

**ASSESSMENT AND COMPARISON OF MECHANICAL PROPERTIES OF  
CONCRETE INCORPORATING FINE RECYCLED CONCRETE AGGREGATES AND  
BRICK DUST**

*A report submitted for fulfillment of the requirement for the award of the degree of*

**MASTER OF ENGINEERING**

**IN**

**STRUCTURAL ENGINEERING**

SUBMITTED BY

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*(i)*

## DECLARATION

I Anmol Sarao hereby declare that the work which is presented in this Thesis entitled "Assessment and comparison of mechanical properties of concrete incorporating fine recycled concrete aggregates and brick dust" as per the requirements for the award of Master of Engineering in Structural Engineering, submitted at the Civil Engineering Department, Thapar Institute of Engineering and Technology, Patiala, is an authentic record of work carried out by me under the supervision of Dr. Shakeel Ahmad Waseem, Assistant Professor, Department of Civil Engineering, Islamic University of science and Technology, Jammu and Kashmir and Dr. A.B Danie Roy, Assistant Professor, Department of Civil Engineering, Thapar Institute of Engineering and technology, Patiala.

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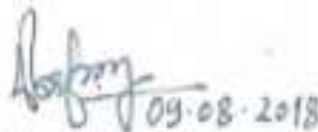


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## CERTIFICATE

This is to certify that the thesis entitled "Assessment and comparison of mechanical properties of concrete incorporating Fine recycled concrete aggregates and Brick dust" being submitted by Anmol Sarao, Roll No.-801624003 in partial fulfillment for award of Master of Engineering in Structural Engineering is work carried out by him under my guidance and that no part of this thesis has been submitted for award of any other degree.

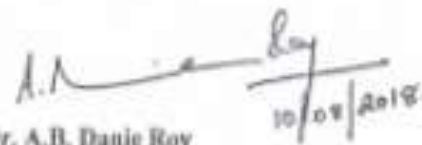


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## ABSTRACT

Concrete is most commonly used construction material all over the world, over ten billion metric tons of concrete is used yearly for different construction purposes. Concrete is a composite material made of three basic materials i.e. Cement, Coarse aggregates and Fine aggregates. Due to heavy consumption of concrete all over the world, there is a large demand for aggregates, but the availability of these natural aggregates is diminishing so to meet the demand of booming Urbanization we need to use recycled aggregates for production of concrete. It is considered that using recycled aggregates is a viable alternative to dumping which is favorable to the sustainability of natural resources and will help in conservation of natural resources.

In the present postgraduate thesis, a study on a comparative study of the mechanical properties of concrete made by replacement of fine aggregates with fine recycled concrete aggregates and crushed brick aggregates. The proportion to which fine aggregates are replaced is 25% and 50%. The free water-cement ratio was kept constant for all the mixes.

Results show different Mechanical properties which include compressive strength, flexural strength, splitting tensile strength, modulus of elasticity, ultrasonic pulse velocity, and rebound hammer test. Compressive strength test and splitting tensile strength test are done after 7-Days and 28-days of age while other tests are done at 28-days of age. Test results indicate that all strength properties were reduced, reduction of strength properties increased with increase in replacement ratios. The reduction of the strength properties was more in case of brick dust. It is seen that on 25% replacement of concrete with Fine recycled concrete aggregates it shows favorable results but if the replacement ratio is increased the strength reduction increases which can not be permitted. Reduction in strength properties of mixes incorporating fine recycled brick aggregates was more than fine recycled concrete aggregates and brick dust was not considered a suitable alternative material.

## TABLE OF CONTENTS

<b>DECLARATION</b>	<b>(i)</b>
<b>ACKNOWLEDGEMENT</b>	<b>(ii)</b>
<b>ABSTRACT</b>	<b>(iii)</b>
<b>TABLE OF CONTENTS</b>	<b>(iv)-(v)</b>
<b>LIST OF TABLES</b>	<b>(vi)</b>
<b>LIST OF FIGURES</b>	<b>(vii)</b>

