concrete takes place. This reduce the alkalinity of concrete. When pH of concrete reduces below 8.3, then passive layer destroyed and corrosion takes place. The products of corrosion occupy a volume as much as six times the original volume of steel. This exert thrust on cover concrete resulting in cracks, spalling or delamination of concrete.

The rate of carbonation can be determined by monitoring the depth of carbonation over a period of time (Kropp and Hilsdorf, 1995; Schiessl, 1988). It generally follows a formula of the form:

$dc = K\sqrt{t}$

where dc = depth of carbonation

K = rate of carbonation, a constant

t = duration of exposure.

In this thesis, a comprehensive analysis on the durability of concrete is done based on resistance against **Carbonation induced corrosion** of concrete made with different types Coarse aggregates, cement binders, W/C ratios, Cement Content. A Comprehensive study of different mechanical properties of concrete such as

Compressive strength, Tensile Strength, workability, air entrainment and their effect on the carbonation process have been assessed.

1.2 Background and Rational:

Factors contributing to acceleration of Carbonation affect are:

- Relative humidity (range: 50%- 70%)
- Hot temperature
- High Concentration of CO2 gas in the atmosphere

Weather and climatic condition of Bangladesh is known to present all such characteristics. As a result, Carbonation plays a major role in the deterioration of concrete in our country.

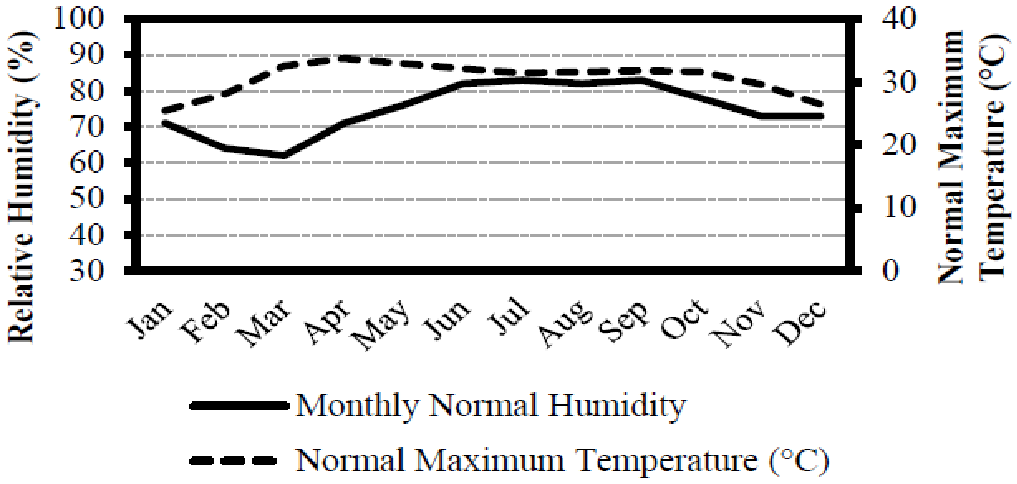


Figure 1.1: Monthly relative humidity and temperature of Dhaka city

Photo 1.1: Corrosion of steel due to Carbonation: structures in Dhaka city.

Due to high market prices of stone aggregates, many local construction company are often reluctant to use it .So, it becomes necessary to study the durability aspects on more commonly used aggregates like Brick chips and other viable alternative like recycled brick aggregates to compare the results and to provide future recommendation for their use. How different aggregate affect the durability of concrete is a major question that needs to be answered to ensure that the structure sustains it's serviceability throughout the design period.

1.3 Objective:

The durability of concrete will be assessed in light of the following objectives:

- To find out the effect of different Binding Materials due to carbonation through concrete.
- To find out the effect of different Aggregate types due to carbonation through concrete.

1.4 Scope:

The scope of the study involves:

- The study of different kind of aggregates, Cement content, W/C, air content on the durability of concrete relating to resistance against Carbonation.
- Studying the relationship between compressive strength and durability property of concrete.
- Finding out possible correlation between ultra pulse velocity(UPV) and durability of concrete.

1.5 Research Flow diagram:

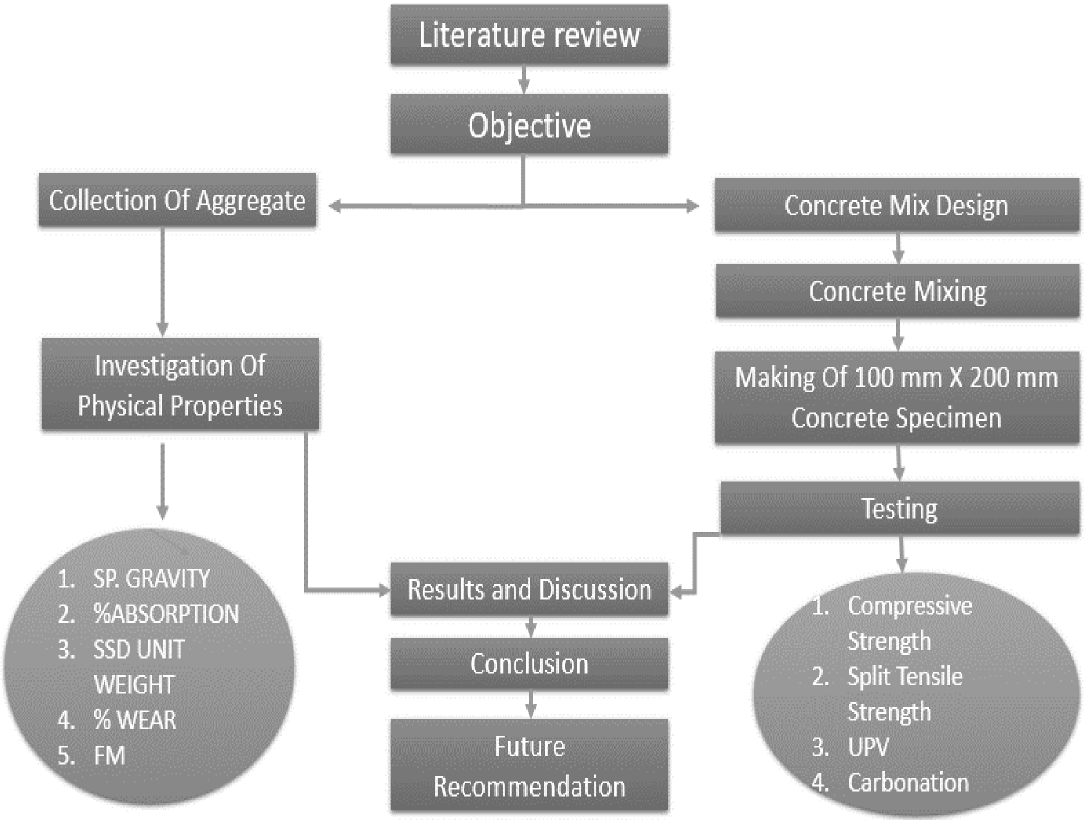


Figure 1.2: Research flow Diagram

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 Recommendation; discusses about the effectiveness of the study, and recommendations for future studies

CHAPTER 2: LITERATURE REVIEW

2.1 General:

In reinforced concrete (RC) structures, the carbonation depth is a key deterioration factor to determine the durability of concrete structures. It is one of the major factors to cause structure deterioration. Carbonation is the reaction of the hydration products dissolved in the pore water with the carbon dioxide in the air which reduces the pH of concrete pore solution from 12.6 to less than 9 and steel passive oxide film may be destroyed and accelerating uniform corrosion (Papadakis V.G. 1992). Carbonation-induced corrosion can increase crack development and decrease concrete durability (Roy S.K. 1999). Many studies were conducted over the years to narrow down the major factors affecting carbonation in concrete:

.

2.2 Cement composition and concrete mix design:

Since hydrated cement is the carbonatable component of the concrete, the carbonation depth is inversely proportional to the cement content. In addition, the amount of CO2 needed to react with the alkaline components of the hydrated cement depends on the type of cement.

According to Bakker (1986), for the same rate of diffusion of CO2, the carbonation depth is related to the amount of alkaline components of the concrete, mainly the CaO.

Several authors (Shroder, F. 1986; Hamada, H. 1968) consider that the rate of carbonation of a mortar, everything else kept being the same, is faster for blended cement than for unblended portland cements. Some authors state (Ho, D.W.S.; Paillere, A.M 1986) that a fly ash mortar carbonates about fifty percent faster than a portland cement mortar.

M. Venuat (1977) also indicates that cements with large quantities of additions carbonate more faster, specially if the concrete has not been kept wet since the beginning of the curing process.

According to S. T. Pham and W. Prince (2014), the carbonation rate of CEM I mortar is slower than the one of CEM II mortar, which is not only because of its greater content of portlandite but also because of the coverage of portlandite crystals by newly formed calcite.

P.A.M. Basheer (1999) et al. concluded rate of carbonation of normal Portland cement concrete is primarily influenced by the water-cement ratio and other factors have only a marginal effect. Therefore, concrete can be designed to have a specific carbonation resistance based entirely on the water-cement ratio. However, this should be verified for different types of and grading of aggregate.

2.3 Porosity:

The concrete porosity is controlled by the W/C ratio (Shroder, F. 1986). Not all the mixing water is used in the hydration reactions, but some of it remains free. As this water evaporates after the curing process, it induces the formation of a network of channels and pores, which make the concrete permeable to certain gases.
The porosity of the concrete therefore increases as the W/C ratio does, which indicates that the rate of carbonation will also increase as the CO2 diffuses more easily through the pores. Also, as the porosity increases, the diffusion of other elements that play a role in the carbonation process, such as $Ca(OH)_2$ also increases.

The porosity depends also on the grain size distribution of the aggregates. This explains how cement paste carbonates slowly and mortar much more rapidly, more than concrete. The reason for this is that normally a mortar is not as densely compacted as concrete. A deficient joint between the aggregate and the cement paste may lead in a very irregular carbonation front, with deep inroads in the contact zones of the two phases mentioned above (Shroder, F. 1986; Bakker 1986).

The porosity of a concrete depends also partly on the type of cement. Thus, slag cement give lower porosity than Portland ones (Litvan, G.G. 1986)

.

2.4 Curing conditions:

Curing conditions affect the carbonation rate considerably in a concrete (Skjolsvold.0 1986; Fattuhi, N.I. 1986). For the same composition and at a given temperature, the pore permeability depends on the degree of hydration. As this increases, the permeability decreases. This is however true only if there is no water loss, which supposes curing under high humidity conditions (Smolckyk, H.G.1976). If there is loss of water, the degree of hydration is inferior, which would in turn increase the carbonation depth.

2.5 Concrete compaction

Concrete must be well compacted, otherwise the zones more permeable than other would develop voids which will conduct to a rapid carbonation of that zone

2.6. Relative humidity

In addition to the factor mentioned above carbonation depends also of variables of the environment, especially on relative humidity, since it is the humidity within the pores of the concrete which eventually determines the permeability to CO_2**.** This internal humidity depends in turn on the ambient relative humidity.

Carbonation in practice, takes place in either dry concrete or water saturated concrete, which means that only a concrete not saturated with water could carbonate. Maximum penetrations appear when RH is between 50 and 65%.

For humidity below 30% the carbonation phenomenon does not take place or is very slow (Litvan, G.G. 1986; Weber, H 1983). This fact confirms the expectation that the hydrated components of the concrete carbonate by formation of intermediate alkaline hydroxides in solution (Suzuki, K. 1985; Blenkin, R.D. 1985). At elevated humidity, carbonation cannot take place due to the slow rate of the CO_2 diffusion in water compared with that in air.

For each relative humidity in the atmosphere there is an equilibrium humidity in the concrete that tends to be approached, although the time for equilibration may be very long when the concrete is dense and the cover thickness is considerable (Woods, H. 1974). In any event, a minimum amount of water is necessary for carbonation becomes possible starting at 0.5-1 % of water by concrete weight in the concrete pores (Venaut, M. 1977). Should also be considered that the process of carbonation may increase the humidity of the pores as water is liberated during the reaction of hydrated components and the CO_2. This could in turn, facilitate the carbonation process.

2.7 Mechanical Properties:

Several mechanical properties of concrete such as compressive strength, surface hardness and resistance to aggressive agents may change due to carbonation (V'eleva. L. 1998). The splitting tensile strength and compressive strength of carbonated concretes slightly increases compared to the non-carbonated concretes and the higher water/binder ratio results in lower splitting strength.

The statistical analysis by Das et al. [Yongsheng JI. 2010] showed that the carbonation potential of concrete decreases with an increase in the compressive strength of the concrete.

2.8 Accelerated and Natural carbonation:

Due to low concentration of CO2 in atmosphere, Carbonation takes more than a decade to initiate in natural process. [Yongsheng JI. 2010]

The rate of carbonation from accelerated carbonation testing can be used for the service life design of concrete in an environment where carbonation is a probable cause of deterioration. However, there is a need to relate the results of the accelerated test to those of natural exposure trials before this approach can be used.

Few researchers still debate about how reliable the results of accelerated carbonation are in comparison to the natural process but F. L. Simsomphon (2007) have used the results from accelerated carbonation tests earlier to predict the carbonation depths on long-term natural exposures and found that results were very consistent with the natural process**.**

2.9 Ultraviolet Pulse Velocity (UPV):

Ultrasonic scanning is a recognized non-destructive evaluation test to qualitatively asses the homogeneity and integrity of concrete. With this technique, following can be assessed:

- Qualitative assessment of strength of concrete, its gradation in different locations of structural members and plotting the same.
- Any discontinuity in cross section like cracks, cover concrete delamination etc.
- Depth of surface cracks.

York, Wiley and Sons (1998) experimented that the method (Using the analysis of the propagation variations of ultrasonic velocity wave, it is possible to detect heterogeneous regions in the concrete) is based on the propagation of a high frequency sound wave which passes through the material. The speed of the wave varies in function of the density of the material, allowing the estimation of the porosity and the detection of discontinuities. The idea is to project the sound inside a material and measure the time necessary for the wave to propagate through it. Once the distance is known, it is possible to determine the average pulse velocity, which will depend on several factors such as the nature of the material and the presence of water in the pores, among others. The method is normally based on the use of portable equipment, composed by the source/detector unit and the surface transducers, which works in the frequency range of 25 to 60 kHz.

The ability to detect porosity and discontinuity in concrete by UPV can prove to be valuable asset while determining causes for carbonation due to non-homogeneity in concrete.

CHAPTER 3: METHODOLOGY

3.1General

In this experiment brick aggregate, recycled brick aggregate, Crushed black stone and shingles as coarse aggregate; Natural river sand(Sylhet sand) as fine aggregate and water, cement as binding material were used to make cylindrical concrete specimen of Size 100mm X 200mm. The chapter describes the full experimental procedure, material properties of both coarse and fine aggregate. Casting process performed according to different codes of ASTM. Specific ASTM standards for carrying out different tests 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:

1 Selecting coarse aggregate and grading them according to ASTM **C33**.
2 Sylhet sand is used as fine aggregate after sieving and grading them according to ASTM **C33**.
3 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.

