AN INVESTIGATION OF CONCRETE PROPERTIES WITH POLYPROPYLENE (PP) AS AN PARTIAL REPLACEMENT OF COARSE AGGREGATE

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ABSTRACT

Plastic is one of the most used materials in today's world. Because of its non-biodegradable characteristics, it is obligatory to recycle the plastic in order to save the nature from its adverse effect. Plastic can be recycled by using it for construction purposes. This study aims at investigating the fresh and hardened properties of concrete while adopting polypropylene (PP) as coarse aggregate in concrete. Three concrete types were prepared using crushed stones and brick chips as coarse aggregate and in three cases these were partially, 10%, 20% and 30% by volume, replaced with PP. Two water cement ratio, i.e. 0.45 and 0.55, were used in the concrete mix design. Compressive strength (for 7 days, 28 days and 90 days) and tensile strength(for 28 days) tests were conducted to find out the feasibility of the plastic concrete and propose a replacement ratio for PP to be used in structural concrete. Compare to the concrete with no PP, 10 % PP replaced concrete (PRC) showed a significant increase in both compressive and tensile strengths for stone and brick chips replacement. However, with 20% and 30% PRC an opposite trend was observed. For 10% PRC, 28 days compressive strength increased as high as 69% and 10%; whereas, tensile strength improved as much as 39% and 48% for stone and brick replaced concrete respectively. Reduction in concrete density was moderate for PRC. The density decreases with the increasing percentage of plastic replacement because of the lighter weight of plastic. Through this study, it is revealed that PP can be used as a partial replacement of crushed stones and brick chips as coarse aggregate and with PRC it is possible to achieve higher strength and reduction in density.

Keywords:

Polypropylene, Plastic, concrete, compressive strength, tensile strength, workability.

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Chapter 1 Introduction

1.1 General

Now a days plastic is the most widely used products in our day to day life.Due to their relatively low cost, ease of manufacture, versatility and imperviousness to water, plastics are used in a wide range of products; from paper clips to spaceships. For more than 50 years, global production of plastic has continued to rise. Some 299 million tons of plastics were produced in 2013, representing a 4 percent increase from 2012 [1]. The main problem with plastic is its non-biodegradable behavior which leads to plastic pollution. It involves the accumulation of plastic products in the environment that adversely affects wildlife, wildlife habitat, or humans.

Polypropylene (PP) is a thermoplastic which is easily available and cheap. Thermoplastics can be readily recycled. The reuse of waste plastic is important from different points of view. It helps to save and sustain natural resources that are not replenished; it decreases the pollution of the environment and it also helps to save and recycle energy production processes.

In our thesis we have tried to determine the concrete properties while using polypropylene (PP) as partial replacement of coarse aggregate. Tests were carried out to compare the compressive strength, tensile strength and flexural strength of 10%, 20% and 30 % replacement with the conventional concrete (0% replacement).

The plastics we are using were initially regarded as completely waste plastic materials (i.e. bucket, jar, toys, bottles, bags etc.).Then the waste plastics were collected and melted and molded as plastic bars. The bars were shredded into pieces which we are now using as plastic aggregates.

The main advantage of using PP for concrete construction is weight reduction of structural members. More over the surface of the recycled PP is relatively rougher than the crushed stone or brick chips so it increases the bonding strength with cement mortar. It also contributes to environmental pollution reduction as well as recycling of waste.

1.2 Literature Review

For the design of protective structures, various materials such as, steel, aluminum, titanium, concrete etc. are of particular interest. Steel and aluminum have high strength and ductility; titanium and titanium alloys have an excellent high strength to weight ratio; and concrete is a low cost material with wide applications.

Rahman et al. [2] investigated the potential of recycled waste polymeric materials as a substitute for aggregates in concrete. Two different types of waste polymer, namely polyurethane formaldehyde (PUF) based packaging waste and high density polyethylene (HDPE) were recycled and used in the experiment. Concrete and masonry poly block specimens were prepared using recycled polymer materials, and test specimens were characterized. The result shows that the inclusion of waste polymer materials decreases density, porosity and water absorption of concrete and poly blocks significantly. According to their results, Due to exceptionally low density, recycled polymer modified blocks and concrete can be used in non-load bearing structures, floating structures and where light-weight materials recommended. The amounts of waste plastic (HDPE) added were 10%, 15%, 20% and 25% based on the weight of stone chips. The inclusion of waste polymer (both HDPE and PUF) is found to result in the decrease of compressive strength of concrete and masonry poly blocks.

The rate of reduction in the compressive strength of the HDPE modified concrete is about 0.6 MPa per volume percent of HDPE added while; the rate of reduction in compressive strength of poly blocks is only 0.21 MPa per volume percent of Poly bubble added. Saikiaet al. [3]has reviewed different types of plastics and types of methods used to prepare plastic aggregate as well as the methods of evaluation of various properties of aggregate and concrete. The review paper has also discussed about the properties of plastic aggregates and the various fresh and hardened concrete properties of cement mortar and concrete, in presence of plastic aggregate. According to their findings the compressive strength, flexural strength and splitting tensile strength of concrete is reduced with the incorporation of plastic as aggregate. They concluded that the reduction in tensile splitting strength and flexural strength were relatively less prominent than the reduction in compressive strength of concrete due to the incorporation of plastic aggregate. Panyakapo et al.[4] worked on the utilization of thermosetting plastic as an admixture in the mix proportion of lightweight concrete. This plastic cannot be melted by heating because the molecular chains are bonded firmly with meshed cross links. Thus, the paper therefore presented an investigation of lightweight concrete using thermosetting plastic waste, especially amino-melamine. The experimental result showed that the strength and dry density have been reduced because of the plastic. This type of concrete meets most of the requirements for non load-bearing lightweight concrete according to ASTM C129 Type II standard. Batayneh et al. [5] studied the problem of the waste that is generated from construction fields, such as demolished concrete, glass, and plastic. In order to dispose of or at least reduce the accumulation of certain kinds of waste, they suggested to reuse some of these waste materials to substitute a percentage of the primary materials used in the ordinary Portland cement concrete (OPC). Ground plastics and glass were used to replace up to 20% of fine aggregates in concrete mixes, while crushed concrete was used to replace up to 20% of coarse aggregates. Here the compressive strength and the splitting tensile strength also decreased because of the incorporation of waste materials.

Foti, D [6] conceive the results of some tests performed on concrete specimens reinforced with fibers made from waste polyethylene terephthalate (PET) bottles. The fibers have been obtained by simply cutting the bottles; the fibers are then added to the mix concrete or they are used as discrete reinforcement of specimens and little beams in substitution of steel bars. More ductile behavior of concrete was observed.

Ismail et al. [7]tested to determine the efficiency of reusing waste plastic in the production of concrete. Waste plastics of fabriform shapes was used as a partial replacement of sand by 0%, 10%, 15% and 20%. These tests include performing slump, fresh density, dry density, compressive strength, flexural strength and toughness indices. Curing ages were 3,7,14 and 28 days. The results proved the arrest of propagation of micro cracks by introducing waste plastic of fabriform shapes to concrete mixture. With increasing the waste plastic ratio, the result show a tendency for compressive strength and flexural strength values of waste plastic concrete mixtures to decrease below the reference concrete mixture. The slump values of waste plastic concrete mixtures showed a tendency to decrease below the slump of the reference concrete mixture. Iucolano et al. [8] worked on artificial aggregates based on recycled plastic materials. Mostly polyolefin and polyethylene terephthalate waste, were used as partial replacement of natural aggregate for manufacturing hydraulic mortar. Different amounts (10-50% by weight) of siliceous sand were substituted by the same weight of the above plastic waste. The influence of plastic addition on physical and mechanical properties (density, porosity, compressibility and flexural behavior and water porosity) were studied. The replacement decreased the flexural and compressive strength with increase in water vapor permeability. They were successful in decreasing the density from 8 to 33% but the mechanical properties were largely reduced.

Elzafraney et al. [9] worked on recycled plastic; high density poly ethylene, poly vinyl chloride and polypropylene were used as coarse aggregate in concrete mixtures alter and improve the thermal properties in buildings. Two similar retail buildings were designed and constructed. One with normal concrete and the other with high content of recycled mixed plastics. Short term and long term monitoring were performed for both the buildings. The experimental and SUNREL (a building simulation program) program results showed that the recycled plastic concrete building exhibit higher level of energy efficiency and comfort when compared with the normal concrete building.

Reddy et al. [10] used melt-densified material as light weight coarse aggregate in concrete. Melt-Densified Aggregates (MDA) were prepared from postconsumer recycled plastic bags by melting in a laboratory Muffle Furnace at 160^{o}C. Reference specimen using conventional aggregates and four mixture specimens (M1-M4) made with part replacement by MDA aggregate were prepared. The compressive strength results are compared with reference specimen. MDA can be used to replace part of aggregates in a concrete mixture. This contributes to reducing the unit weight of the concrete and attracts a growing ecological interest especially due to the increasing volume of polymer wastes. The use of post-consumer plastic waste as MDA in concrete will be one of the safe disposal method.

Zargar et al. [11] experimental research on the application of waste plastic bottles (Polyethylene Terephthalate (PET) as an additive in stone mastic asphalt (SMA). Wheel tracking, moisture susceptibility, resilient modulus and drain down tests were carried out on the mixtures that included various percentages of waste PET as 0%, 2%, 4%, 6%, 8% and 10% by weight of bitumen content. The results show that the addition of waste PET into the mixture has a significant positive effect on the properties of SMA which could improve the mixture's resistance against permanent deformation (rutting), increase the stiffness of the mix, provide lower binder drain down and promotion of re-use and recycling of waste materials in a more environmentally and economical way. The main objective of this study, however, was to determine the impact of incorporating waste PET on the engineering properties of SMA with and without chopped PET.