Table 3.1 ASTM Test Methods Followed

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

3.3.1 Binding Material

As a binding material Ordinary Portland Cement (OPC), CEM Type II B-M, CEM Type II B-S and CEM Type II B-S(40% OPC – 60% Slag) 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.

Table 3.2: Classification of Cement as Per BDS EN 197-1 (CEM I and CEM II)

Composition (%)	Type of Portland cement		
	CEM I	CEM II/B-M	CEM II/B-S
Clinker	95-100	65-79	65-79
Blast-furnace Slag	-	21-35	21-35
Silica Fume	-		-
Pozzolana	-		-
Fly Ash	-		-
Burnt Shale	-		-
Limestone	-		-
Additional Constituents	0-5	0-5	0-5

3.3.2 Aggregate

We used brick aggregate, recycled brick aggregate, Crushed black stone and shingles as coarse aggregate. We used Natural river sand (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**.

Photo 3.1: Shingles(Round shaped stones)

Photo 3.2: Black Stone

Photo 3.3: Recycled brick aggregate

Photo 3.4: Brick Chips

Table 3.3: 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 3.4: 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)
2258.6	2284.5	1423.6	2.65	
2379	2401.7	1495.9	2.65	2.65
2087	2111.3	1313.2	2.65	

Table 3.5: 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)**
1523.7	1867.2	926.1	1.98	
1484	1818.4	901	1.98	1.98
1445	1765.1	875.1	1.98	

Table 3.6: 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)**
2322.7	2571	1369.6	2.14	
2067.7	2282.2	1219.8	2.15	2.14
2303.5	2540.8	1355.8	2.14	

Table 3.7: Absorption of Black stone chips

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	1.5
2219.3	2248.9	1453.5	1.33	
1990.9	2020.6	1304.6	1.49	

Table 3.8: 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 (%)
2258.6	2284.5	1423.6	1.15	1.1
2379	2401.7	1495.9	0.95	
2087	2111.3	1313.2	1.16	

Table 3.9: 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 (%)
1523.7	1867.2	926.1	22.54	22.4
1484	1818.4	901	22.53	
1445	1765.1	875.1	22.15	

Table 3.10: 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 (%)
2322.7	2571	1369.6	10.70	10.5
2067.7	2282.2	1219.8	10.37	
2303.5	2540.8	1355.8	10.30	

Table 3.11: % Abrasion Wear of Black Stone chips

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**
5000	4320	680	13.6

Table 3.12: % 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**
5000	3670	1330	26.6

Table 3.13: % 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**
5000	3027.2	1972.8	39.5

Table 3.14: %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**
5000	2874.5	2125.5	42.5

Photo 3.5: Los Angeles Abrasion test

Table 3.15: Unit weight of Black Stone chips

Volume of Mold =0.0131 m^3

Mass of mold (kg)	**Mass mold and aggregate (kg)**	**Unit weight** (kg)	**Avg. unit weight (kg)**	**SSD unit weight (kg)**
6.6	26.43	1513.74	1528	1551
6.6	26.75	1538.17		
6.6	26.67	1532.06		

Table 3.16: Unit weight of Shingles

Volume of Mold =0.0131 m^3

Mass of mold (kg)	**Mass mold and aggregate (kg)**	**Unit weight** (kg)	**Avg. unit weight (kg)**	**SSD unit weight (kg)**
6.6	28.27	1654.2	1656	1674
6.6	28.32	1658		
6.6	28.30	1656.5		

Table 3.17: Unit weight of brick aggregate

Volume of Mold =0.0131 m^3

Mass of mold (kg)	**Mass mold and aggregate (kg)**	**Unit weight** (kg)	**Avg. unit weight (kg)**	**SSD unit weight (kg)**
6.6	18.92	987.8	988	1209
6.6	18.84	985.5		
6.6	19.07	990		

Table 3.18: Unit weight of recycled brick aggregate

Volume of Mold =0.0126 m^3

Mass of mold (kg)	**Mass mold and aggregate (kg)**	**Unit weight** (kg)	**Avg. unit weight (kg)**	**SSD unit weight (kg)**
6.6	20.68	1074.8	1090	1204
6.6	21.09	1106.1		
6.6	20.85	1087.6		

Photo 3.6: Unit weight test

3.3.2.2 Gradation of Coarse Aggregate

Sieve analysis of coarse aggregate was within the upper and lower limit set by ASTM **C33** of shown in figure

Table 3.19: Gradation of Coarse Aggregate according to ASTM C33

Max CA size	**37.5 mm**	**25.0 mm**	**19.0 mm**	**12.5 mm**
Sieve opening (mm)	**% passing**			
37.5	90	100	-	-
25.0	40	90	100	-
19.0	10	50	90	100
12.5	-	15	40	90
9.5	0	0	10	50
4.75	-	0	0	0

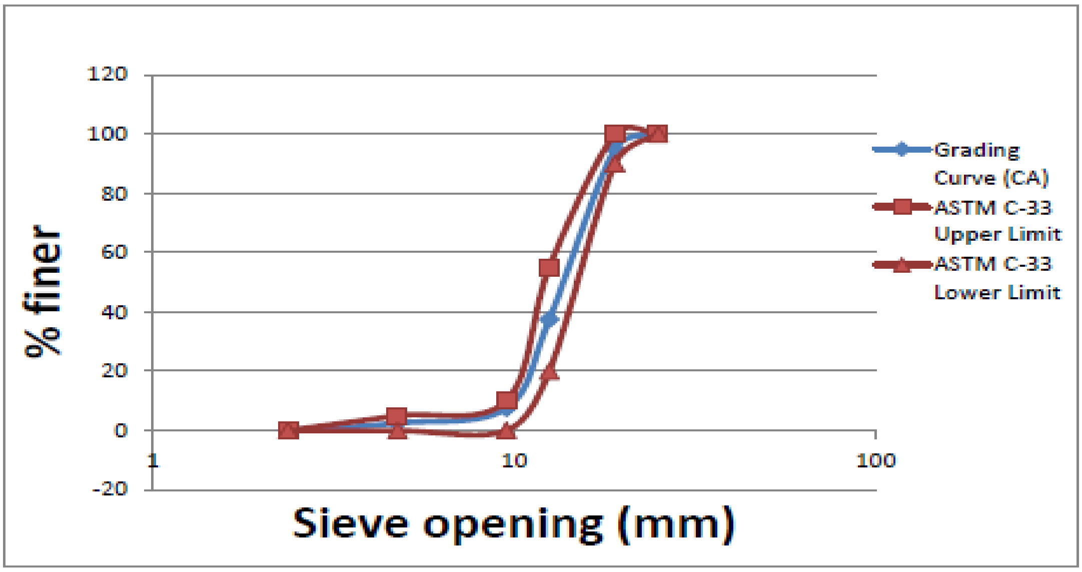


Fig 3.1 : Gradation curve for Coarse Aggregate

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 3.20: 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	1237.3	2.47	
283.3	791.4	1578.1	1276.2	2.46	2.46
288.2	831.9	1599.3	1279.6	2.43	

Table 3.21: 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	518.7	503.3	3.06	3
283.3	791.4	508.1	492.7	3.13	
288.2	831.9	543.7	528.6	2.86	

Table 3.22: Unit weight of fine aggregate

Volume of mold = 0.002958 m^3

Mass of mold (kg)	Mass mold and aggregate (kg)	Unit weight (kg)	Avg. unit weight (kg)	SSD unit weight (kg)
2.81	7.32	1524.7	1528	1574
2.81	7.34	1531.4		
2.81	7.33	1528.1		

3.3.2.2.1 Gradation of Fine Aggregate

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

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 (**FM**) = 2.58

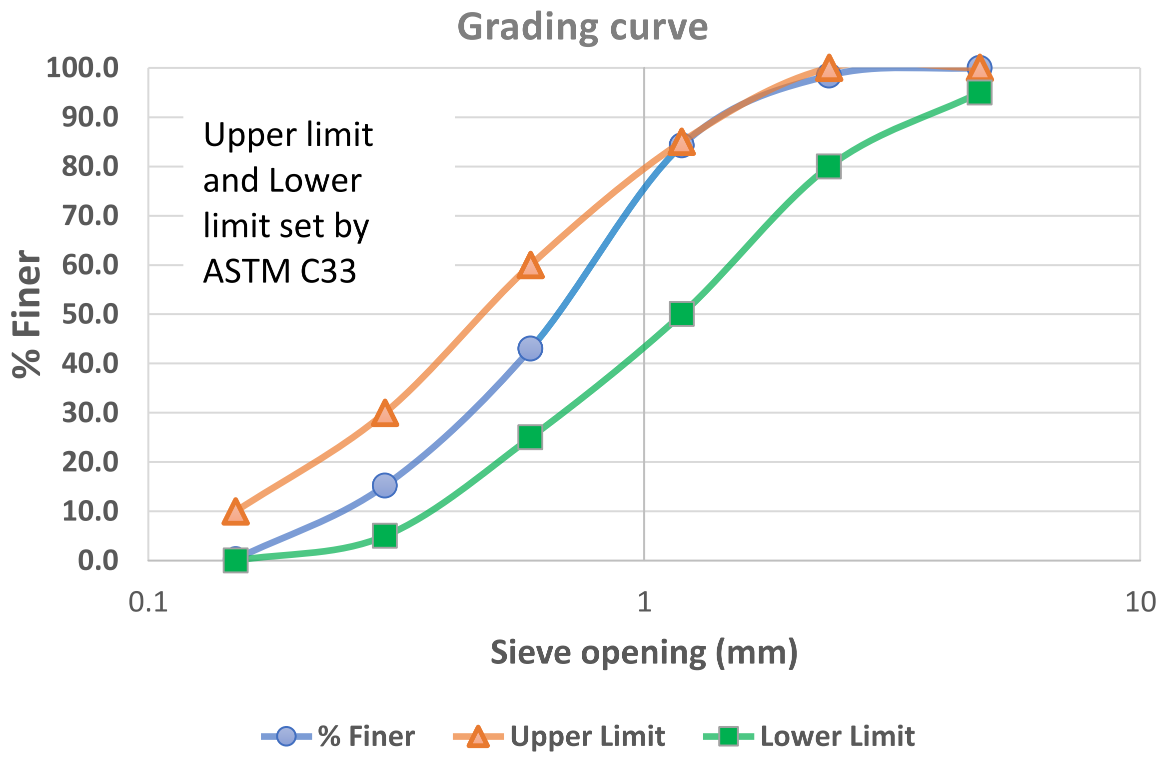


Fig 3.2 : Grading Curve for Fine Aggregate

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%	1090	1204	42%
	Brick chips	1.98	10.5%	988	1209	39%

3.4 Materials estimation

Number of cases= 42

Number specimen is each case = 16

Total Number of specimen = 42 x 16 =672

Cement : 400 Kg/m^3 x 672 x 0.00157 m^3 x 1.5 = (14 bags)

Fine Aggregate: 895 Kg/m^3 x 672 x 0.00157 m^3 x 1.5 = (50 cft)

Coarse Aggregate:

Brick aggregate : 924 Kg/m^3 x 672 x 0.00157 m^3 x 1.5 = 50 cft (735 Nos)

Recycled brick aggregate: 936 Kg/m^3 x 672 x 0.00157 m^3 x 1.5 = 50 cft

Crushed stone: 1064 Kg/m^3 x 672 x 0.00157 m^3 x 1.5 = 50 cft

Shingles: 1044 Kg/m^3 x 672 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.

Photo 3.7: Sand Before Sieving(left) and After Sieving in SSD Condition(right).

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.

Photo 3.8: Coarse Aggregate Before(left) and After (Right) 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 and CEM Type II B-S(40% OPC – 60% Slag). The cement content for each test procedure was weighted very carefully.

3.5.4 Water Source:

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	OPC	Brick Aggregate	0.45	0.44	340
2			0.50		340
3			0.45		400
4			0.50		400
5		Recycled Brick Aggregate	0.45		340
6			0.50		340
7			0.45		400
8			0.50		400
9		Black Stone	0.45		340
10			0.50		340
11			0.45		400
12			0.50		400

13		Shingles	0.45		340
14			0.50		340
15		Shingles	0.45		400
16			0.50		400
17	CEM Type II B-M	Brick Aggregate	0.45		400
18			0.50		
19		Recycled Brick Aggregate	0.45		
20			0.50		
21		Black Stone	0.45		
22			0.50		
23		Shingles	0.45		
24			0.50		
25	CEM Type II B-SL	Brick Aggregate	0.45	0.44	400
26			0.50		
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**			
	Compressive Strength & UPV	Split Tensile	RCPT	Chloride Ingress
28d	3	1	1	-
60d	3	1	-	1
6m	3	1	-	1
Total	10	3	1	2

Specimens per case = 10+3+1+2 = 16 Nos

Total number of cases = 42

Total number of specimens

= Total cases x Specimen per cases

= 42 x 16

= 672 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.

Photo 3.9: Slump test

3.7.2 Air Entrainment Test

Pressure Type "B" Meter 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. Applicable Standards: ASTM C231

Photo 3.10: Air entrainment 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.

Photo 3.11:Mixing 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.

Photo 3.12: pouring and tamping of concrete

Photo 3.13: scaling and hammering

Photo 3.14: 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.

Photo 3.15: Initial 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.

Photo 3.16: Final curing

3.9 Testing

3.9.1 Non Destructive Test

3.9.1.2 UPV testing:

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.

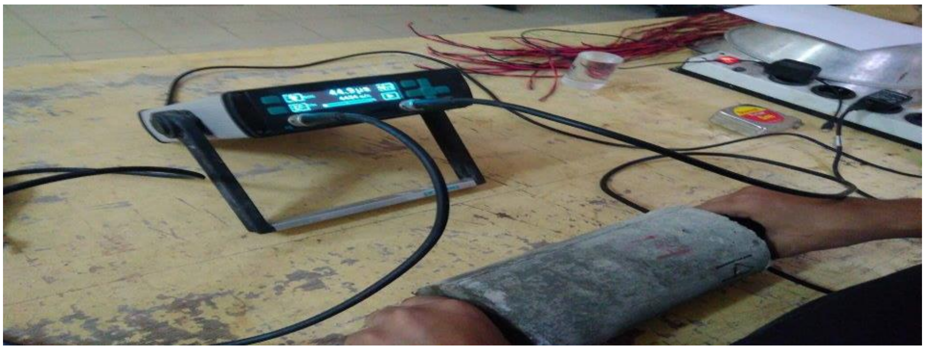


Photo 3.17: UPV Test

3.9.2 Destructive Tests

3.9.2.1 Compressive Strength test

The compressive strength of concrete was measured at 28th day using compressive strength ting machine according to ASTM C M C39. 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.

Photo 3.18: 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 validate the findings of this investigation.

Photo 3.19: Splitting tensile test

3.9.3 Carbonation Test

In this method, first concrete specimen is kept in an open environment for a number of years or in Carbonation Chamber for a number of months. Generally, conditions of 70% CO_2, 50% Relative Humidity, and 20-22ºC is maintained in a carbonation chamber. Then sample is broken and is sprayed with a pH indicator. Popularly a standard solution of 1% phenolphthalein in 70% ethyl alcohol is used The phenolphthalein indicator solution is applied to a fresh fracture surface of concrete. If the indicator turns purple, the pH is above 8.6. Where the solution remains colorless, the pH of the concrete is below 8.6, suggesting carbonation. A fully-carbonated paste has a pH of about 8.4.