1.3 Observation of Literature Review

1. The compressive strength, tensile strength and flexural strength decreases with the increasing percentage of replacement by plastic aggregate. These plastic aggregates are high density polyethylene (HDPE), polyurethane formaldehyde (PUF), polyolefin and polyethylene terephthalate, poly vinyl chloride and polypropylene (PP).
2. Different types of concrete which are partially replaced by plastic aggregate can be used for non-load bearing structures.
3. Plastics are more energy efficient, ductile and lighter than the regular aggregates.

1.4 Objectives

The objective of this work is as follows:

1. Investigate the fresh and harden properties of concrete while using polypropylene (PP) as a partial replacement of coarse aggregate.
2. Propose a replacement ratio for PP to be used in structural concrete.

3. Introducing new trend of concrete structures having environment friendly behavior.

1.5 Scope

To achieve the objectives following work has been performed:

1. Testing of various aggregates, such as sand, crushed stones and bricks, and polypropylene (PP) according to the ASTM standard.
2. Preparing mix ratios for concrete, cast concrete and measure slump values for workability.
3. Testing of cylinder compressive strength, splitting tensile strength and flexural strength of concrete with and without PP as partial replacements.

1.6 Organization of the Thesis

In this thesis work, the contents has been arranged in a gradual manner according to their place of suitability and importance. The chapter one has been introduced with a general introduction, which follows an extensive literature review emphasizing on the previous experimental attempts and the corresponding outcomes.

A precise observation has been made later on & the objectives along with the scope of this work has been stated. In chapter two, the methodologies adopted for different experimental procedure for the fine & coarse aggregate such as determining specific gravity, slump test, process of casting & curing, compressive strength test, tensile splitting test, flexural strength test, and mix design of concrete has been discussed. In chapter three, the overall selected materials for this research work has been discussed elaborately including the physical properties of fine & coarse aggregate. Besides, other chemical & typical properties of Poly Propylene & binding material has been showcased. In chapter four, the results of this research work have been enlisted in different segments such as workability, density, compressive strength, tensile strength,& therefore the proper reasoning have been made. Finally, in chapter five, the net outcome of this research work has been demonstrated as conclusions & a series of recommendations have been made within the provisions of future work.

Chapter 2 METHODOLOGY

2.1 Introduction

Using plastic as a replacement for coarse aggregate is an innovative idea. To conduct the research work, we've to do a lot experiments to investigate the outcome.The ideas were to find out the compressive, tensile as well as flexural strength of the sample concrete cylinder and also to inspect the uniqueness of the materials used. Thus, the experimental procedure includes Los Angles test, slump test, specific gravity test, water absorption test, density measurement, compressive strength test, tensile strength test and flexural strength test.

2.2 Specific Gravity and Water Absorption

Specific Gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. In Portland Cement Concrete the specific gravity of the aggregate is used in calculating the percentage of voids and the solid volume of aggregates in computations of yield. The absorption is important in determining the net water-cement ratio in the concrete mix.

Standard test method for determining Specific gravity and absorption of coarse aggregate and Fine aggregate can be found in ASTM C 127 and ASTM C 128 respectively.

$$\text{Water absorption} = (B-A)/A \tag{2.1}$$

Here,

A=weight of oven dry test sample in air, g

B=weight of saturated surface dry test sample in air, g

The specific gravity test measures aggregate's weight under three different sample conditions:

1. Bulk Specific Gravity
2. Bulk saturated surface dry (SSD) Specific Gravity
3. Apparent Specific Gravity

2.2.1 Bulk Specific Gravity (also known as Bulk Dry Specific Gravity)

The ratio of the weight in air of a unit volume of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at the stated temperature.

Bulk specific Gravity (Oven Dry),

$$S_d = \frac{A}{B-C} \tag{2.2}$$

Here,

A=weight of oven dry test sample in air, g

B=weight of saturated surface dry test sample in air, g

C=weight of saturated test sample in water, g

2.2.2 Bulk Saturated Surface Dry (SSD) Specific Gravity

The condition in which the aggregate has been soaked in water and has absorbed water into its pore spaces. The excess, free surface moisture has been removed so that the particles are still saturated, but the surface of the particle is essentially dry.

Bulk specific Gravity (saturated surface dry) SS:

$$SS = \frac{B}{B-C} \tag{2.3}$$

2.2.3 Apparent Specific Gravity

The ratio of the weight in air of a unit volume of the impermeable portion of aggregate (does not include the permeable pores in aggregate) to the weight in air of an equal volume of gas-free distilled water at the stated temperature.

Apparent specific gravity, Sa:

$$Sa = \frac{A}{A-C} \tag{2.4}$$

2.3 Slump test

Slump test is the most common method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It does not measure all factors contributing to workability, nor is it always representative of the placability of the concrete. However it's used conveniently as a control test and gives an indication of the uniformity of concrete.

The apparatus used for conducting slump test essentially consists of a metallic mold in the form of a frustum of a cone having the internal dimensions as under:

Bottom Diameter:20 cm

Top Diameter : 10 cm

Height : 30 cm

For taming of concrete, a 16 mm diameter,0.6 m long tamping rod is used. After cleansing and placing the mold on a smooth,horizontal, rigid and non-absorbent surface, the mold is filled in four layers of concrete approximately 1/4th of the height of the mold. Each layer is tamped 25 times by tamping rod.

After the top layer has been rodded, the concrete is struck off level with a trowel and tamping rod. The mold is removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside. The subsidence is referred as slump of concrete. The difference in level between the height of the mold and that of the highest point of the subsided concrete is measured. The difference in height in mm is taken as the slump of the concrete.

The pattern of the slump indicates the characteristics of the concrete. If the concrete slumps evenly, then it’s called true slump. If one half of the cone slides down, it’s called shear slump. If the cone collapsed completely, then it’s called collapse slump.

2.4 Casting and Curing

Non absorptive, metal cylinder molds are placed on a level, rigid horizontal surface, free of vibration and other disturbance. 4” x 8” cylinder molds are used for casting fresh concrete. Grease is applied at the joints of the molds, so that water doesn’t leak and mobile is applied in the inner portion of the mold so that hardened concrete can be easily removed from the mold without any damage. Concrete is placed in the mold using a scoop, blunted trowel, or shovel. The molds are filled up with concrete in three layers. In each layer 25 blows are given with a tampering rod. Proper curing is a must for achieving desired strength. Top is covered with non-absorptive, non-reactive plate or placed in an impervious plastic bag to prevent loss of moisture. At this time moist curing is done. Concrete is removed from the molds at the end of 24 hours of approximate moist curing. Ponding method of the samples is selected as curing method for the concrete specimens. After 24 hours of casting, all the cylinders are kept under water for 90 days at controlled temperature.

2.5 Ultrasonic Pulse Velocity (UPV) test

UPV stands for Ultrasonic pulse velocity method, which involves the measurement of the time of travel of electronically generated mechanical pulses through the concrete.

The Pulse generator circuit consists of electronic circuit for generating pulses and a transducer for transforming these electronic pulses into mechanical energy having vibration frequencies in the range of 150 to 50 kHz. The time of travel between initial onset and the reception of the pulse is measured electronically .The path length between transducer divided by the time of travel gives the average velocity of wave propagation.

2.6 Compressive Strength Test

Compressive strength test results are mainly used to determine that the concrete mixture as delivered meets the requirements of the specified strength,f'_c .In the job specifications, ASTM C39 / C39M - 15a was followed for testing of our cylindrical specimen. Compressive strength test was done after 7 days,28 days and 90 days casting of concrete.

After casting properly, capping was done for all the sample cylinders. Caps were made as thin as practicable and care had been taken so that flaw or fracture does not take place, when the specimen is tested. We've used compressive strength test machine as well as Universal testing Machine(UTM) for the purpose.

The Structural lightweight concretes have densities ranging from 1360 to 1920 kg/m3 (85 to 120 lb/ft3) and minimum compressive strengths of 17.0 MPa (2500 psi). On the other hand, Low-density concretes, whose density seldom exceeds 800 kg/m3 (50 lb/ft3), are used chiefly as insulation. While their thermal insulation values are high, their compressive strengths are low, ranging from approximately 0.7 to 7.0 MPa (100 to 1000 psi) (ACI Education Bulletin E1-07).

2.7 Tensile Splitting Test

This test is referred as Brazilain test. This test is carried out by placing a cylindrical specimen horizontally.

The test is carried out by placing a cylindrical specimen horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder,along the vertical diameter.

When the load is applied along the genetarix, an element on the vertical diameter of the cylinder is subjected to a vertical compressive stress of

$$T = \frac{2P}{\pi l d} \qquad (2.5)$$

Where,

T=Splitting Tensile Strength,psi

P= Maximum Applied load,lbf[N]

l= length [mm]

d= diameter[mm]

2.8 Flexure Strength Test

Beam tests are found to be dependable to measure flexural strength property of concrete.

The value of modulus of rupture (extreme fiber stress in bending)depends on the dimension of the beam and manner of loading .The system of loading used in finding out the flexural tension are central point loading and third point loading .In the central point loading the maximum fiber stress will come below the point of loading where the bending moment is maximum.

The standard size of the specimen is Y x Z x k

The flexural strength of the specimen is expressed as the modulus of rupturef_b, which if "a" equals the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen, in cm, is calculated to the nearest 0.05 MPa as followsf_b

$$f_b = \frac{P \times l}{b \times d \times d}$$

When 'a' is greater than 20.00cm for 15.0 cm specimen or greater than 13.3 cm for a 10.0.cm specimen ,or

$$f_b = \frac{3P \times a}{b \times d \times d}$$

When 'a' is less than 20.00cm for 17.0 cm specimen for 15.0 cm specimen or less than 13.3 cm but greater than 11.0 cm for a 10.0 cm specimen where

b= measured width in cm of the specimen

d= measured depth in cm of the specimen at the point of failure

l= length in cm of the span on which the specimen was supported

P=maximum load in kg applied to the specimen

2.8 Los Angeles Test

Los Angeles Test is characterized by the quickness with which a sample of aggregate may be tested. The applicability of the method to all type of commonly used aggregate makes this method popular. The test involves taking specified quantity of standard size material along with revolutions. The particle size smaller than 1.7 mm size is separated out. The loss in weight expressed as percentage of the original weight taken gives the abrasion value of the aggregate. The abrasion value should not be more than 30 per cent for wearing surfaces and not more than 50 per cent for concrete other than wearing surfaces.

The formula used for Los Angeles abrasion test is:

Los Angeles abrasion value= $\frac{Weig\,ht of f raction passing \quad 1.7\ mm sieve}{weig\,ht of t he materials}$×100%

2.9 Mix Design

Two different water cement ratios were chosen for the concrete mix design and that is 0.45 and 0.55. Four sets of concrete were prepared for both stone and brick chips: (a) with no PP, (b) with 10% PP as a replacement for crushed stone chips and brick chips, and (c) with 20% PP as a replacement for crushed stone and brick chips and (d) with 30% PP as a replacement for crushed stone and brick chips.

Table 2.1 summarized the mix proportions for all the components, cement, water, sand, crushed stone and PP, of the concrete by weight for 1 m^3 of volume.

Table 2.1 Mix design (crushed stone replaced concrete)

Sample Designation	Cement (Kg)	Water (Kg)	Sand (Kg)	Crushed stone (Kg)	PP (Kg)
Water Cement ratio = 0.45					
WC45P0	340	153	539	1251	-
WC45P10	340	153	539	1126	40.5
WC45P20	340	153	539	1001	81.0
WC45P30	340	153	539	876	121.5
Water Cement ratio = 0.55					
WC55P0	340	187	514	1192	-
WC55P10	340	187	514	1073	38.6
WC55P20	340	187	514	954	77.2
WC55P30	340	187	514	834	115.8

Table 2 summarized the mix proportions for all the components, cement, water, sand, brick chips, sand and PP, of the concrete by weight for 1 m3 of volume.

Table 2.1 Mix design (brick chips replaced concrete)

Sample Designation	Cement (Kg)	Water (Kg)	Sand (Kg)	Crushed stone (Kg)	PP (Kg)
Water Cement ratio = 0.45					
WC45P0	340	153	539	1149	-
WC45P10	340	153	539	992	40.5
WC45P20	340	153	539	882	81.0
WC45P30	340	153	539	771	121.5
Water Cement ratio = 0.55					
WC55P0	340	187	514	1110	-
WC55P10	340	187	514	945	38.6
WC55P20	340	187	514	840.3	77.2
WC55P30	340	187	514	735.3	115.8

2.10 Conclusions

Tests which are described above mostly done for determining the characteristics of the materials used for making sample cylinders. Different strength measuring tests are done for determining the compressive, tensile and flexural strength of sample cylinders. From the tests, not only values are measured, but also the failure patterns of the cracked concrete to determine whether it’s mortar or aggregate failure and characterized the concrete in that way.

Chapter 3 Materials

3.1 Introduction

In the research work, crushed stone, brick chips and polypropylene (PP) were used as coarse aggregate. Sylhet sand was used as fine aggregate and cement as binding material. Mixing all these along with water, different cylindrical concrete specimens and beams were casted. The chapter describes the properties of the materials used. The properties need to be known to find the mix design, gradation of aggregates, preparation of materials before casting etc. The tests were performed according to different codes of ASTM.

3.2 Properties of Material

This section describes the properties of coarse aggregate, fine aggregate, binding material and water .The tests were performed according to the following ASTM codes.

Table 3.1 Material properties and testing methods

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
Flexural Strength of Concrete	ASTM C78 – 02

3.2.1 Binding Material

Portland composite cement (PCC) has been used as binding material. In this research, CEM type-II/A-M was selected to carry out the experiments. Specific gravity of cement was found out to be 2.9 by test carried out according to ASTM specification C 188-14.

Table 3.2Chemical Composition of Binding materials

Chemical Composition	Unit	Test result
Calcium Oxide (CaO)	(%)	51.63
Silicon dioxide(SiO2)	(%)	23.79
Aluminium Oxide(Al2O3)	(%)	8.36
Ferric Oxide(Fe2O3)	(%)	3.41
Sulfur trioxide(SO3)	(%)	2.24
Magnesium Oxide(MgO)	(%)	1.67
Loss of Ignition(LOI)	(%)	3.17
Insoluble Residue(IR)	(%)	17.30

3.2.2 Aggregate

Crushed stone and brick chips are generally used as coarse aggregate for concrete casting. Polypropylene (PP) was also used for our research work. Sylhet sand was used as fine aggregate.

Table 3.3 Aggregate properties

Material property	Crushed Stone	Brick Chips	Polypropylene (PP)	Sylhet Sand
FM	Was controlled according to ASTM C33	Was controlled according to ASTM C33	Was controlled according to ASTM C33	2.6
% Wear	34.04	38.26	0.11	-
Bulk Specific Gravity	2.61	2.3	0.8452	2.25
Apparent Specific Gravity	2.58	2.8	-	2.43
% Water Absorption	1.05	15.06	0.8	3.4

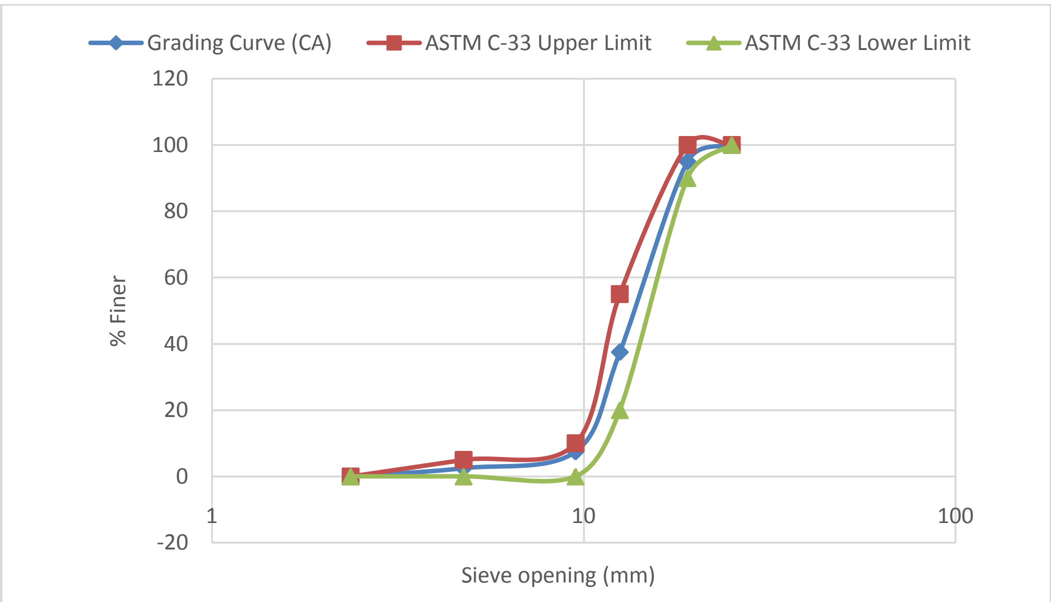

Figure 3.1 Gradation curve of coarse aggregate

3.2.2.1 Crushed Stone

Crushed stone was collected from the local markets. For the ASTM requirements various tests like specific gravity, absorption test, Los Angeles Abrasion test and sieve analysis were done. Los Angeles Abrasion test was done according to ASTM C131 and other tests were done according to ASTM C127.

Table 3.4 Specific Gravity and Absorption of Stone Chips

Mass of oven dry test sample in air, A (g)	Mass of saturated surface dry test samplein air,B (g)	Apparent massof saturated test samplein water,C (g)	Specific Gravity (SSD)	Avg. Sp.Gr. (SSD)	Specific Gravity (Apparent)	Avg. Sp. Gravity (Apparent)	Specific Gravity (OD)	Avg. Sp.Gr. (OD)	Absorption (%)	Avg. Absorption (%)
1706	1731	1071	2.62		2.68		2.58		1.46	
1300	1308	809.4	2.62	2.61	2.64	2.65	2.60	2.58	0.61	1.05
1371	1386	854.3	2.60		2.65		2.57		1.09	

Figure 3.2 Stone chips (crushed)

Table 3.5 % Abrasion wear of 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	3297.8	1702.2	34.04

3.2.2.2 Brick Chips

Brick chips as coarse aggregate was collected from the crushing of locally available bricks. Crushing of bricks was done as to the required sizes. Then crushed aggregates were washed and oven dried for material testing.

The table below contains specific gravity of brick aggregates. Specific gravity in OD basis, SSD basis and apparent specific gravity along with %Absorption were determined. The tests are done according to ASTM C127. The results are described and tabulated below.