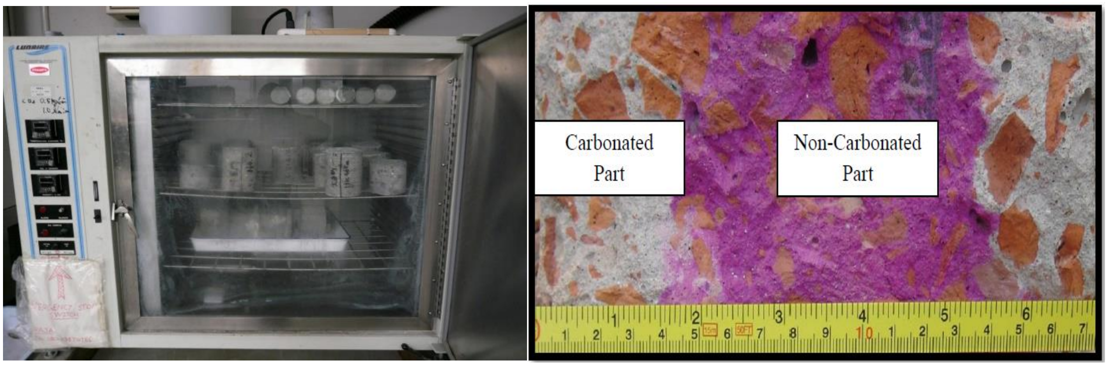


Photo 3.20: Carbonation Test.

CHAPTER 4: RESULT AND DISCUSSION

4.1 General

As per the objectives of the experimental methods stated above a number of experiments have been performed. Thus the data obtained from the experiments have been analyzed to measure the fresh and hardened properties of concrete for different coarse aggregate. This chapter contains various relationship among the properties of concrete like workability, compressive strength, split tensile strength, Young's modulus, ultrasonic pulse velocity (UPV), unit weight etc. with respect to different coarse aggregate and different cement types.

4.2 Effect of different W/C ratio on Workability of concrete

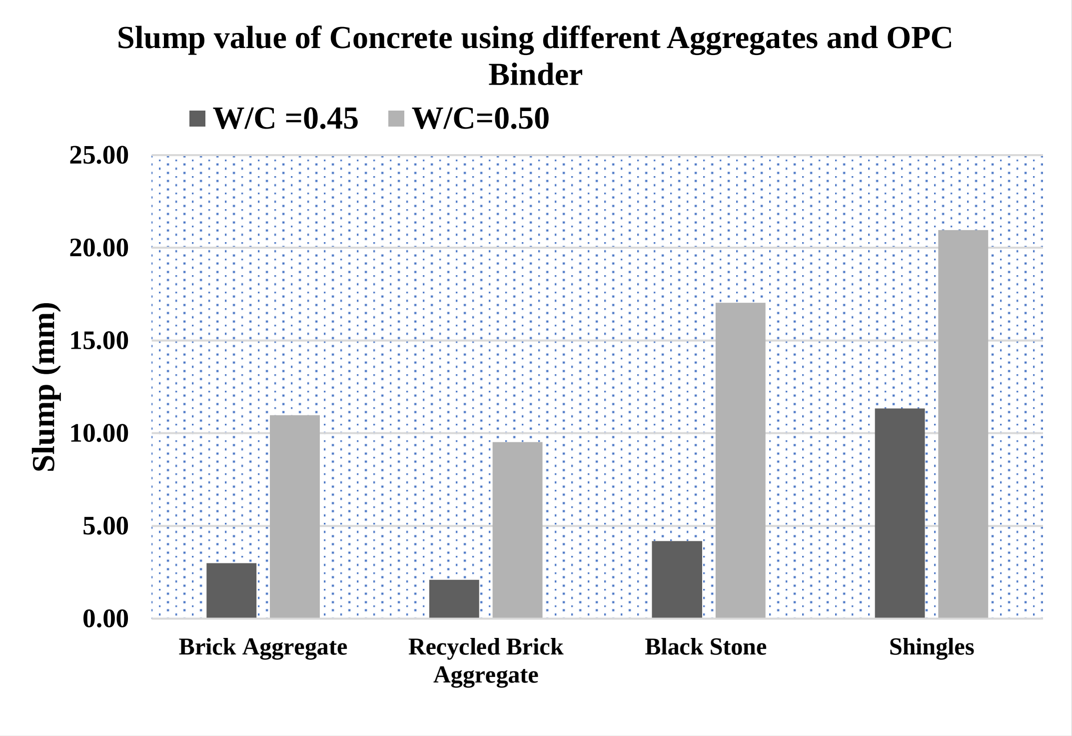


Fig 4.1: Workability of Concrete made using different Aggregates and OPC Binder

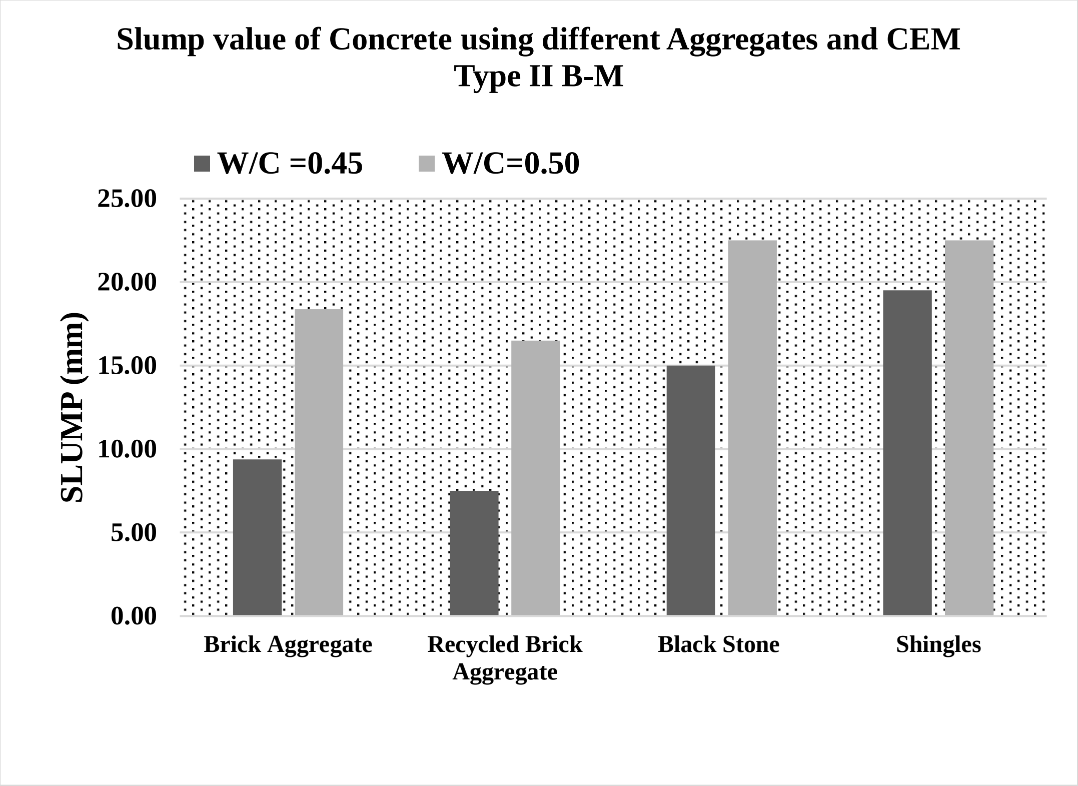


Fig 4.2: Workability of Concrete made using different Aggregates and CEM Type II B-M

The effect of different aggregate and cement types on workability of concrete W/C ratio is shown in fig. 4.1, fig.4.2 .The workability of concrete increases with the increase of maximum aggregate size and W/C ratio. It is established that with the increase of water-cement ratio the workability of concrete increases. The above charts shows exactly how much variation in slump occurs for each aggregate and binder type with the increase of W/C ratio. The charts indicates that for the same W/C ratio recycled brick aggregate showed lowest slump whereas Shingles showed the highest slump value. Therefore, we can expect high workability property for shingles in fieldwork. The charts also shows the fact that the use of CEM Type II B-M binder provides greater workability to concrete compared to OPC cement.

4.2 Effect of W/C ratio on Compressive Strength of concrete for different Aggregate and Cement types

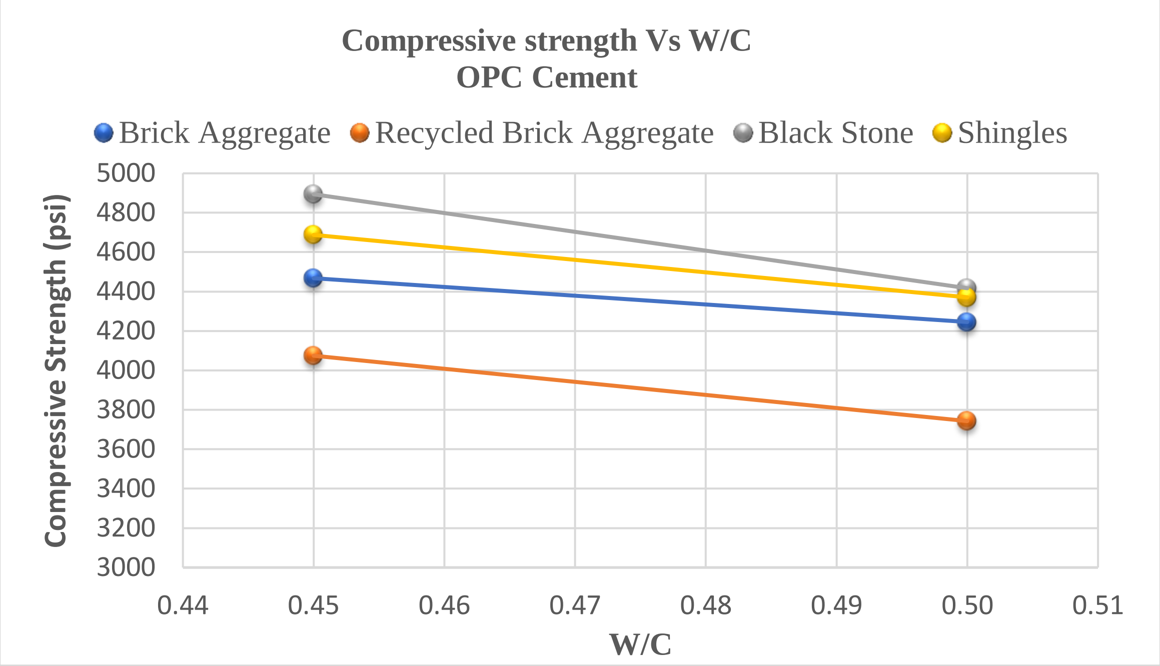


Fig 4.3: Change of Compressive strength with W/C for different Aggregate types (OPC).

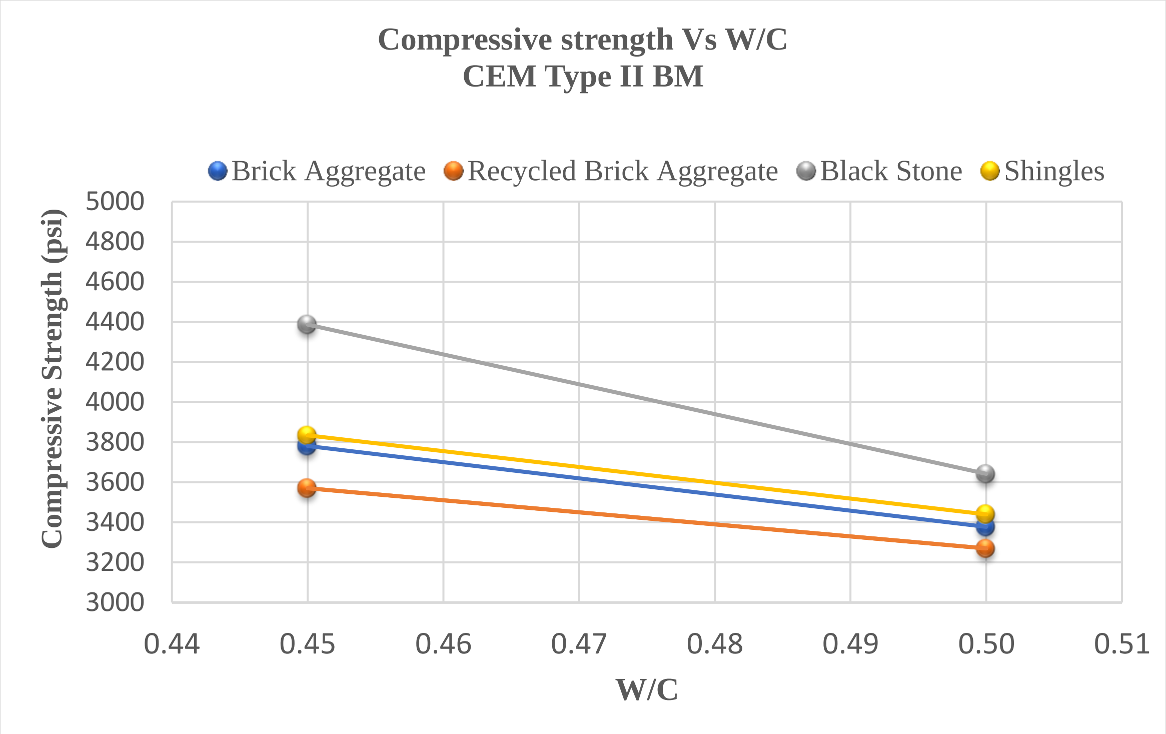


Fig 4.4: Change of Compressive strength with W/C for different Aggregate types (CEM Type II BM)

The graphs are plotted for Compressive strength Vs W/C for different Aggregate types and Cement types in the Fig 4.3 and Fig 4.4. The graphs clearly show that with the increase of W/C ratio the compressive strength of concrete for all aggregate types and for both cement types decreased gradually.

4.3 Effect of Cement Content on Compressive Strength of concrete for different Aggregates.

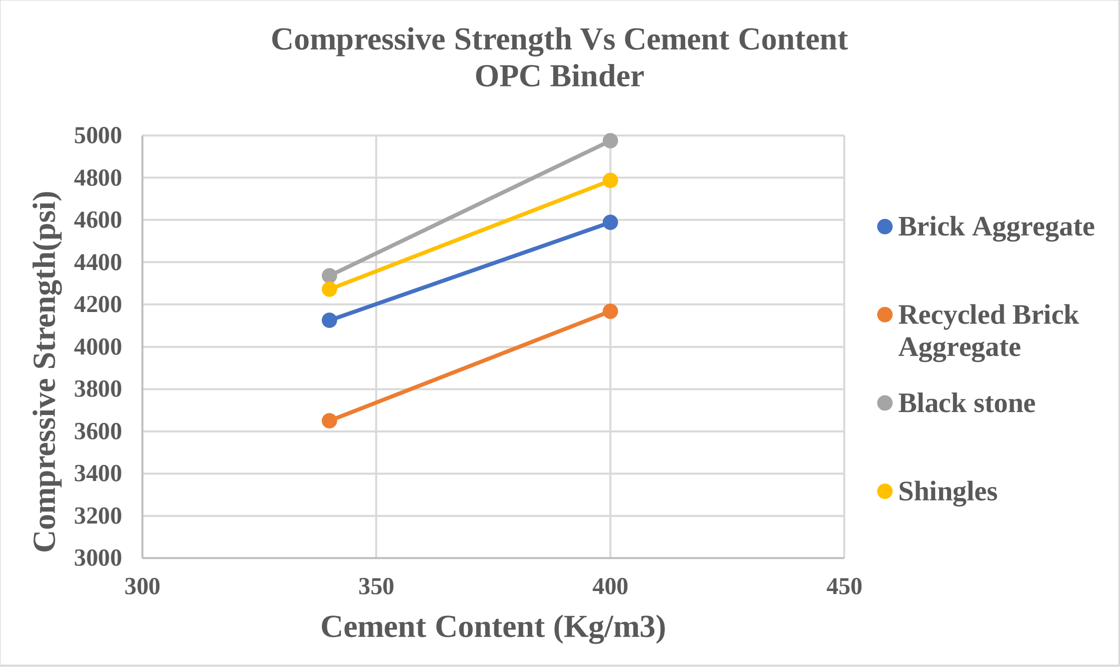


Fig 4.5: Variation of Compressive strength with Cement content for all Aggregate types.

The Above graph shows the Variation of Compressive Strength for different cement Content. In this case, Concrete specimen ware made with different aggregates and OPC cement. Mainly two different cement content 340 kg/m^3 and 400 kg/m^3 were used. We can see from the above graph that the increase of cement content led to higher Compressive strength of concrete for all aggregate types.

4.4: Variation of Compressive Strength of concrete for different cement aggregate types

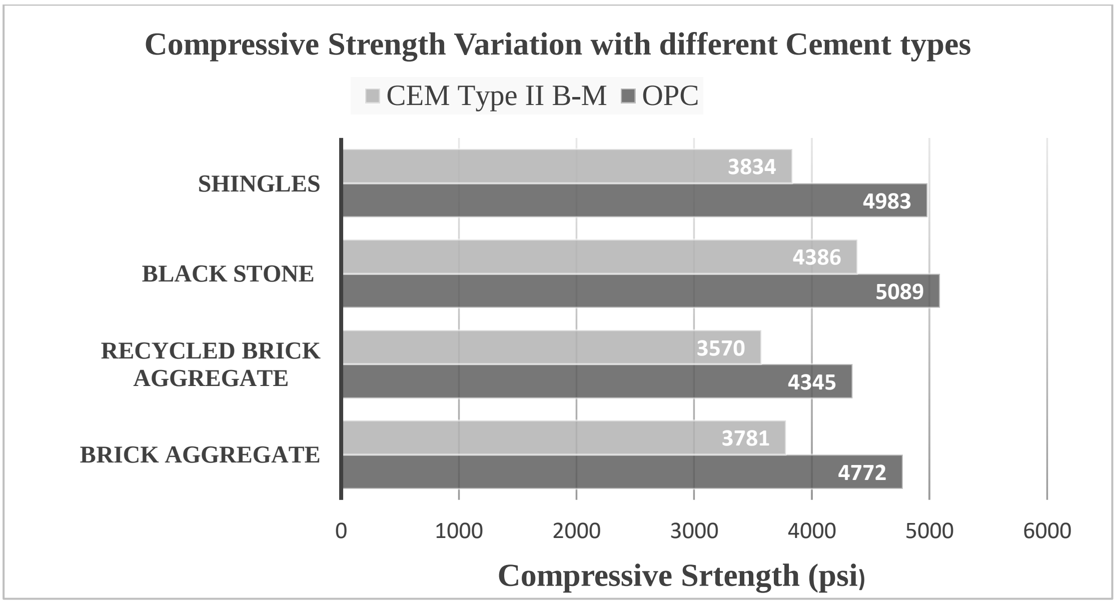


Fig 4.6:Variation of Compressive Strength of concrete for different cement types and aggregate types (Cement Content= 400 kg/m3 and W/C=.45)

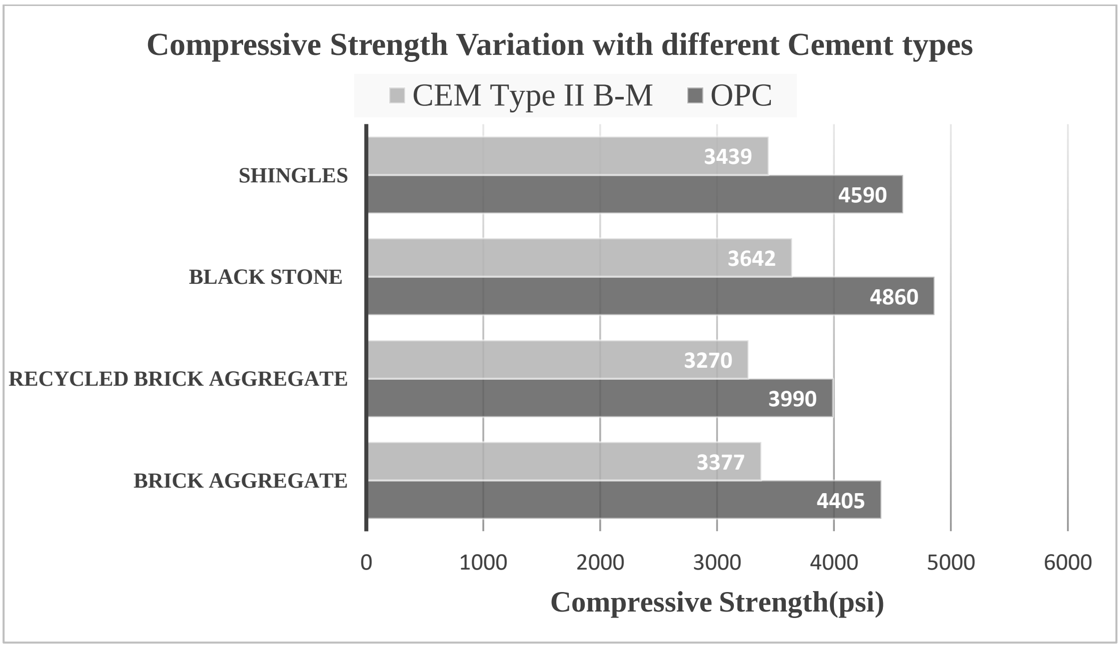


Fig 4.7:Variation of Compressive Strength of concrete for different cement types and aggregate types (Cement Content= 400 kg/m^3 and W/C=.50)

Above Chart illustrates the variation of compressive strength of concrete made with different aggregates and different cement types. Here mainly compressive strength attained by concrete specimen made with two different cement types i.e. OPC and CEM Type II B-M is highlighted. It is evident that in all cases specimens made with OPC attained much higher Compressive strength than it's CEM Type II B-M counterpart. Concrete specimen made with black stone aggregate had the compressive strength. While on the contrary, the specimen made with recycled brick aggregate had the lowest. But since these comparisons are made for 28 days compressive strength a conclusion on the long term variation in compressive strength could not be made. Also the comparison was made for Concrete specimens having Cement Content of 400 Kg/m^3.

4.5: Variation of %Air content of concrete for different cement and aggregate types

The following Fig 4.7 shows the variation in %Air content for different cement types. The bar chart clearly indicate that the concrete specimen made with OPC cement for all aggregate types had much higher %Air entrainment than the specimens made with CEM Type II B-M. Here the comparison was made for Concrete specimens having Cement Content of 400 Kg/m^3. Average air Content for both W/C ratio of 0.45 and 0.50 was considered.

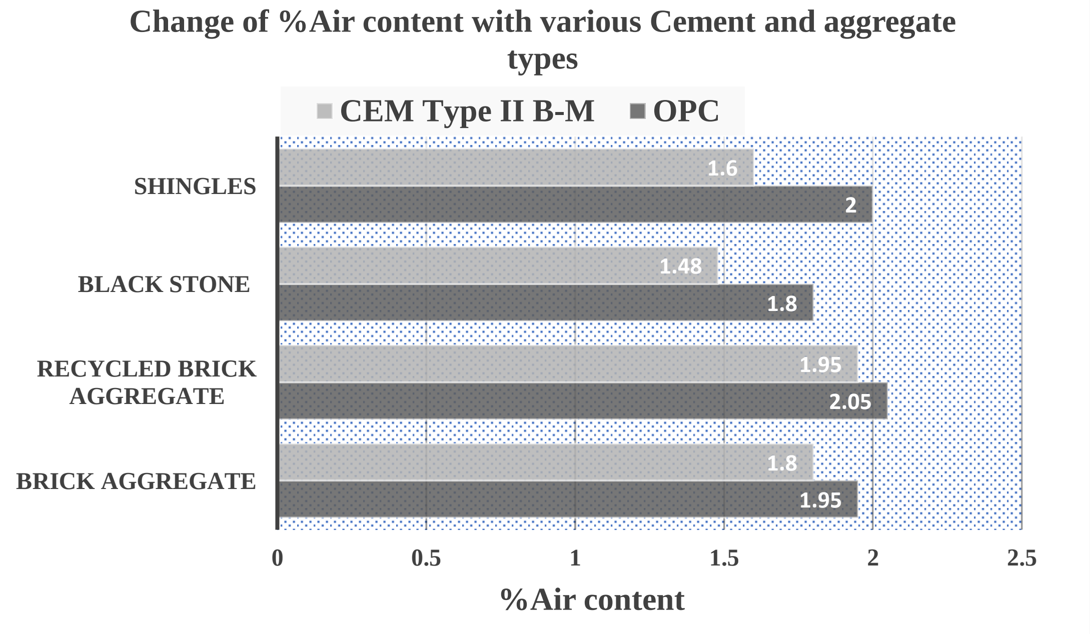


Fig 4.8: Change of %Air content with various Cement and aggregate types.

4.6: Variation of Tensile Strength of concrete for different cement and aggregate types

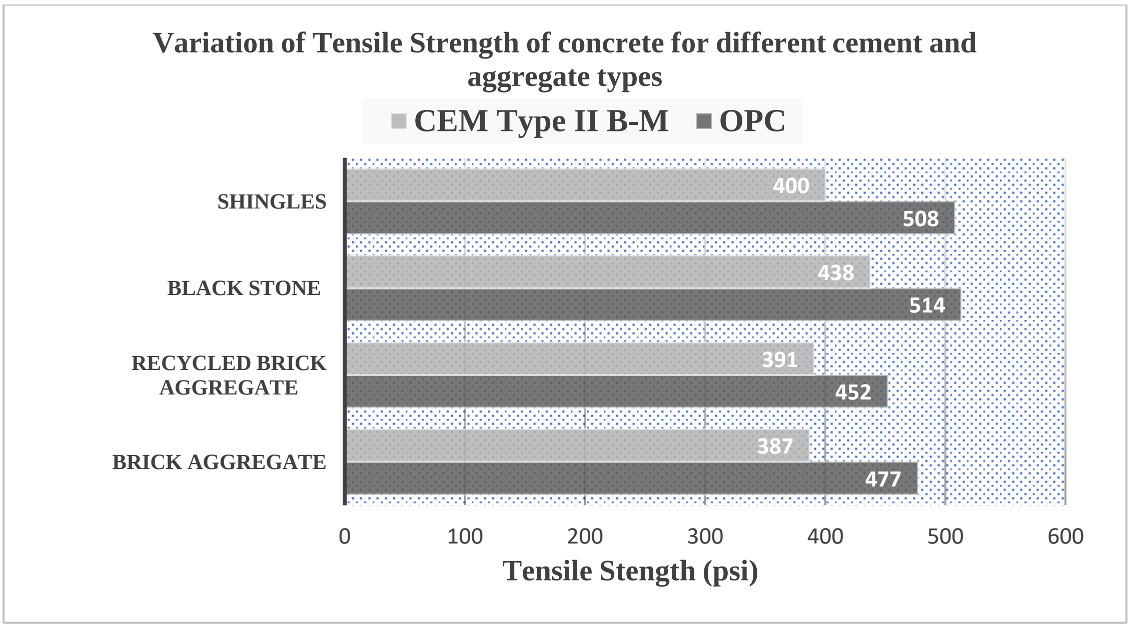


Fig 4.9: Variation of Tensile Strength of concrete for different cement types and aggregate types (Cement Content= 400 kg/m3 and W/C=.45)

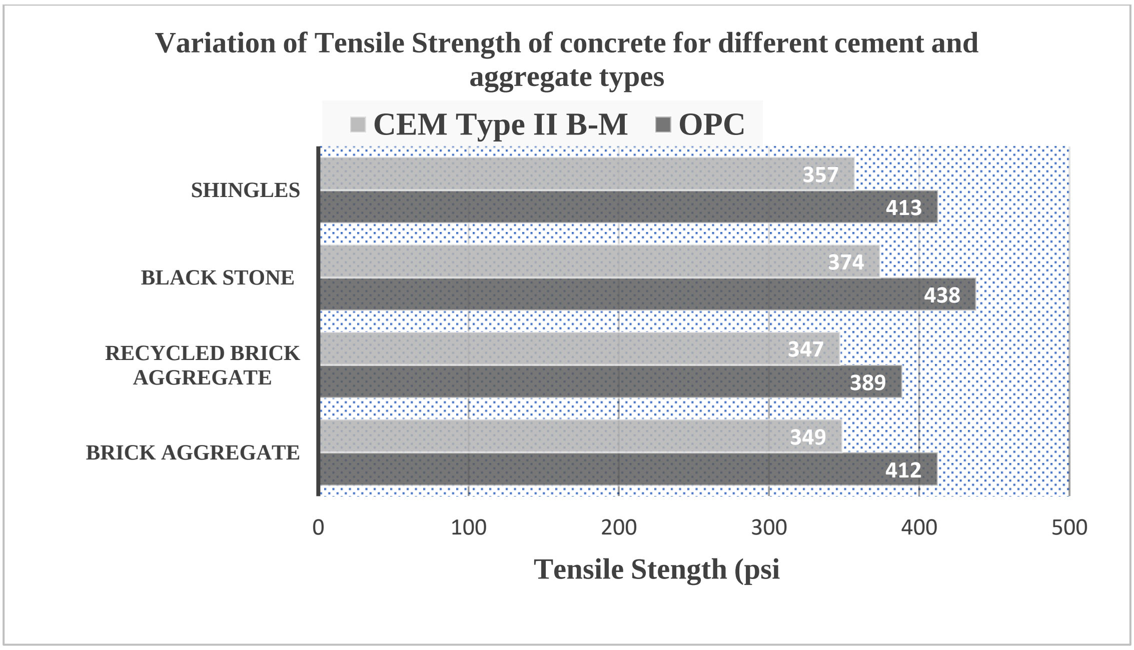


Fig 4.10:Variation of Tensile Strength of concrete for different cement types and aggregate types (Cement Content= 400 kg/m3 and W/C=.50)

Above Charts shows the variation of tensile strength of concrete made with different aggregates and different cement types. These charts are quite similar in manner to the charts shown for Compressive strength. Because the here also we see that the specimens made with OPC led to higher tensile strength than CEM Type II B-M. Also the specimens made with black stone gave the highest tensile strength followed by shingles, brick chips and recycled brick aggregate. The W/C ratio also had effect on the tensile strength of the specimen as the strengths decreased with increase of W/C ratio which is quite similar to property of Compressive strength.