Table 3.6Specific Gravity and Absorption of Brick Chips

Mass of oven dry test sample in air, A (g)	Mass of saturated surface dry test sample in air,B (g)	Apparent mass of saturated test sample in water,C (g)	Specific Gravity (SSD)	Avg. Sp.Gr. (SSD)	Specific Gravity (Apparent)	Avg. Sp. Gravity (Apparent)	Specific Gravity (OD)	Avg. Sp.Gr. (OD)	Absorption (%)	Avg. Absorption (%)
3000	3451	1931	2.3	2.3	2.8	2.8	2.0	1.97	15.0	14.83
3008	3449	1902	2.2		2.7		1.9		14.7	
3000	3445	1950	2.3		2.9		2.0		14.8	

Table 3.7% Abrasion wear of Brick chips

Mass of sample before test (g)	Mass retained on sieve size 1.70 mm (g)	Mass passing on sieve size 1.70mm (g)	% Wear
5009	3092.8	1916.2	38.3

(a) (b)

Figure 3.3 (a) First class brick. (b) Brick chips

3.2.2.3 Polypropylene (PP)

Polypropylene (PP) is a cheap and plentiful thermoplastic used in a wide variety of applications including food packaging, textiles, laboratory equipment, automotive components, and polymer banknotes. It is generally resistant to most of the chemical solvents, bases and acids. It shows very good resistance to fatigue, and thus, most plastic living hinges, such as flip-top bottles, are made from this material.

PP were mainly used as the partial replacement of crushed stone and brick chips where the replacement ratio ranged between 0% - 30% by volume. Polypropylene which was also collected from local supplier is shredded into specific sizes for uniform grading. The PP aggregate and its preparation process are shown in the following figures.

Figure 3.4 Plastic aggregate (Polypropylene) and its preparation process

Table 3.8 % Abrasion wear of Polypropylene (PP)

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
5010	5004	6	0.11

3.2.2.4 Fine aggregate (Sylhet Sand)

Sylhet sand was used as fine aggregate for the research work. It was collected from the local supplier as well. Sand was sieved through 4.75 mm sieve to eliminate particles larger than 4.75mm. It was then further washed to remove unwanted dust.

Figure 3.5 Gradation curve of fine aggregate

Chapter 4 Results and Discussion

4.1 Introduction

This chapter includes the results of all the experiments that have been done to find out the feasibility of using PP as a partial replacement of coarse aggregate (Stone chips and Brick Chips).

A comparison has been performed with the conventional regular concrete and Partial PP replaced concrete. Regular concrete has been replacedwith both stone chips and brick chips of regular concrete with polypropylene. Around 192 sample cylinders were cast for experiment. Experiments include different characteristics of concrete like workability, compressive strength, tensile strength, surface hardness, (UPV) and failure patterns.A number of tables, Graphs, bar chart have been provided to find out the applicability of using PP replaced concrete. A comparison also have been shown whether it's feasible to replace brick chips with PP or to replace Stone chips with PP for construction purpose.

4.2 Workability

Workability can be defined as the property of the concrete which determines the amount of useful internal work necessary to produce full compaction.

According to ACI (American Concrete Institute) Workability is defined as "That property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished".

Generally Workability increase with higher water-cement ratios. But higher w/c ratio sometimes shows a little tendency of "bleeding", a particular form of segregation, during the casting of concrete which is undesirable. The shape of aggregate has great influence on good workability, where angular and flaky shaped aggregates make the concrete harsh in comparison to the rounded aggregates. The used brick aggregates were angular and flaky in shape while the used PCA were more rough and irregular shaped.

There are some methods for determining the workability of the concrete. Slump test has been done for determining the workability of concrete.

According to our tests the slump value increased with the increasing w/c ratio. For both stone and brick the value was higher for the 55% w/c ratio.

We have provided two different types of water cement ratios 0.45 and 0.55, the slump value changed with the variation of aggregate replacements. According to M.S Shetty table has been derived from “Concrete technology” book is the following.

Table 4.1: Degree of workability vs. slump value(in cm)

Degree of Workability	Slump value (cm)
Very Low (VL)	-
Low (L)	2.5-7.5
Medium (M)	5-10
High (H)	10-15
Very High (VH)	-

Following table shows the workability of the sample concrete of both brick chips and stone chips replaced with Polypropylene. Based on the slump value,it’s found that Concrete having water cement ratio 0.55 shows much workability than concrete having water cement ratio 0.45, for both the cases. Overall, it seems much easier to work with stone chips replaced with Polypropylene as most of the cases workability were Medium to high.

Table 4.2: Slump values of Regular concrete with PP replaced Concrete.

w/c ratio	Coarse Aggregate (PP)	PP replaced concrete (Stone chips)			PP replaced concrete (Brick chips)		
		Designations	Slump Value(cm)	Degree of Workability	Designations	Slump Value(cm)	Degree of Workability
0.45	0	WC45P0	0	VL	BWC45P0	1	VL
	10%	WC45P1	0	VL	BWC55P1	1	VL
	20%	WC45P2	4	L	BWC45P2	0	VL
	30%	WC45P3	3	L	BWC45P3	2	VL
0.55	0	WC55P0	10	H	BWC45P2	17	VH
	10%	WC55P1	20	VH	BWC55P1	3	L
	20%	WC55P2	18	VH	BWC55P2	12	H
	30%	WC55P3	12	H	BWC55P3	15	H

4.3 Density

The density of the samples were measured from the volume (area x height) and the weight of the sample of cylinders. The density measurement was done on 7, 28 and 90 days; prior to the compressive strength and tensile splitting test.

For both brick and stone replacements; the density decreased with the increasing amount of the replacement percentage. Lowest density was found for 30% PP replaced concrete. The reason behind this is the light unit weight of PP than the traditional brick or stone aggregate.

The density was always higher for the 45% w/c ratio than the 55% w/c ratio. For similar w/c ratio and replacement percentage the density was lower for brick than the stone case as stone has higher unit weight than brick.

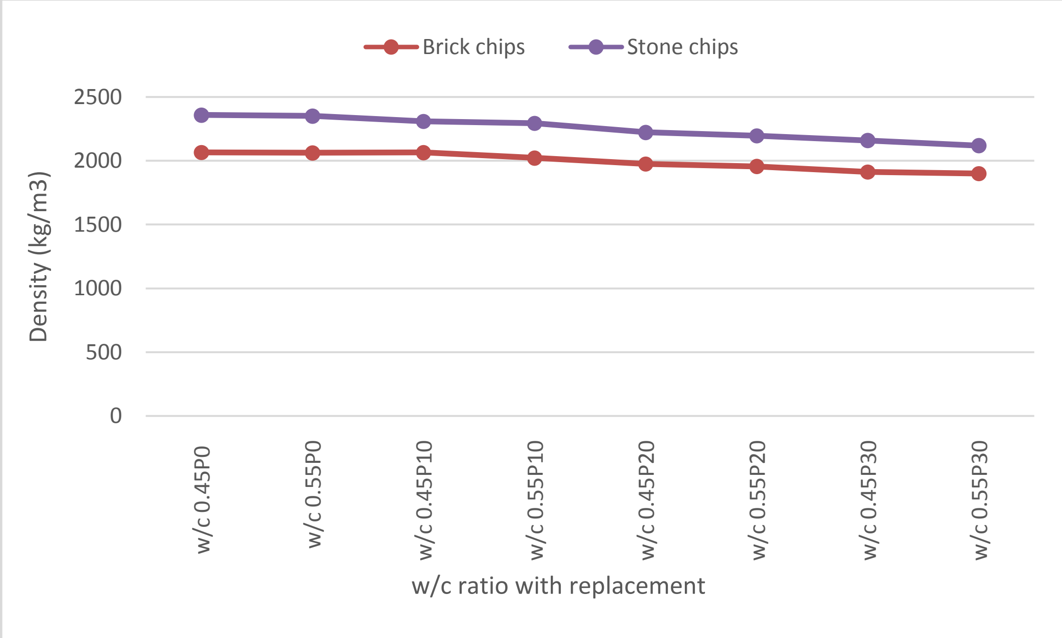

Figure 4.1 Density variation for different replacement

4.4 Ultrasonic Pulse Velocity (UPV)

UPV test has been done specially for the 28-days of sample concrete cylinders. Sample cylinders, where both stone chips and brick chips are replaced with Polypropylene, show significant increase of UPV value with the increasing compressive strength.

Another observation is that, the plots shows that that with decreasing w/c ratio, the compressive strength tends to increase and the UPV for concrete (stone chips and brick chips replaced concrete) tends to increase too.

From the plotted graph it's clearly visible that stone chips replaced with polypropylene shows better values than brick chips replaced concrete.The reason behind this is the angular shape of crushed stone which provides better interlocking between the aggregates; especially between stone chips and Polypropylene. Due to good interlocking of aggregate, less bleeding occurs in concrete made with crushed stone, as water cannot move upward.

Also the abrasion value for Crushed stone (34%) was found to be better than that of brick chips (38.8%). Crushed stone has harder in mass than brick, which helped the pulse getting passed within shorter period of time.

Unit weight and specific gravity are another two reasons for better UPV value. As brick chips has less unit weight and specific gravity with respect to stone chips, it confirms comparatively less dense concrete .So UPV value is less in that type of sample cylinder.

Following figure shows the value of UPV vs Compressive strength

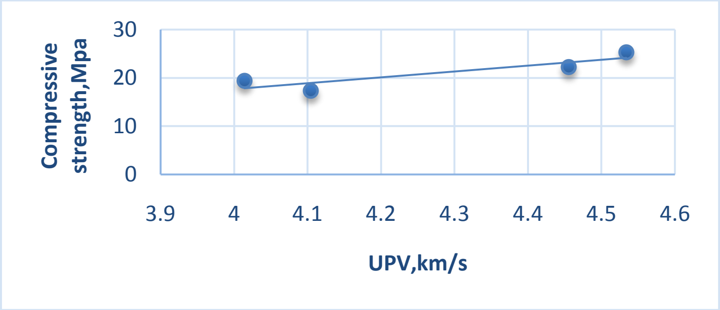

Figure 4.2 UPV vs Compressive strength plot for stone chips replaced PP with w/c= 0.45

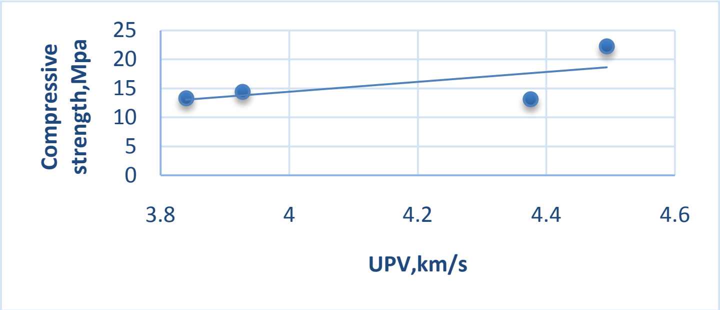

Figure 4.3 UPV vs Compressive strength plot for stone chips replaced PP with w/c= 0.55

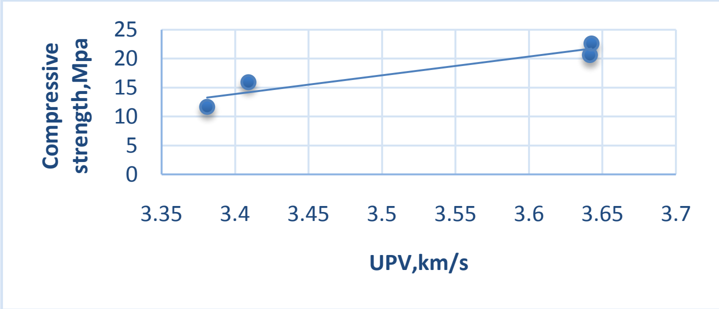

Figure 4.4 UPV vs Compressive strength plot for brick chips replaced PP with w/c= 0.45

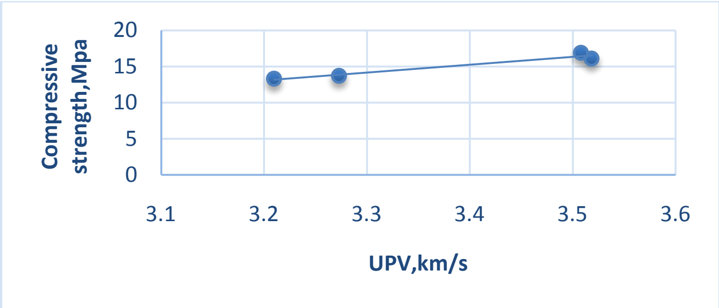

Figure 4.5 UPV vs Compressive strength plot for brick chips replaced PP with w/c= 0.55

4.5 Compressive Strength

For sample cylinders, PP were replaced with both Crushed Stone chips and Bricks chips. The variation of compressive strength were given for stone chips and brick chips respectively.

4.5.1 Stone Chips Partially Replaced with PP

Compressive test of concrete cylinders were performed for 7 days, 28 days and 90 days concrete. The following figures represents the test data for concrete with and without PP replacement. Test results indicate that the concrete with w/c ratio of 0.45 has got better strength than the concrete with w/c ratio of 0.55. Furthermore, for 10% PP replaced concrete (WC45P1 and WC55P1) a significant increase in compressive strength was observed for both w/c ratios. The increments in strengths were 14% and 69% for WC45P10 and WC55P10, respectively. This increase in strength may be caused due the rough and edgy surface texture of the PP aggregates. However, with further increase in PP content in concrete (WC45P20 and WC55P20) a decrease in strength trend was observed.

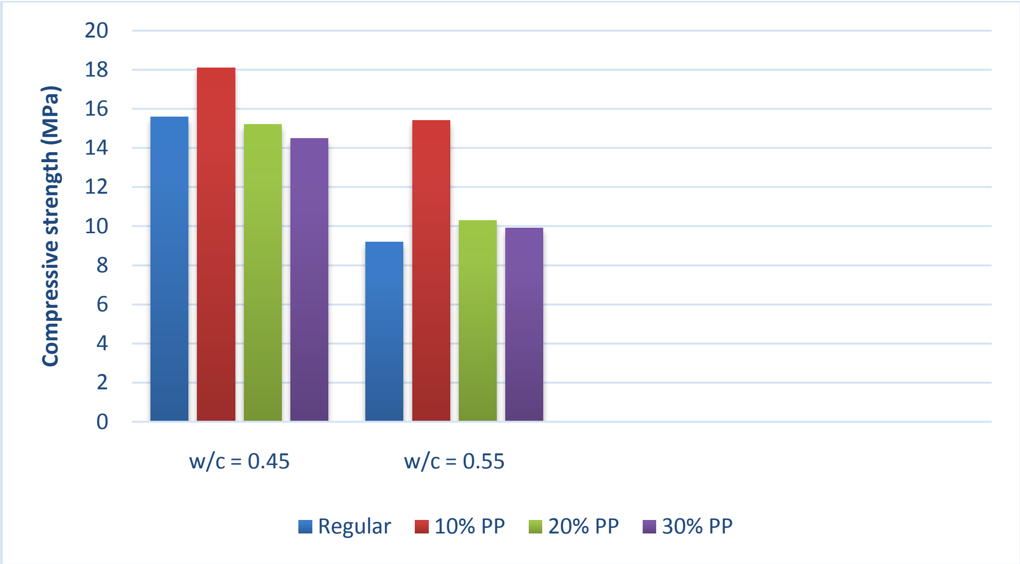

Figure 4.6 Compressive strength (7 days) of Regular and PP replaced concrete

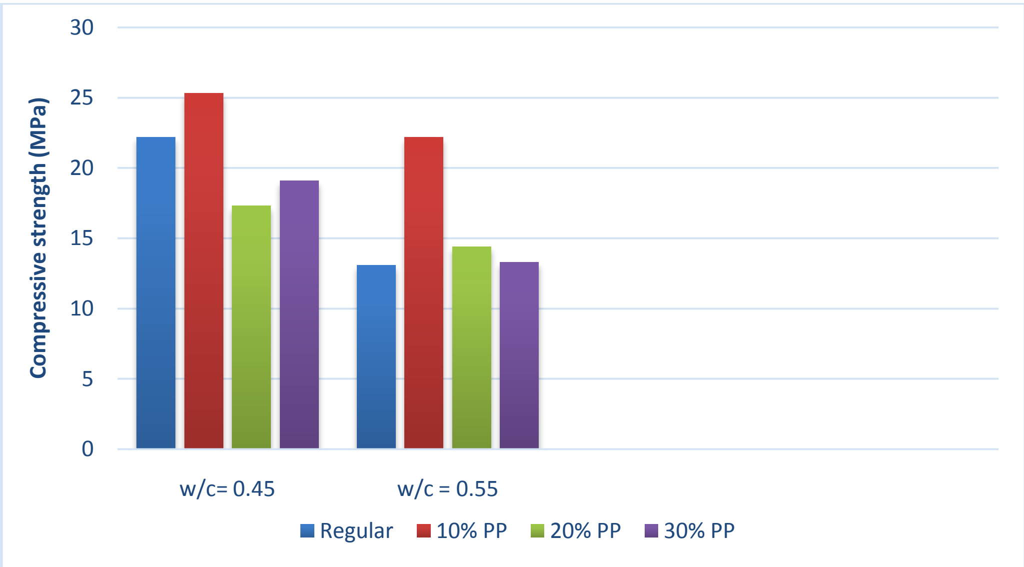

Figure 4.7Compressive strength (28 days) of Regular and PP replaced concrete

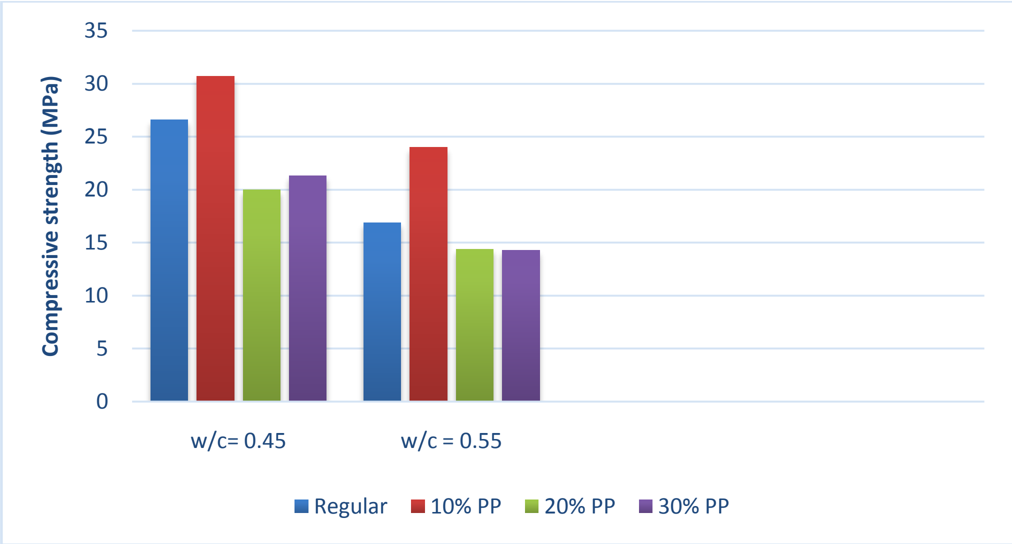

Figure 4.8 Compressive strength (90 days) of Regular and PP replaced concrete

(a) (b) (c)

Figure 4.9 Compressive strength of stone replaced with PP concrete (a) 7 days. (b) 28days. (c) 90 days

4.5.2 Brick Chips Partially Replaced with PP

Similar to the stone chips replacement, compressive strength test of concrete cylinders were performed for 7 days, 28 days and 90 days concrete. The figures below will represent the test data for concrete with and without PP replacement. Test results indicate that the concrete with w/c ratio of 0.45 showed better strength than the concrete with w/c ratio of 0.55. Furthermore, for 10% PP replaced concrete a significant increase in compressive strength was observed for both w/c ratios. The increments in strengths were 10% and 5% for BWC45P10 and BWC55P10, respectively. However, with further increase in PP content in concrete (BWC45P20 and (BWC55P20) a decrease in strength trend was observed.