4.7: Variation of UPV of concrete for different cement and aggregate types

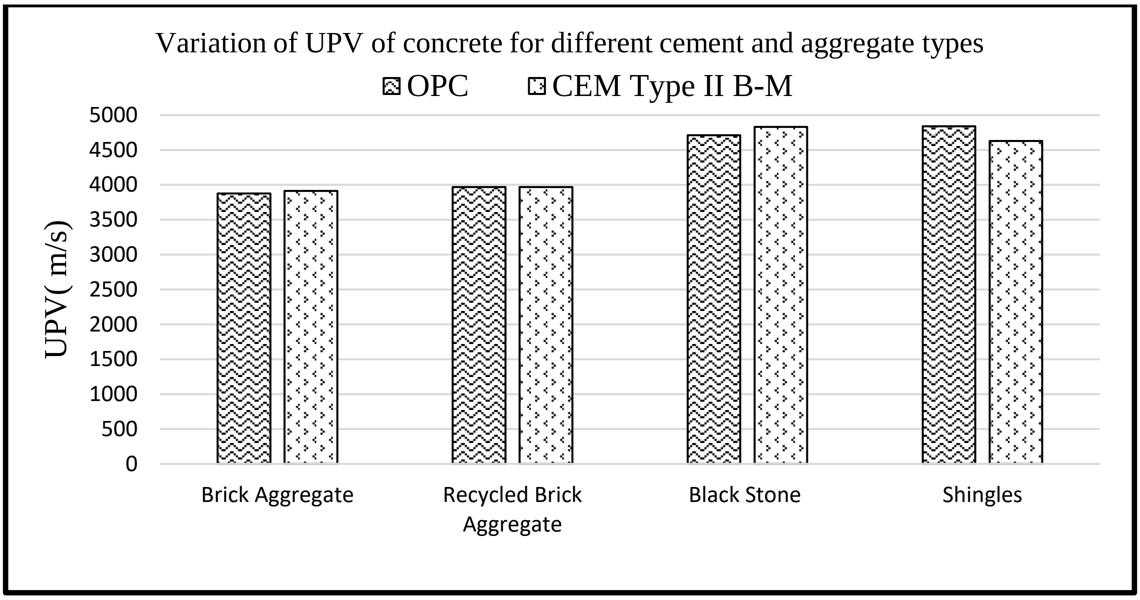


Fig 4.11: Variation of UPV of concrete for different cement types and aggregate types (Cement Content= 400 kg/m3 and W/C=0.45)

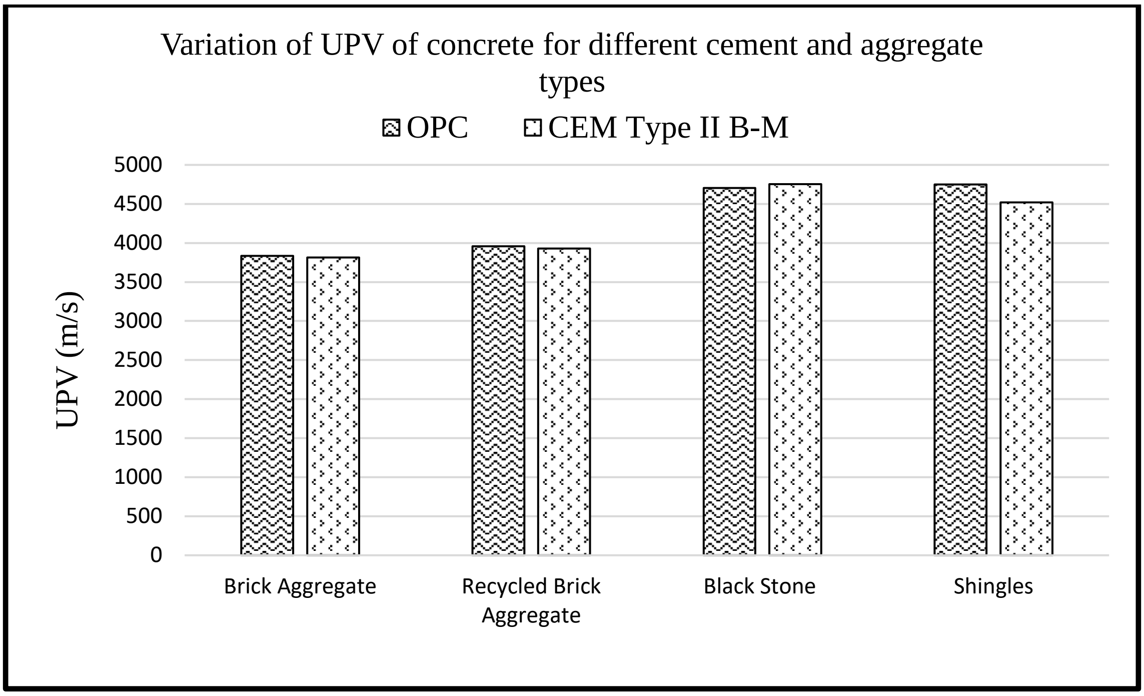
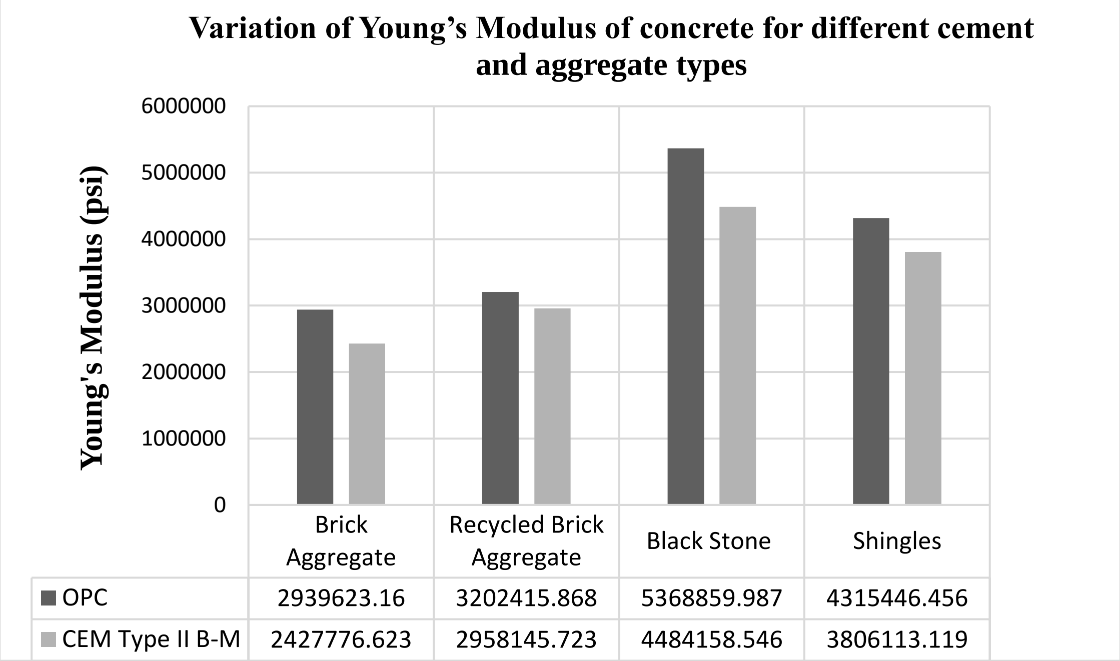


Fig 4.12: Variation of UPV of concrete for different cement types and aggregate types (Cement Content= 400 kg/m3 and W/C=.50)

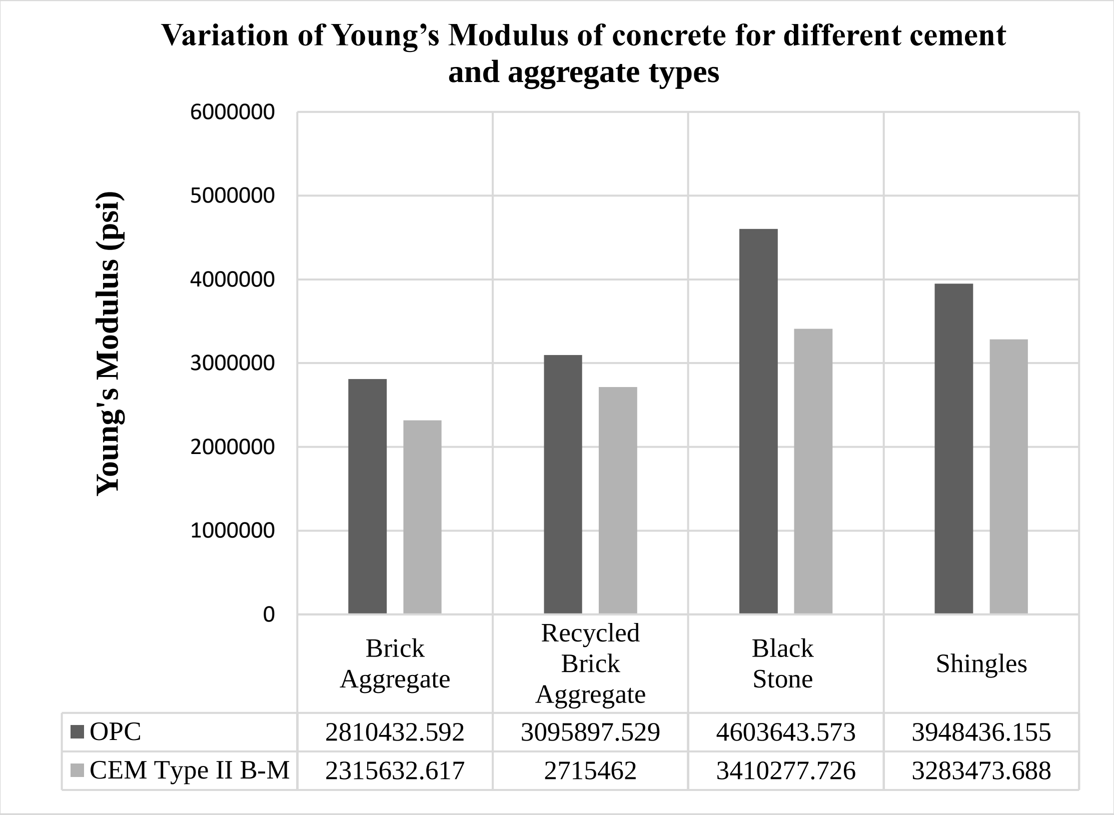
Fig 4.11 and Fig 4.12 tries to shows the variation of UPV of concrete for different cement types and aggregate types. But the variations are too little to come to any kind of conclusion. Irregular pattern of the increase and decrease of UPV with cement type and W/C ratio is found. The charts also show that the UPV value of specimens made with stone aggregates are much higher than the specimens made with brick and recycled brick aggregates in both cases.

4.8: Variation of Young’s Modulus of concrete for different cement and aggregate types



	Brick Aggregate	Recycled Brick Aggregate	Black Stone	Shingles
■ OPC	2939623.16	3202415.868	5368859.987	4315446.456
■ CEM Type II B-M	2427776.623	2958145.723	4484158.546	3806113.119

Fig 4.13: Variation of Young’s Modulus of concrete for different cement and aggregate types (Cement Content= 400 kg/m3 and W/C=0.45)



	Brick Aggregate	Recycled Brick Aggregate	Black Stone	Shingles
■ OPC	2810432.592	3095897.529	4603643.573	3948436.155
■ CEM Type II B-M	2315632.617	2715462	3410277.726	3283473.688

Fig 4.14: Variation of Young’s Modulus of concrete for different cement and aggregate types (Cement Content= 400 kg/m3 and W/C=0.50)

The Charts above illustrates the variation of Variation of Young's Modulus of concrete for different cement and aggregate types. It is quite clear that the young's modulus shares a strong correlation with both compressive strength and tensile strength because the nature of variation shown above are quite similar to variation shown concrete strengths. Concrete specimen made with black stone shows the highest value. But unlike compressive and tensile strength where recycled brick showed the lowest value here it is found that the young's modulus of brick aggregate is lowest instead of recycled brick aggregate. Other characteristics remain the same as OPC cement and lower W/C value of 0.45 provided higher value compared to the rest.

4.8: Variation of Unit Weight of concrete for different cement and aggregate types.

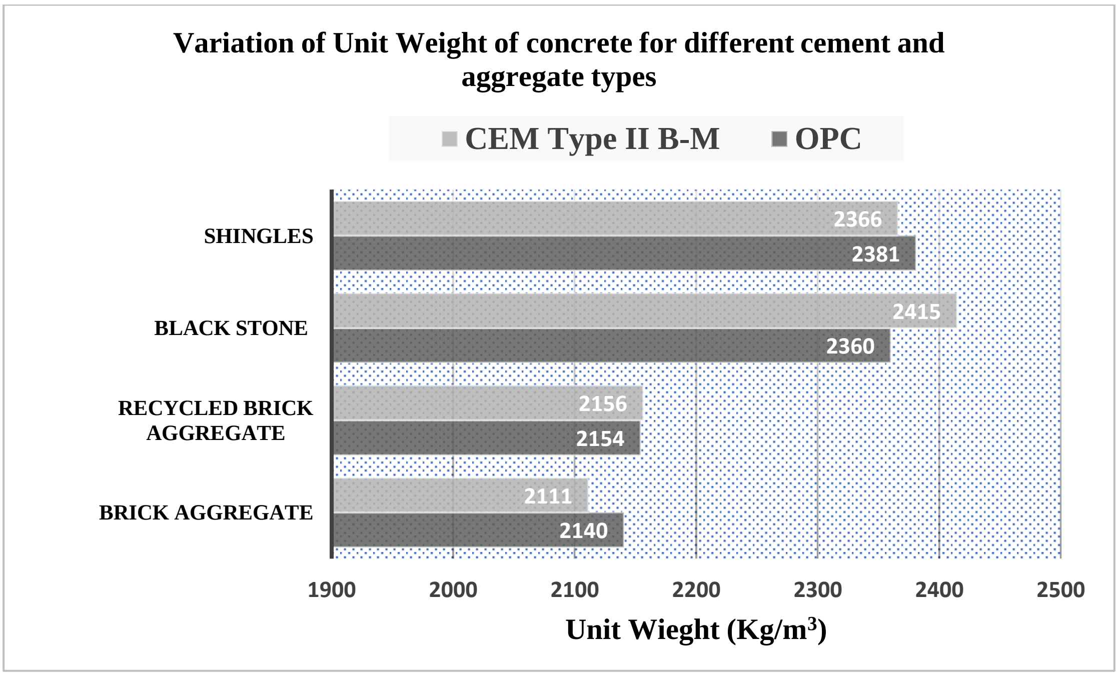


Fig 4.15: Changes in Unit Weight of concrete for different cement and aggregate types (Cement Content= 400 kg/m3 and W/C=0.45)

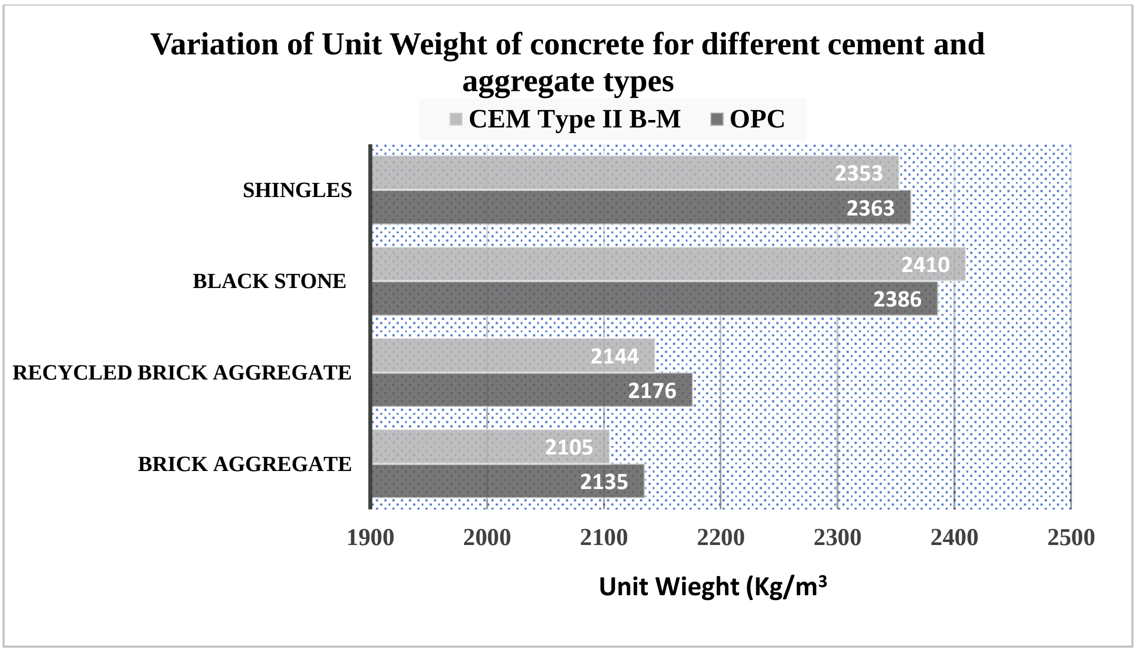


Fig 4.16: Changes in Unit Weight of concrete for different cement and aggregate types (Cement Content= 400 kg/m3 and W/C=0.50)

The charts above clearly establishes that there is no direct correlation for unit weight of concrete with cement types or W/C ratio. The only discernable difference that can be found from the charts are that stone aggregates like shingles and black stone shows much higher unit weight than brick and recycled brick aggregates.

4.9: Relation between Young's Modulus and Compressive strength of concrete for different aggregate types.

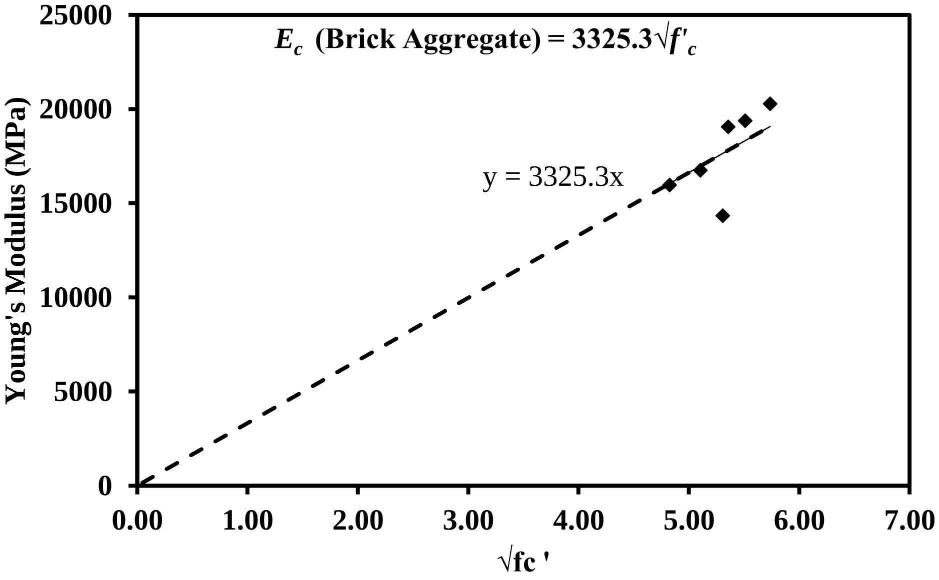


Fig 4.17: Regression model for relation between young's modulus and compressive strength of concrete.(Brick Aggregate)

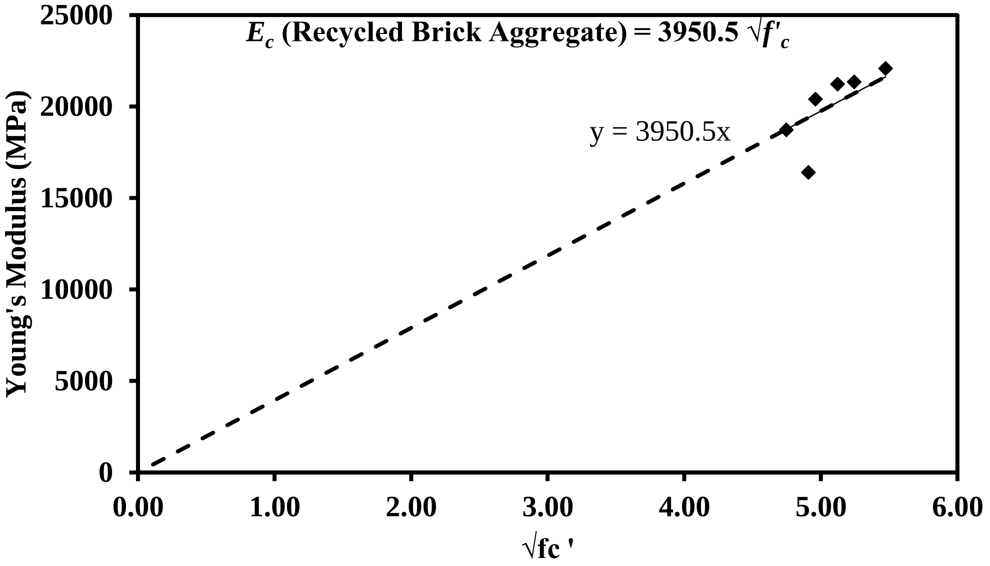


Fig 4.18: Regression model for relation between young's modulus and compressive strength of concrete.(Recycled Brick Aggregate)

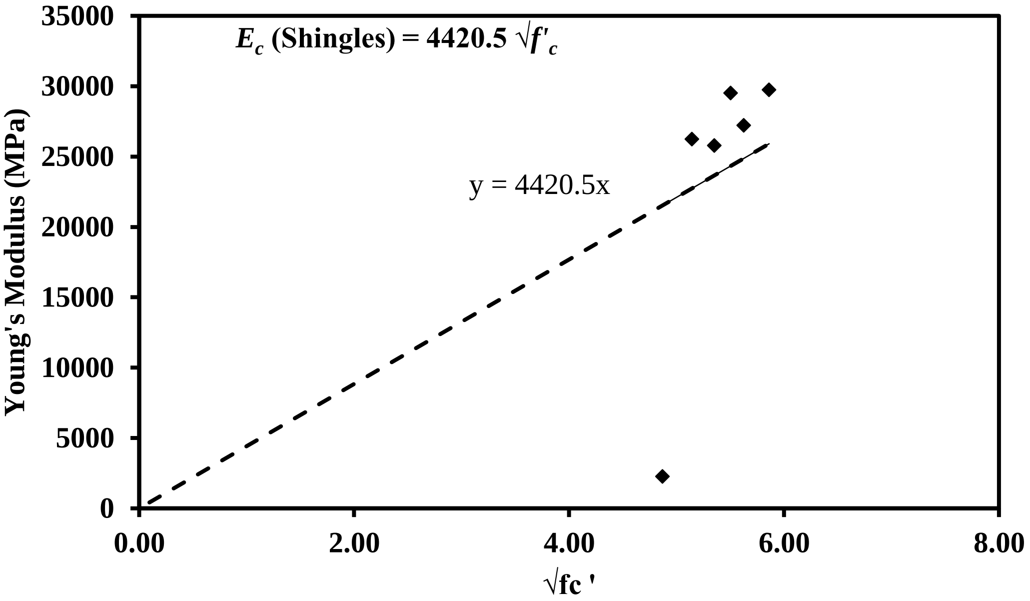


Fig 4.19: Regression model for relation between young's modulus and compressive strength of concrete.(Shingles)

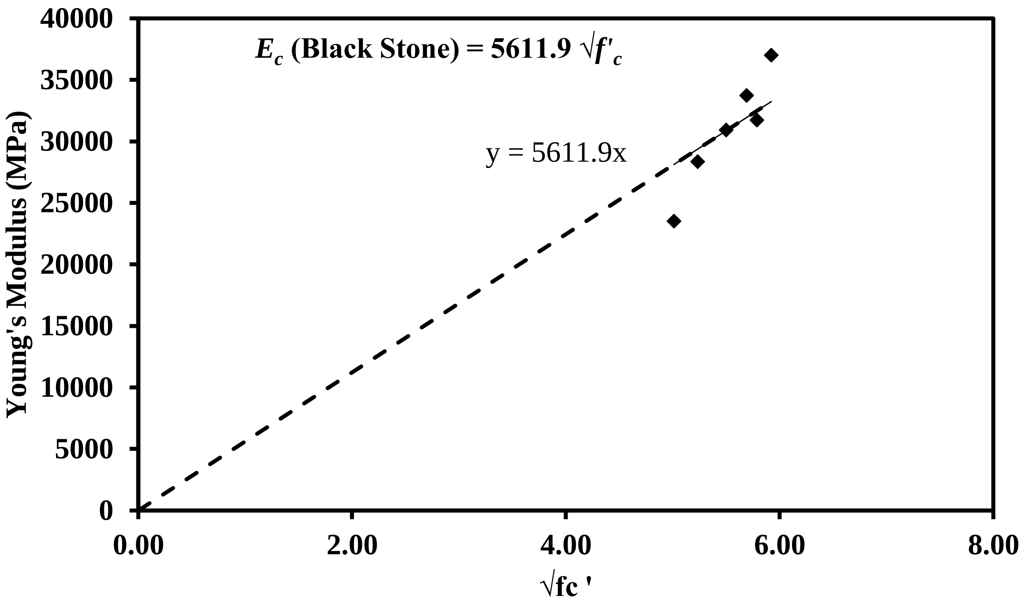


Fig 4.20: Regression model for relation between young's modulus and compressive strength of concrete.(Black stone)

Fig. 4.17, fig. 4.18, fig. 4.19, fig. 4.20 shows the relationship between the Young's modulus and square root of compressive strength of concrete for different aggregate types. Based on Fig. 4.17, fig. 4.18, fig. 4.19, fig. 4.20 the relationships between Young's modulus and compressive strength of brick aggregate concrete for different maximum aggregate size are proposed as following:

E_c (Brick Aggregate) = 3325.3 $\sqrt{f'_c}$ (1)

E_c (Recycled Brick Aggregate) = 3950.5 $\sqrt{f'_c}$ (2)

E_c (Shingles) = 4420.5 $\sqrt{f'_c}$ (3)

E_c (37.5 mm) = 5611.9 $\sqrt{f'_c}$ (4)

Where, Ec is the Young's modulus and f'c is the compressive strength of concrete in MPa.

It is understood that for the same strength of concrete, the Young’s modulus Brick aggregates are lower than stone aggregates. It is important to note that, ACI 318-14 suggests the following equation for Young’s modulus of concrete:

$$E_c \text{ (Stone aggregate)} = 5050 \sqrt{f'_c} \qquad (5)$$

Where, E_c is the Young's modulus and f'_c is the compressive strength of concrete in MPa.

It is evident that coefficients of equations (1) – (4) for different aggregate varies around a range close to the coefficient suggested by ACI 318-14. This may be due to the fact that, the Young's modulus of brick is less than that of stone and it is well established that the Young's modulus of concrete is a function of the Young's modulus of the aggregate itself [ACI 318-14 and Kesegić, Netinger, Bjegović (2008)]

4.10: Relation between Tensile and Compressive strength of concrete for different aggregate types.