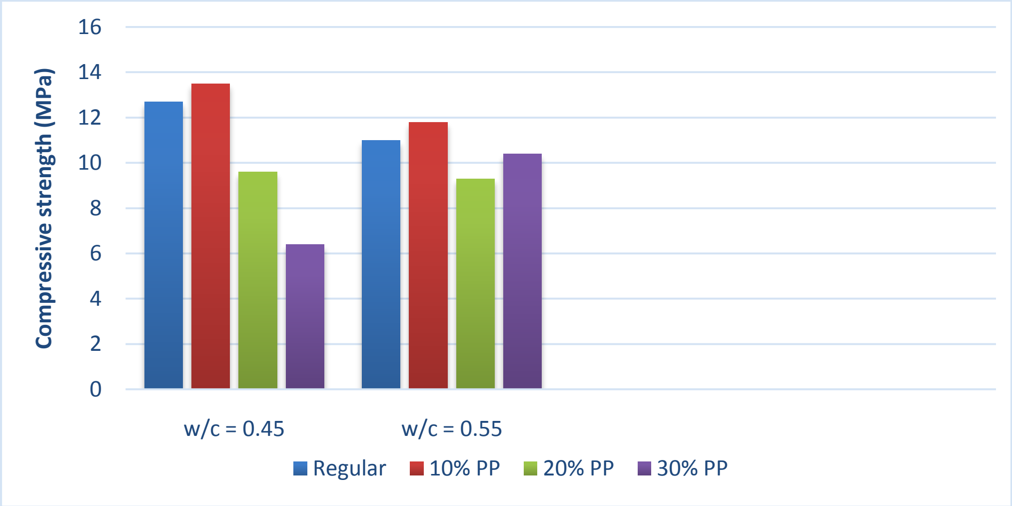

Figure 4.10Compressive strength (7 days) of Regular and PP replaced concrete

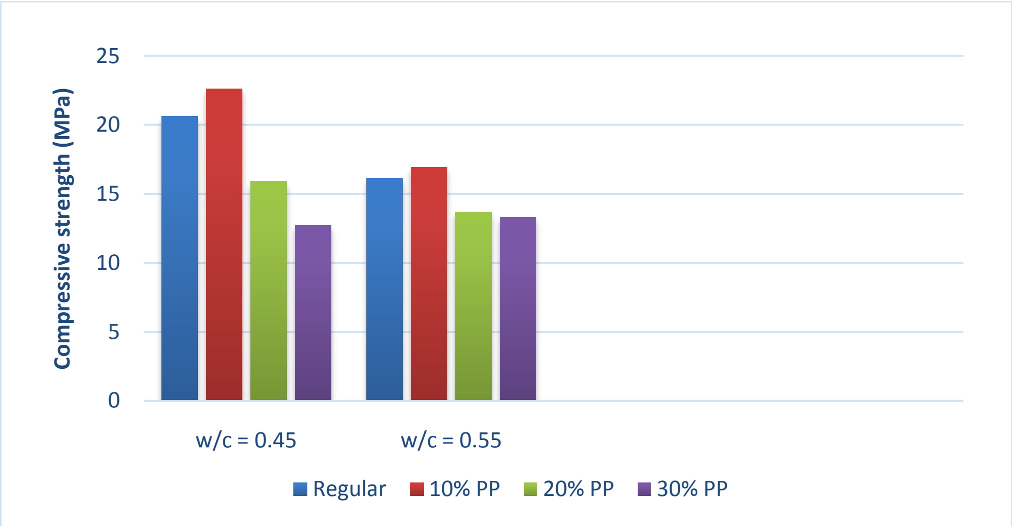

Figure 4.11Compressive strength (28 days) of Regular and PP replaced concrete

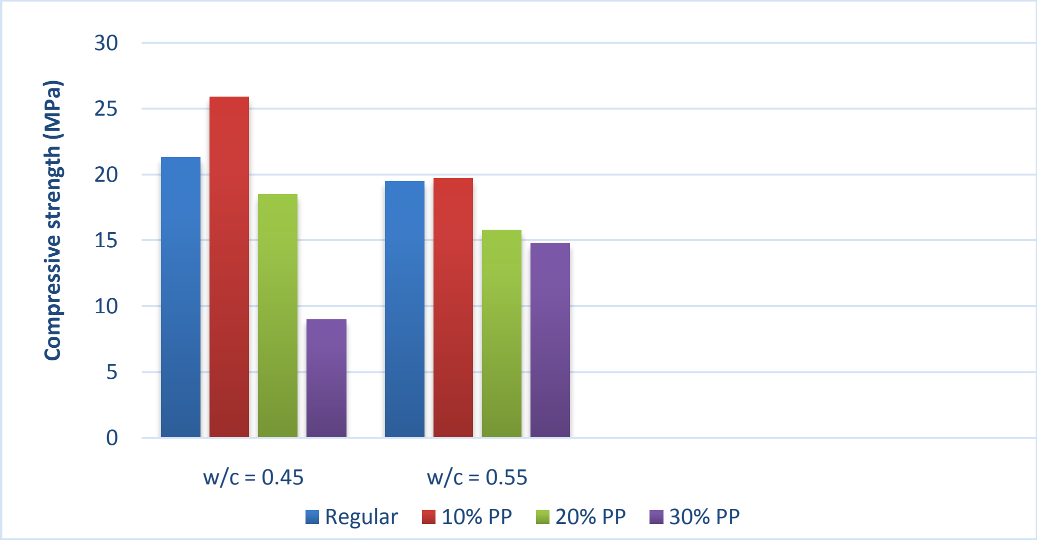

Figure 4.12 Compressive strength (90 days) of Regular and PP replaced concrete

(a) (b) (c)

Figure 4.13 Compressive strength of brick chips replaced with PP concrete (a) 7 days. (b) 28days. (c) 90 days

4.6 Tensile Strength

In order to evaluate the tensile strength of concrete, two tests were conducted.

Namely-

1. Split tensile test
2. Flexural strength test

Both of the tests were conducted on the 28th day of casting.

4.6.1 Split Tensile Test

Regular concrete has been replaced brick chips and stone chips with Polypropylene (PP). Here results are provided for two different sample cylinders with two different characteristics. The tests were conducted on the 28th day of casting.

(a) (b)

Figure 4.14 Split tensile test of (a) stone chips replaced PP. (b) brick chips replaced PP

4.6.1.1 Stone Chips Replaced with PP

Similar to compressive strength, for 10% PP replaced concretes (WC45P1 and WC55P1) tensile strengths were increased by 36% and 25% respectively from the regular concrete. However, significant reduction was observed with 20% PP replaced concrete. About 30% replacement,we didn’t have the enough strength to use it as the regular concrete mixture.

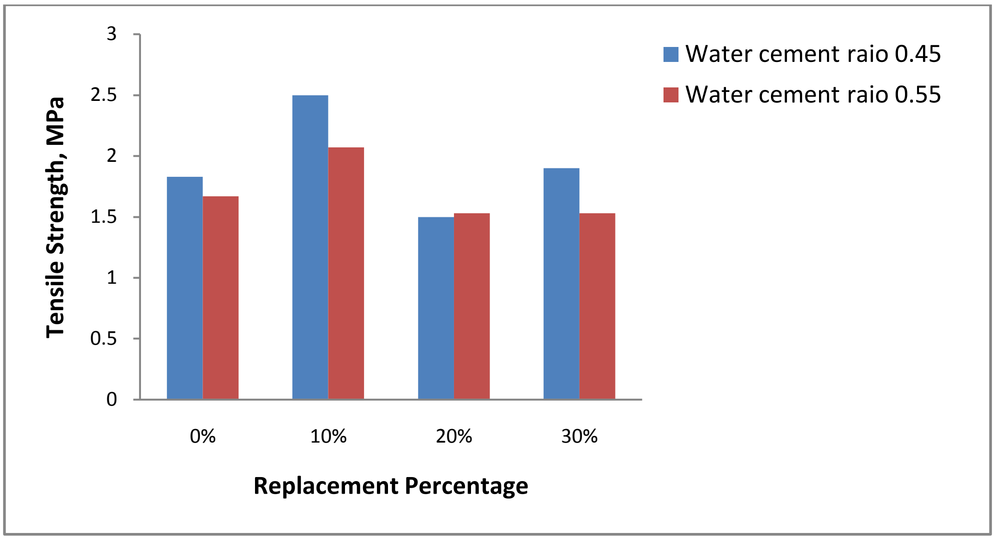

Figure 4.15 Stone Chips Replaced with PP (split tensile strength)

4.6.1.2 Brick Chips Replaced with PP

In case of brick chips the tensile strength increased around 48% and decreased 4% for the 10% PP replaced concrete where the samples had w/c ratios of 45% and 55% respectively. Then the tensile strength gradually decreased with the increasing amount of PP replacement. This phenomena took place for both the w/c ratios.

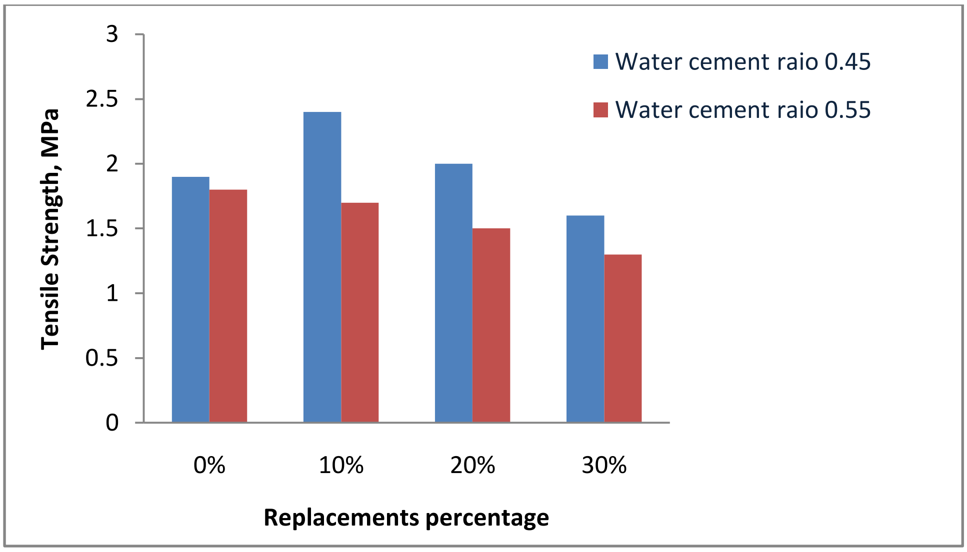

Figure 4.16Brick Chips Replaced with PP (split tensile strength)

4.6.2 Flexural Strength Test

The flexural strength of the specimen is expressed as the modulus of rupture. The tests were conducted according to the ASTM standard (C 78-2). Beams having a dimension of 420mm×140mm×140mm was tested in the UTM machine. The beams were casted with stone chips and brick chips which were partially replaced with PP.

Here we can see, for 10% replacement the modulus of rupture increased uniformly for both water cement ratio. Around 19% increment than regular concrete is found in the 10% replacement for 0.45 water cement ratio. On the other hand, for 0.55 water cement ratio around 13% increment of modulus of rupture was found for the 10% replacement.

For 20% replacement, an increase in strength is found for 0.45 cement ratio but in terms of water cement ratio 0.55, a decreasing behavior was observed. For 30% replacement, a significant decrease has been observed for both water cement ratio.

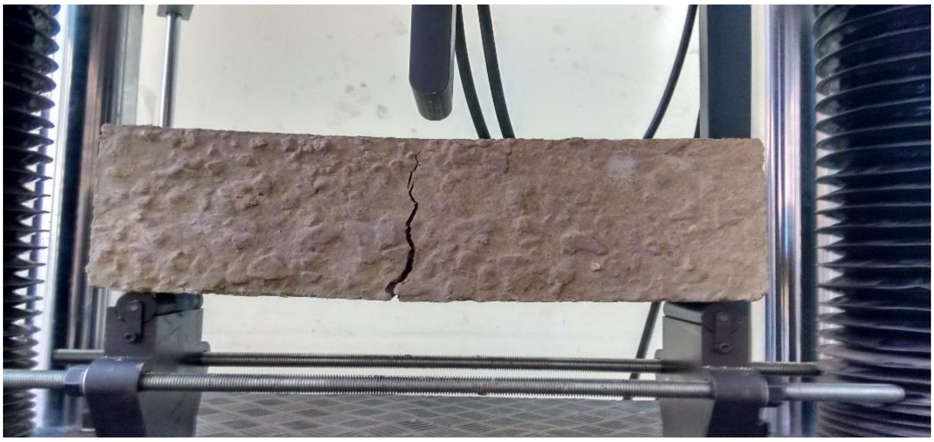

Figure 4.17 Flexural strength test of beam

In case of Brick chips replaced with PP, for 10% replacement the modulus of rupture increased around 3% for the 45% w/c ratio. But for 55% w/c ratio a significant decrease of around 19% was found. For 20% and 30% replaced concrete, both of them showed lower value than regular concrete in flexure strength.

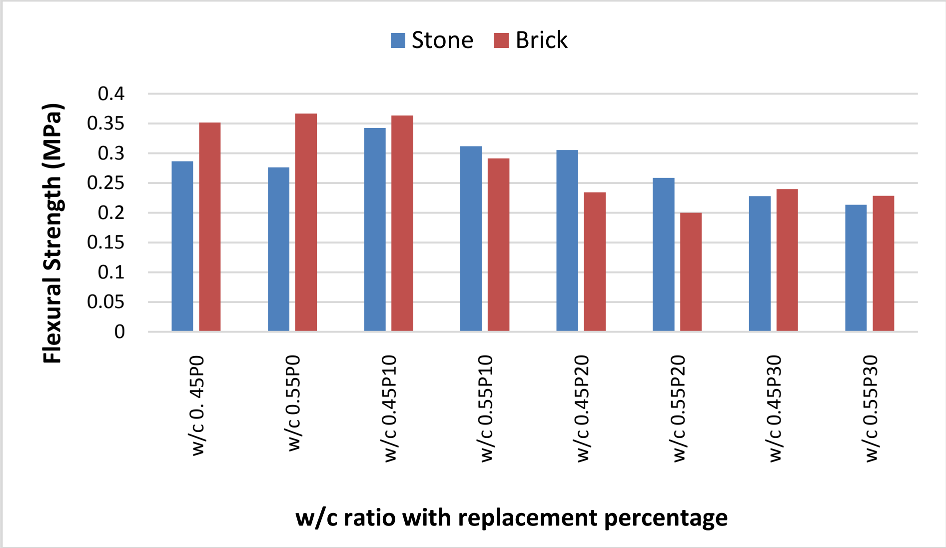

Figure 4.18 Variation in flexural strength for different samples

4.7 Conclusion:

Conducting several tests and experiments and after proper discussion, it's clearly visible that, replacement of coarse aggregate with plastic can be a feasible study. Again, it's also seen that, density of concrete has also been decreased. So, investigations can also be done in future if such replacement can be used in lightweight concrete or not.

Chapter 5 Conclusion

5.1 General

The present experimental work deals with the possibility of using PP as a partial replacement of conventionally used coarse aggregates (crushed stone and brick chips) to reduce the weight of concrete mixture which can be used in load bearing structures. Various experiments have been performed and results have been analyzed to justify the possibility. Based on the obtained results and analyzed data the findings of the experimental work and recommendations are described in this chapter.

5.2 Costing of Using PP Aggregate

According to our finding, PP aggregate takes 14 to 21 tk/cft which is relatively cheaper than the traditional coarse aggregate like crushed stone or brick chips.Sofor a poor country like ours PP replaced concrete can be of great help in the construction sector. It will also reduce the adverse effect of plastic on the environment as well.

5.3 Summary and Conclusion

The experimental results lead to the following conclusions:

1. The partially PP replaced concrete can be used as an alternative for regular concrete; especially for the case of 10% replacement. It gives better compressive, tensile and flexural strength.
2. Although PCA concrete has lower unit weight but still they are above the range of ASTM specification of lightweight concrete.
3. 20% and 30% PP replaced concrete can be used for non-load bearing structures.

4. The bonding and interlocking property is improved due to the relatively rough surface of PP aggregate.

5.4 Recommendation for Future Studies

We need some further study on the sustainability of the PP replaced concrete. We need to monitor the structural degradation of concrete. Since the slump value for the 45% w/c ratio was very low so plasticizers may be added in further research work and the behavior may be observed.

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Appendix

Table: 7 Days Stone Compression

Sample Designation	Sample No.	Avg. Dia (mm)	Weight (g)	Density (kg/m^3)	Crushing Load (kN)	Strength (MPa)	Average Strength (MPa)	Average Strength (psi)
WC45P0	1	101.96	3975.9	2375.064	133.32	16.3	15.6	2262
	2	101.8	3913.8	2368.739	123.64	15.2		
	3	101.86	3980.9	2382.722	124.97	15.3		
WC55P0	1	102.43	3985	2366.555	69.61	8.4	9.2	1339
	2	102.2	3943.3	2344.846	68.32	8.3		
	3	101.9	3887.2	2328.904	89.91	11		
WC45P1	1	102.4	3909	2313.872	139.41	16.9	18.1	2630
	2	101.4	3815	2294.812	141.54	17.5		
	3	102.1	3971	2360.563	163.56	20		
WC55P1	1	102.2	3804	2270.874	128.09	15.6	15.4	2228
	2	101.9	3840	2298.388	111	13.6		
	3	102.3	3812	2249.891	139.38	16.9		
WC45P2	1	102.3	3631	2195.596	136.8	16.7	15.2	1847
	2	101.8	3701	2225.33	63.4	7.8		
	3	102.3	3803	2251.867	112.9	13.7		
WC55P2	1	101.5	3564	2155.641	77.2	9.5	10.3	1499
	2	101.9	3671	2213.796	89.9	11		
	3	101.8	3615	2175.747	85.3	10.5		
WC45P3	1	102.5	3677	2178.67	114.3	13.9	14.5	2122
	2	101.9	3644	2176.109	121.9	14.9		
	3	102.6	3692	2162.846	124.6	15.1		
WC55P3	1	102.5	3480	2051.919	87.3	10.6	9.9	1436
	2	102.1	3476	2076.422	85.1	10.4		
	3	102.1	3415	2043.317	71	8.7		