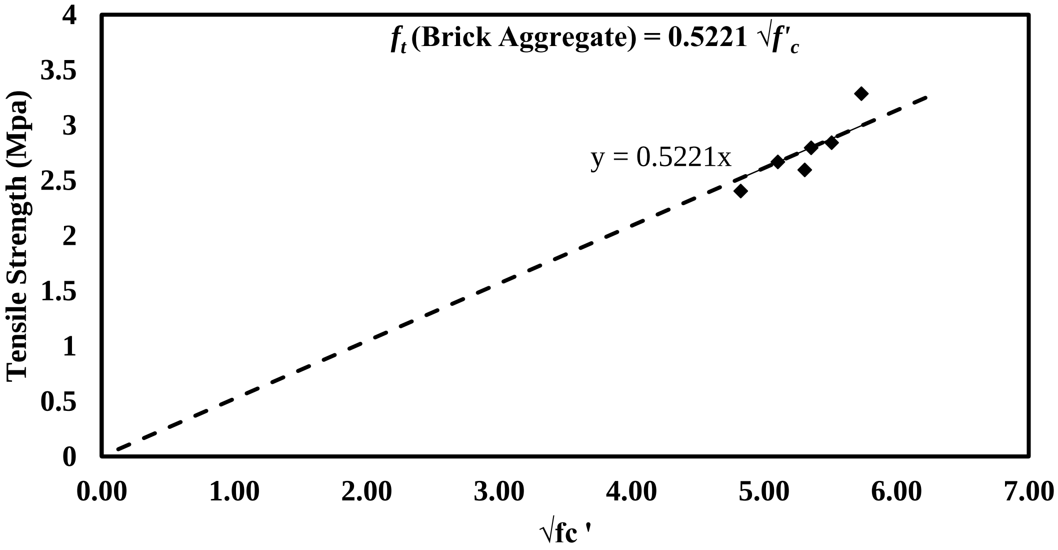


Fig 4.21: Regression model for relation between tensile and compressive strength of concrete.(Brick Aggregate)

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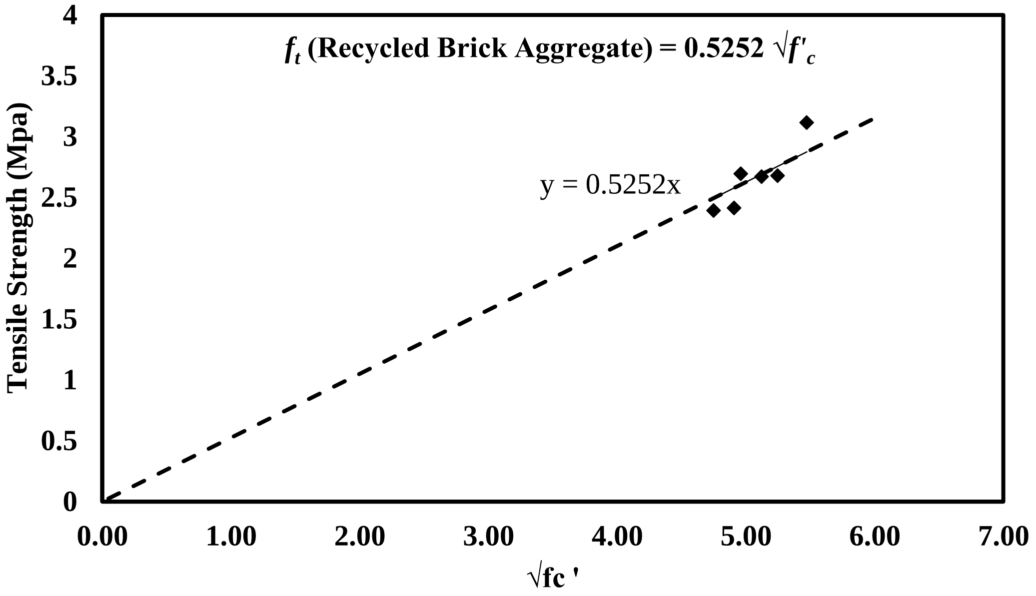

Fig 4.22: Regression model for relation between tensile and compressive strength of concrete.(Recycled Brick Aggregate)

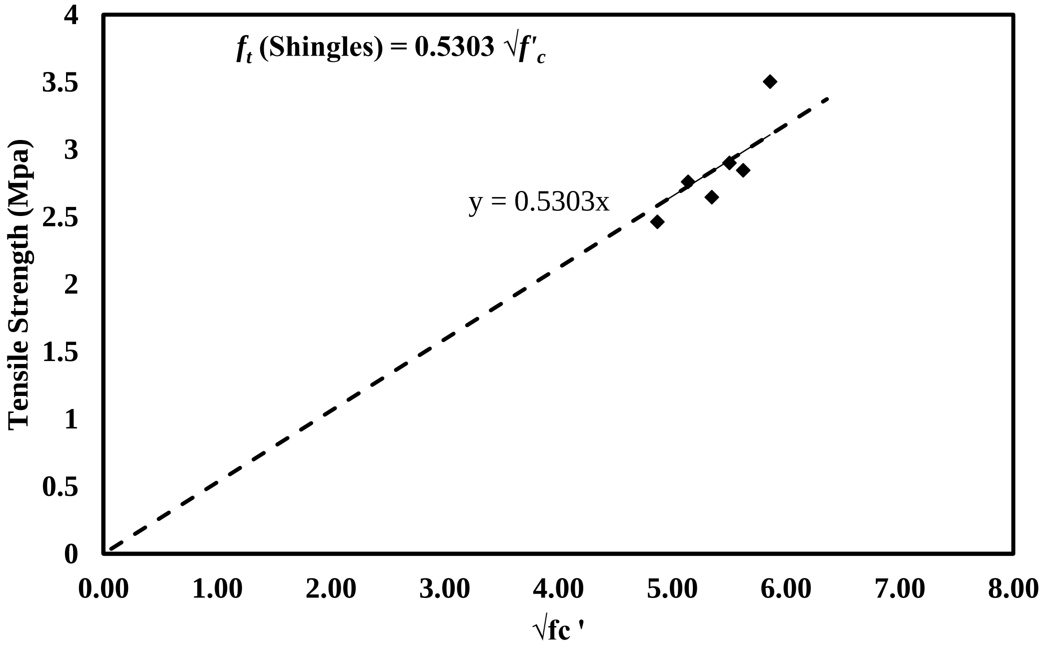

Fig 4.23: Regression model for relation between tensile and compressive strength of concrete.(Shingles)

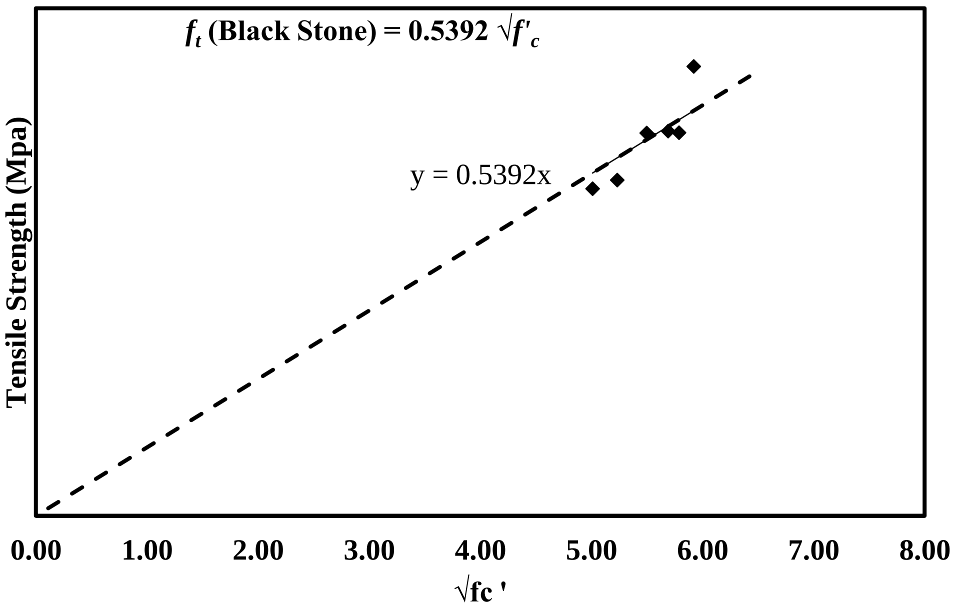

Fig 4.24: Regression model for relation between tensile and compressive strength of concrete.(Black Stone)

The variation of splitting tensile strength of concrete made with different types of aggregates with compressive strength is shown in fig. 4.21, 4.22, 4.23, 4.24. Based on the experimental data in fig. 4.21, 4.22, 4.23, 4.24.the tensile strength of concrete can be correlated with compressive strength by the following equations:

$$f_t(\text{Brick aggregate}) = 0.5221\sqrt{f'_c} \quad (6)$$

$$f_t(\text{Recycled Brick Aggregate}) = 0.5252\sqrt{f'c} \quad (7)$$

$$f_t(\text{Shingles}) = 0.5303\sqrt{f'c} \quad (8)$$

$$f_t(\text{Black stone}) = 0.5392\sqrt{f'c} \quad (9)$$

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

The relationship between splitting tensile strength and compressive strength of concrete proposed by ACI 318-14, Ivey and Buth (1967), and Hanson (1961) is as follows:

$$f_t(\text{Normal weight concrete}) = 0.556\sqrt{f'_c} \quad (10)$$

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

It is evident that the coefficient proposed in equations (6) – (9) are slightly lower than that proposed in equation (10). This can be attributed to the use of brick aggregate, which may result in a lower splitting tensile strength compared to stone aggregate concrete.

4.11: Relation between UPV and Compressive strength of concrete for different aggregate types.

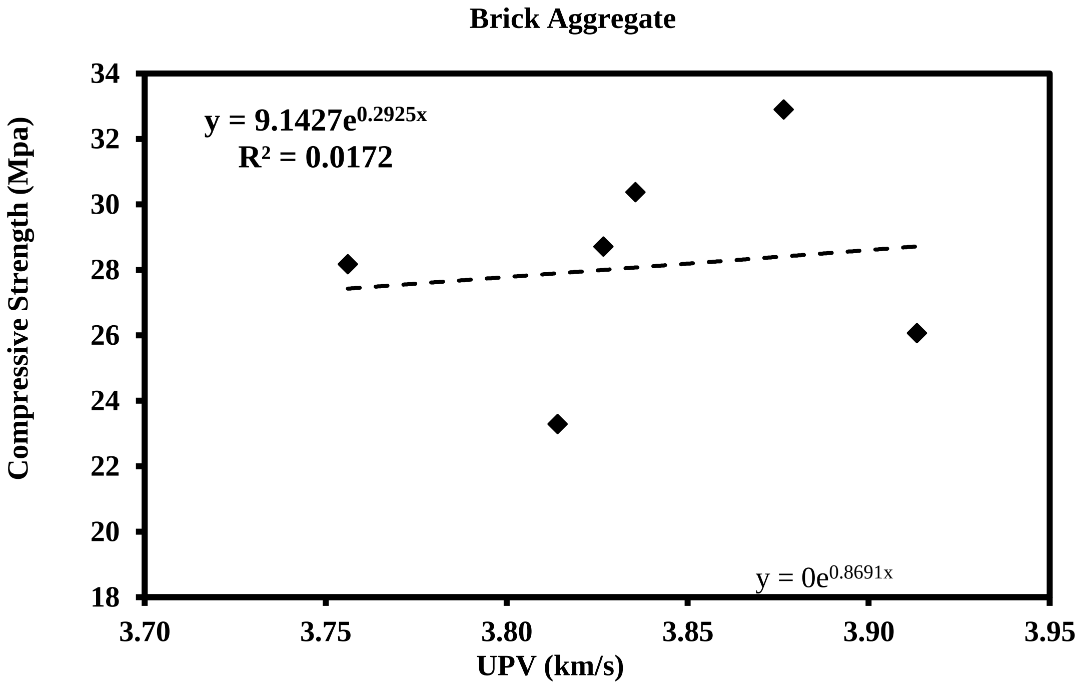

Fig 4.25: Regression model for relation between UPV and compressive strength of concrete.(Brick aggregate)

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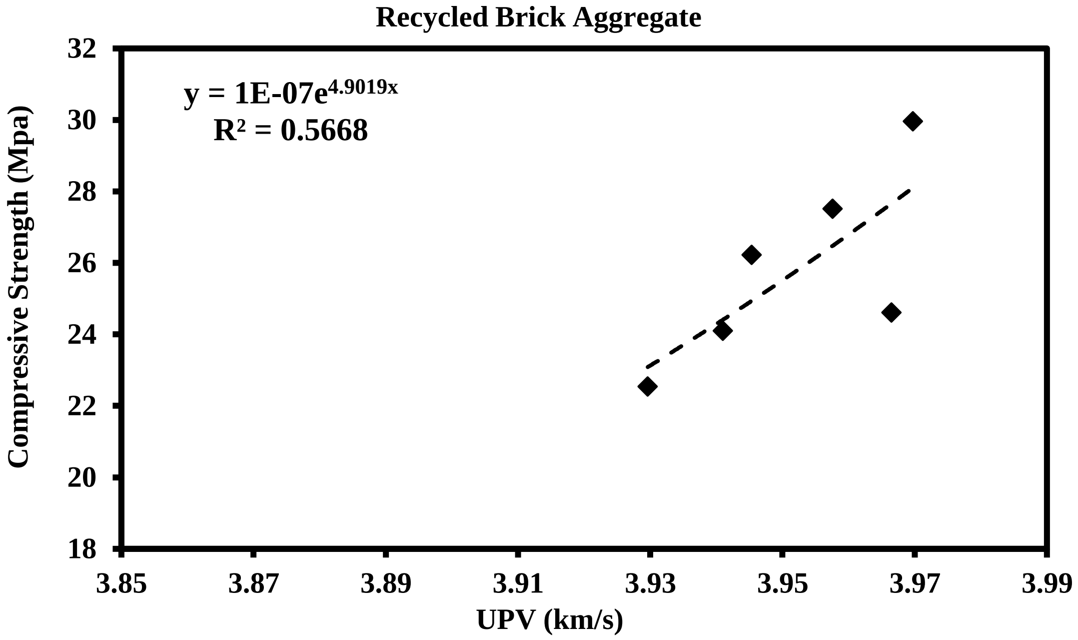

Fig 4.26: Regression model for relation between UPV and compressive strength of concrete.(Recycled Brick Aggregate)

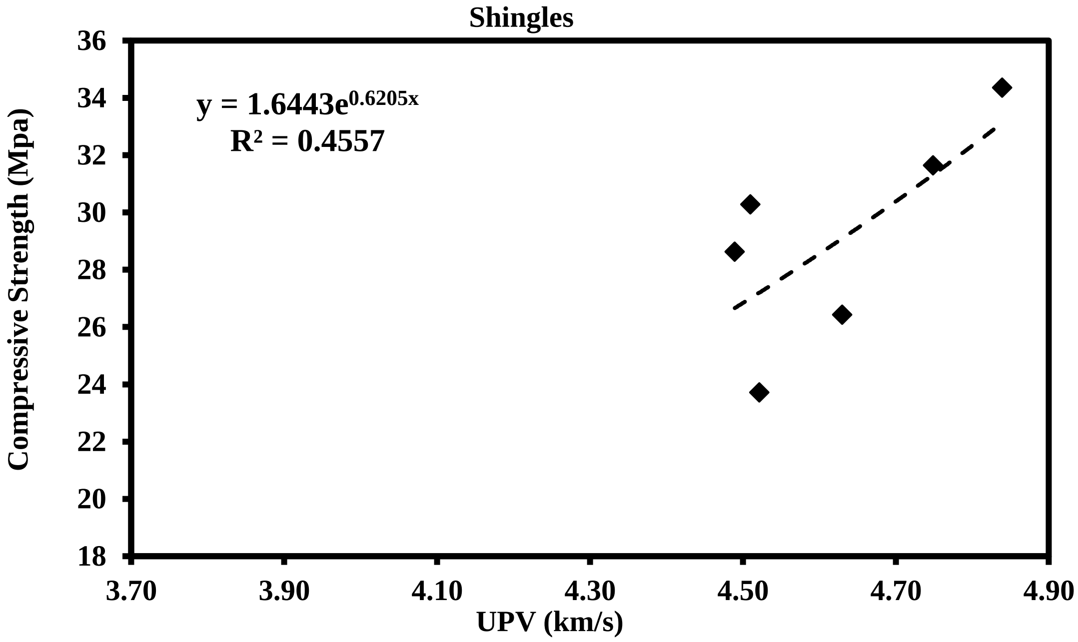

Fig 4.27: Regression model for relation between UPV and compressive strength of concrete.(Shingles)