Table: 7 Days Brick Compression

Sample Designation	Sample No.	Avg. Dia (mm)	Weight (g)	Density (kg/m^3)	Crushing Load (kN)	Strength (MPa)	Average Strength (MPa)	Average Strength (psi)
BWC45P0	1	102.63	3526	2079.035	109.9	13.3	12.7	1847
	2	102.1	3461	2065.443	90.4	11		
	3	102.63	3494	2063.522	114.8	13.9		
BWC55P0	1	102.4	3518	2083.782	92.4	11.2	11	1590
	2	102.23	3445	2050.535	88.4	10.8		
	3	102.4	3509	2080.481	89.7	10.9		
BWC45P1	1	102.0	3412	2038.862	142.1	17.4	13.5	1962
	2	101.5	3412	2056.995	96.7	12		
	3	102.3	3368	1997.534	91.8	11.2		
BWC55P1	1	101.6	3347	2017.118	91	11.2	11.8	1716
	2	102.4	3444	2043.272	102.2	12.4		
	3	102.3	3492	2067.715	97.6	11.9		
BWC45P2	1	101.8	3229	1941.527	66.2	8.1	9.6	1291
	2	102.1	3247	1931.441	61.4	7.5		
	3	102.4	3235	1925.548	91.6	11.1		
BWC55P2	1	101.8	3201	1921.556	75.9	9.3	9.3	1354
	2	102.0	3279	1958.76	76.3	9.3		
	3	102.5	3278	1942.897	77.7	9.4		
BWC45P3	1	102.2	2937	1748.163	48.3	5.9	6.4	885
	2	102.8	2991	1759.59	46.7	5.6		
	3	102.8	3100	1820.749	56.3	6.8		
BWC55P3	1	102.2	3208	1909.468	81.3	9.9	10.4	1504
	2	102.0	3201	1914.028	87.6	10.7		
	3	102.6	3226	1912.712	86.6	10.5		

Table: 28 Days Stone Compression

Sample Designation	Sample No.	Avg. Dia (mm)	Weight (g)	Density (kg/m^3)	Crushing Load (kN)	Strength (MPa)	Average Strength (MPa)	Average Strength (psi)
WC45P0	1	101.26	3892	2361.037	192.7	23.9	22.2	3214
	2	102.4	3998	2364.251	161.7	19.6		
	3	102.46	3981	2351.135	189.6	23		
WC55P0	1	102.6	3986	2363.32	111.5	13.5	13.1	1900
	2	101.96	3934	2353.862	111.1	13.6		
	3	101.5	3862	2334.35	99.1	12.2		
WC45P10	1	101.7	3832	2314.67	199.6	24.6	25.3	3669
	2	102.2	3838	2291.171	213.5	26		
	3	102.3	3911	2319.583	208.1	25.3		
WC55P10	1	102.3	3844	2285.047	188.7	23	22.2	3224
	2	101.9	3830	2294.634	152.3	18.7		
	3	101.9	3852	2302.555	203.7	25		
WC45P20	1	102.1	3752	2226.763	158.1	19.3	17.3	2441
	2	102.2	3711	2204.566	130.3	15.9		
	3	102.0	3743	2236.653	125.2	15.3		
WC55P20	1	102.0	3669	2185.316	110.6	13.5	14.4	2088
	2	102.2	3683	2192.198	115	14		
	3	102.4	3721	2209.05	129.3	15.7		
WC45P30	1	102.3	3568	2115.472	155.4	18.9	19.1	2813
	2	102.2	3613	2153.34	164.4	20.1		
	3	102.2	3711	2208.151	157.4	19.2		
WC55P30	1	101.7	3553	2130.119	111.7	13.8	13.3	1924
	2	102.2	3524	2117.54	106.1	12.9		
	3	102.8	3549	2107.733	108.4	13.1		

Table :28 Days Brick Compression

Sample Designation	Sample No.	Avg. Dia (mm)	Weight (g)	Density (kg/m^3)	Crushing Load (kN)	Strength (MPa)	Average Strength (MPa)	Average Strength (psi)
BWC45P0	1	102.13	3440	2044.909	147.3	18	20.6	2982
	2	102.13	3478	2077.617	174	21.2		
	3	102.36	3493	2073.693	185.1	22.5		
BWC55P0	1	102.16	3469	2070.889	151.6	18.5	16.1	2330
	2	102.16	3435	2050.592	129.1	15.7		
	3	102.4	3483	2064.394	115.5	14		
BWC45P10	1	102.2	3519	2081.024	195.8	23.9	22.6	3277
	2	102.8	3502	2052.853	174.6	21		
	3	102.5	3475	2058.982	189.1	22.9		
BWC55P10	1	102.5	3424	2027.445	141.5	17.1	16.9	2456
	2	101.9	3344	2002.151	142.3	17.4		
	3	102.1	3425	2037.322	133.3	16.3		
BWC45P20	1	102.2	3364	2000.371	131.3	16	15.9	2325
	2	101.9	3246	1946.646	132.8	16.3		
	3	102.1	3335	1979.279	129.2	15.8		
BWC55P20	1	102.0	3308	1973.502	101.8	12.5	13.7	1982
	2	102.1	3287	1953.341	111.8	13.7		
	3	102.3	3278	1940.999	122.1	14.8		
BWC45P30	1	102.5	3275	1939.218	115.3	14	12.7	1697
	2	102.4	3193	1898.684	80.1	9.7		
	3	102.5	3221	1899.815	94.1	11.4		
BWC55P30	1	102.3	3235	1909.339	108.7	13.2	13.3	1929
	2	102.5	3197	1889.954	112.1	13.6		
	3	102.5	3220	1901.697	107.9	13.1		

Table : 90 Days Stone Compression

Sample Designation	Sample No.	Avg. Dia (mm)	Weight (g)	Density (kg/m^3)	Crushing Load (kN)	Strength (MPa)	Average Strength (MPa)	Average Strength (psi)
WC45P0	1	101.53	3896	2347.242	223.8	27.6	26.6	3857
	2	101.6	3966	2378.546	217.9	26.9		
	3	101.96	3967	2369.747	207	25.3		
WC55P0	1	101.9	3937	2351.082	142	17.4	16.9	2451
	2	101.86	3960	2358.706	101.1	12.4		
	3	102.3	3975	2362.919	172.1	20.9		
WC45P10	1	102.1	3895	2316.897	255	31.1	30.7	4447
	2	102.3	3965	2345.515	235.3	28.6		
	3	102.1	3946	2339.637	264.4	32.3		
WC55P10	1	102.1	3851	2298.185	204.7	25	24	3480
	2	102.4	3946	2331.236	194.8	23.7		
	3	101.8	3819	2287.315	189.6	23.3		
WC45P20	1	102.3	3775	2230.959	182.2	22.2	20	2784
	2	102.6	3809	2249.558	146.7	17.7		
	3	102.5	3737	2199.889	145.6	17.7		
WC55P20	1	101.9	3567	2148.964	127.5	15.6	14.4	2088
	2	102.2	3702	2207.101	118.2	14.4		
	3	102.1	3667	2186.247	107.8	13.2		
WC45P30	1	102.4	3665	2176.518	166.3	20.2	21.3	3021
	2	102.2	3643	2161.348	163.7	19.9		
	3	102.3	3651	2168.203	184.3	22.4		
WC55P30	1	102.3	3528	2098.57	119.2	14.5	14.3	2079
	2	102.0	3521	2108.806	111.2	13.6		
	3	102.2	3561	2127.895	122.4	14.9		

Table: 90 Brick Days Compression

Sample Designation	Sample No.	Avg. Dia (mm)	Weight (g)	Density (kg/m^3)	Crushing Load (kN)	Strength (MPa)	Average Strength (MPa)	Average Strength (psi)
BWC45P0	1	102.2	3475	2066.376	153.9	18.8	21.3	3084
	2	101.76	3540	2116.111	180.6	22.2		
	3	101.63	3474	2088.881	184.9	22.8		
BWC55P0	1	101.7	3407	2039.278	116.4	14.3	19.5	2823
	2	101.83	3493	2085.282	178.6	21.9		
	3	101.7	3440	2063.726	180.5	22.2		
BWC45P10	1	102.2	3471	2058.649	205	25	25.9	3761
	2	102.4	3484	2048.334	219.5	26.7		
	3	101.9	3487	2074.256	212.7	26.1		
BWC55P10	1	102.1	3418	2027.903	160.9	19.7	19.7	2852
	2	102.0	3404	2030.13	164.7	20.2		
	3	102.3	3395	2016.173	156.8	19.1		
BWC45P20	1	101.8	3301	1971.951	130.1	16	18.5	2330
	2	102.1	3251	1935.701	91.7	11.2		
	3	101.9	3321	1975.51	171.6	21		
BWC55P20	1	102.0	3309	1972.182	128.3	15.7	15.8	2296
	2	101.7	3241	1950.675	135.2	16.7		
	3	104.2	3296	1888.49	129	15.1		
BWC45P30	1	101.6	3021	1823.619	73.7	9.1	9	1358
	2	101.5	3097	1864.06	82.6	10.2		
	3	101.8	2972	1782.92	71.3	8.8		
BWC55P30	1	102.3	3271	1924.359	132.6	16.1	14.8	2151
	2	101.8	3174	1901.005	121.4	14.9		
	3	101.8	3241	1934.841	110.1	13.5		