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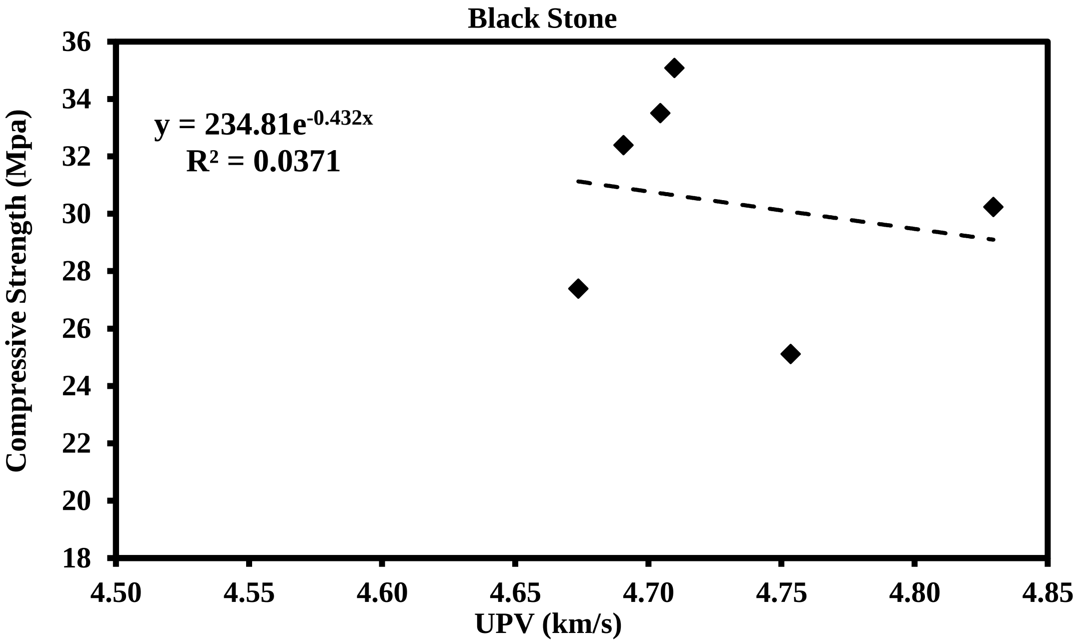

Fig 4.28: Regression model for relation between UPV and compressive strength of concrete.(Shingles)

From the above plots of strength Vs. UPV (Fig. 14.25, 14.26, 14027, 14.28), it can be observed that strength of concrete be likely to have an increasing trend with the UPV of concrete. But, whether it has linear trend is questionable. It is because of the fact that the plot is not only very ambiguous but also it has not been related to any strength regarding parameters like W/C ratio or s/a ratio. Very less value of coefficient of determination (the square of the Pearson product moment correlation coefficient, R^2=0.0172, 0.5668, 0.4557, 0.0371) also indicates that the linear trend found in the plots might not be the actual relationship between compressive strength and UPV of concrete The conclusion established from this simplified approach states that the increasing UPV of concrete indicates its increased strength.

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4.11: Relation between Unit weight and Compressive strength of concrete for different aggregate types.

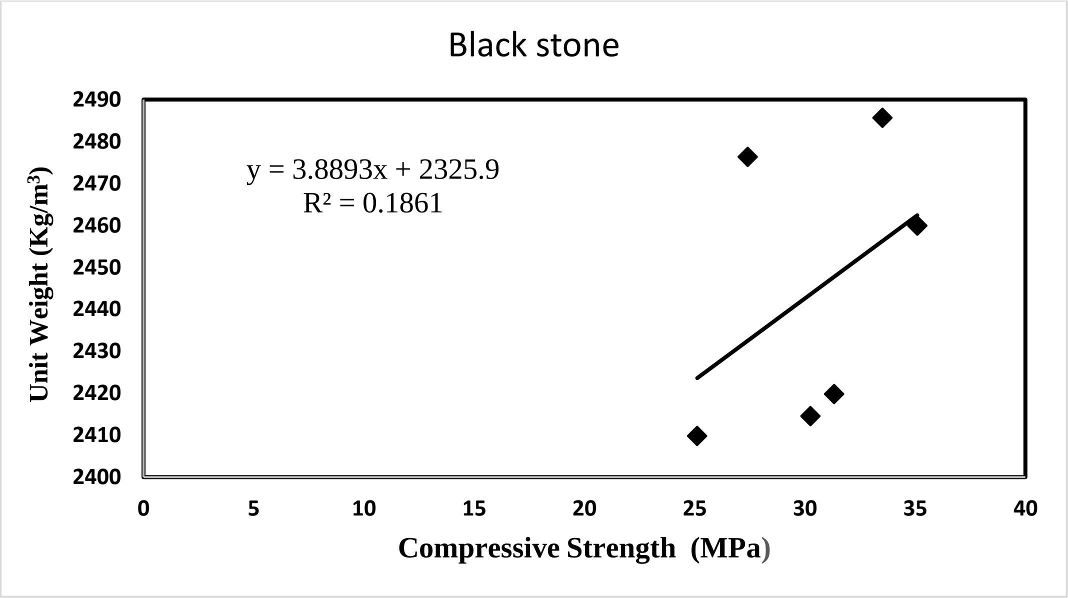

Fig 4.29: Regression model for relation between unit weight and compressive strength of concrete.(Black stone)

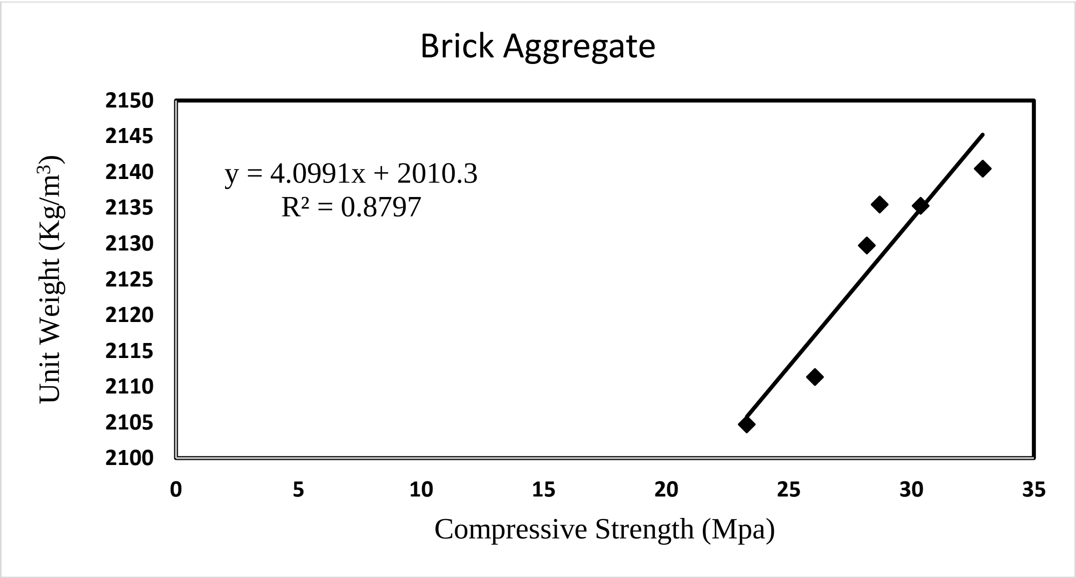

Fig 4.30: Regression model for relation between unit weight and compressive strength of concrete.(Brick Aggregate)

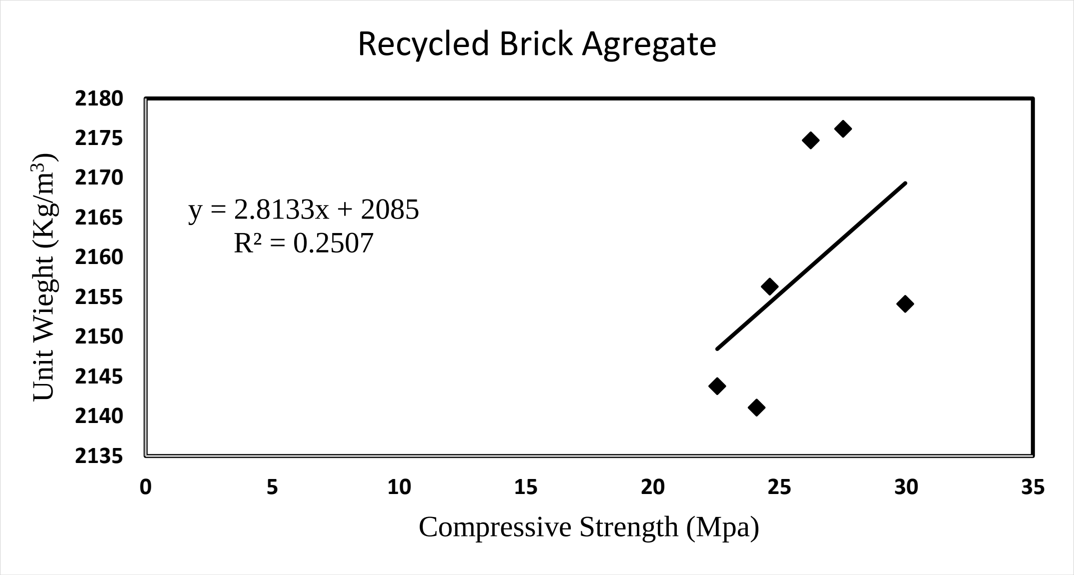

Fig 4.31: Regression model for relation between unit weight and compressive strength of concrete.(Recycled Brick Aggregate)

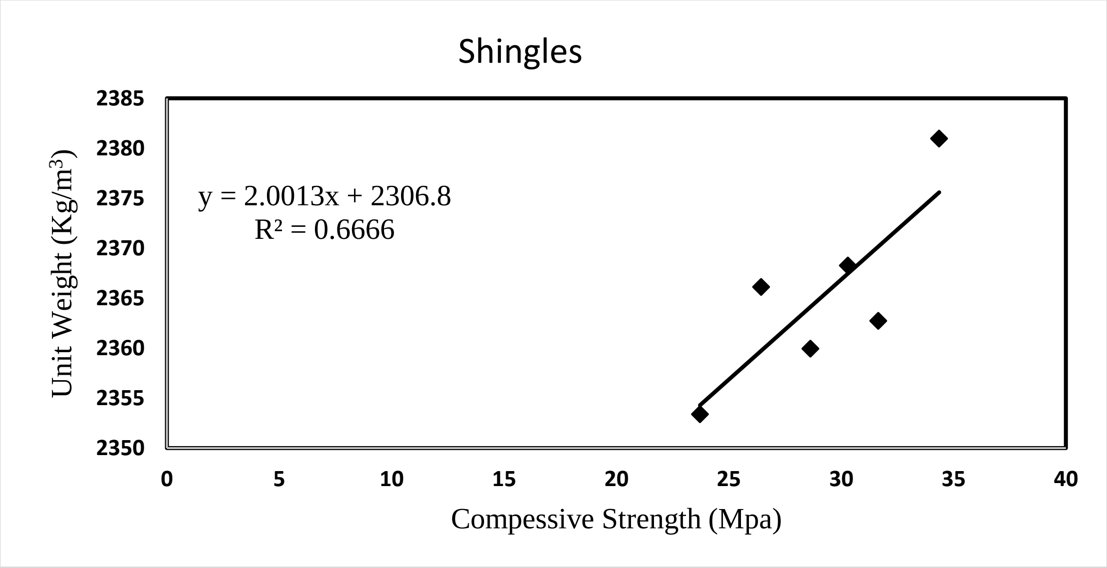

Fig 4.32: Regression model for relation between unit weight and compressive strength of concrete.(Shingles)

From above regression models, relationship between Unit weight of concrete and compressive strength has been developed for concrete made with different aggregates. Figure 14.29, 14.30, 14.31, 14.32 demonstrates the best fit lines for the unit weight obtained from samples showing different compressive strength. From these figures following relationships have been determined:

$$U(\text{Black stone}) = 3.8893\, f'c + 2325.9 \qquad (11)$$

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$$U(\text{Brick aggregate}) = 4.0991 f'c + 2010.3 \qquad (12)$$

$$U(\text{Recycled Brick aggregate}) = 2.8133 f'c + 2085 \qquad (13)$$

$$U(\text{Shingles}) = 2.0013 f''c + 2306.8 \qquad (14)$$

Where, U and f'c are the unit weight in Kg/m^3 and f'c 28 days Compressive strength in Mpa for the respective specimens made with that particular aggregate.

Value of coefficient of determination R^2= 0.1861, 0.8797, 0.2504 and 0.6666 for black stone, brick, recycled brick and shingles respectively are merely satisfactory. However, more samples are needed for the experiment to get more perfect analysis results. Better correlation between unit weight and compressive strength is expected if more experiments are conducted.

From these relationships, concrete unit wieght can be predicted for a particular compressive strength if unit weight test cannot be performed.

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CHAPTER 5: CONCLUSION AND FUTURE STUDIES

5.1 General

The principle objective of our study is to find out the effect of different coarse aggregate on the durability of concrete. In order to achieve this objective 672 concrete cylinders were made using four different aggregates and four different cement types that were tested for various properties like workability, compressive strength, tensile strength etc. Also relationship among the compressive strength, tensile strength, young`s modulus. workability, UPV, unite weight etc. had been analyzed. To fulfill our goal these properties of concrete will to help understand the durability property of the concrete when further investigation related to durability testing is done.

This chapter gives an overview of the important findings of this research. The findings are discussed in detail based on the fresh and harden property of concrete. This is followed by suggestion for further investigation.

5.2 Summary and Conclusions:

- Among the cylinder specimens, specimens made black stone shows the highest compressive strength and highest tensile strength followed by shingles, brick and recycled brick aggregate in that order.
- Between OPC and CEM Type II B-M specimens made with OPC shows higher 28 days compressive strength and split tensile strength.
- OPC specimens for all aggregate shows much higher air entrainment compared to specimens made with CEM Type II B-M.
- Based on slump value the specimens made with Shingles showed highest workability followed by black stone, brick and lastly the recycled brick aggregate.
- Compressive strength and tensile strength of concrete increased with increase of cement content and decreased with increase of W/C ratio.
- Like compressive strength and tensile strength the Young’s modulus of the concrete was also highest for black stone aggregate and OPC cement. But the lowest value was shown by brick aggregates instead of recycled brick aggregate.
- There exists strong correlation between compressive strength and tensile strengths of the concrete

- There exists strong correlation between compressive strength and Young’s modulus of the concrete.
- Correlation between Compressive strength and UPV was also found.
- Overall UPV value found for stone aggregates were much higher than the brick aggregates.

Similar to UPV the Unit weight of the stone aggregates found ware much larger than brick aggregates.

5.4 Recommendation for Future Studies:

- Since our main goal is to find out the durability aspects of the concrete made with different aggregate and binder types. So, further tests should be performed to assess the durability of the concrete.
- Carbonation testing to find the carbonation depth in the concrete should be carried out to evaluate durability of concrete made with different aggregate and cement types. It will also help to identify the best combination of aggregate and cement type that should be used to resist carbonation related corrosion.
- Analysis should be done to find out if there exist any correlation between carbonation depth and mechanical properties like compressive strength, tensile strength, UPV etc. Furthermore, if correlation does exist then it becomes necessary find out extent of the correlation.
- Until now mechanical properties of 28 days testing was used for doing the analysis. So, further tests should be done to find out the mechanical properties of concrete corresponding to greater duration and find out variation in mechanical properties with time or age
- The influence of mix design of concrete on carbonation depth of the concrete should also be analysed.

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