<b>CHAPTER 1</b>	<b>INTRODUCTION</b>	<b>PAGE NO</b>
1.1	CONCRETE CONSUMPTION AND ITS EFFECTS ON ENVIRONMENT	1-2
1.2	FINE RECYCLED CONCRETE AGGREGATES	2-6
1.3	BRICK DUST	7-8
1.4	OBJECTIVES OF THESIS	8
1.5	ORGANISATION OF THESIS	9
<b>CHAPTER 2</b>	<b>LITERATURE REVIEW</b>	
2.1	PHYSICAL PROPERTIES	10-11
2.2	MIX COMPOSITIONS	12
2.3	WORKABILITY	13
2.4	DENSITY	13
2.5	COMPRESSIVE STRENGTH	14-15
2.6	SPLIT TENSILE STRENGTH	15
2.7	MODULES OF ELASTICITY	15
2.8	ABRASION RESISTANCE	16
2.8	ULTRASONIC PULSE VELOCITY	17
<b>CHAPTER 3</b>	<b>EXPERIMENTAL STUDIES</b>	
3.1	MATERIALS USED	18
3.1.1	Cement	18
3.1.2	Natural fine aggregates	19
3.1.3	Recycled fine concrete aggregates	20-22
3.1.4	Brick dust	22-23

3.1.5	Natural coarse aggregates	24-25
3.1.6	Water	25
3.2	CONCRETE MIX	26-27
3.3	CASTING AND CURING	27
3.4	TESTS CONDUCTED	28-36
<b>CHAPTER 4</b>	<b>RESULTS AND DISCUSSION</b>	
4.1	SLUMP TEST	37-38
4.2	COMPRESSIVE STRENGTH TEST	38-40
4.3	SPLITTING TENSILE STRENGTH TEST	40-42
4.4	FLEXURAL STRENGTH TEST	42-43
4.5	MODULUS OF ELASTICITY TEST	44-45
4.6	ULTRASONIC PULSE VELOCITY TEST	46-47
4.7	REBOUND HAMMER TEST	47-48
<b>CHAPTER 5</b>	<b>CONCLUSION</b>	<b>49</b>
	<b>REFERENCES</b>	<b>50-51</b>

## LIST OF TABLES

Table 2.1 Physical Properties .....	11
Table 2.2 Details of concrete mixes.....	12
Table 2.3- Compressive Strength of concrete specimens.....	14
Table 2.4- Split tensile strength Results.....	15
Table 2.5- Modulus of Elasticity .....	16
Table 3.1- Physical Properties of Cement.....	18
Table 3.2- Physical Properties of Fine Natural Aggregates.....	19
Table 3.3- Sieve Analysis of Fine Natural aggregates.....	19
Table 3.4- Physical Properties of Fine Recycled Concrete Aggregates.....	21
Table 3.5- Sieve Analysis Fine recycled concrete aggregates.....	22
Table 3.6- Physical properties of Brick Dust.....	23
Table 3.7- Sieve Analysis of Brick Dust.....	23
Table 3.8- Gradation of 20mm Natural Coarse aggregates.....	24
Table 3.9- Gradation of 10mm Natural Coarse aggregates.....	24
Table 3.10- Physical Properties of Natural Coarse aggregates.....	25
Table 3.11-Mixes Prepared.....	27
Table 4.1- Slump Values of all Mixes.....	37
Table 4.2- Compressive Strength Test Results.....	38
Table 4.3- Splitting Tensile Strength Test Results.....	40
Table 4.4- Flexural Strength Test Results.....	42
Table 4.5- Modulus of Elasticity Test Results.....	44
Table 4.6- Ultrasonic Velocity Test Results.....	46
Table 4.7- Rebound Hammer Test Results.....	48

## LIST OF FIGURES

Figure 1.1-General Composition of concrete .....	1
Figure 1.2- Schematic representation recycling technique .....	4
Figure_1.3- Benefits of recycling .....	5
Figure 1.4- Types of Recycled Concrete Aggregates .....	6
Figure 1.5- Jaw crusher.....	7
Figure 1.6- Number of Brick Kilns in Asian Countries .....	7
Figure 3.1- Laboratory Waste used for producing FRCA.....	20
Figure 3.2- Jaw crusher used to crush Concrete waste from Laboratory.....	20
Figure 3.3- Fine recycled Concrete Aggregates.....	21
Figure 3.4- Brick Dust.....	21
Figure 3.5- Concrete Mixing Machine.....	22
Figure 3.6- Slump Test Apparatus.....	28
Figure 3.7- Compression Testing Machine.....	30
Figure 3.8- Splitting tensile strength using CTM.....	31
Figure 3.9- Universal Testing machine.....	33
Figure 3.10- Frame Assembly For Modulus of Elasticity Test.....	34
Figure 3.11- Ultrasonic Pulse Velocity test Apparatus.....	35
Figure 3.12- Rebound Hammer Test Apparatus.....	36
Figure 4.1- Slump Values of concrete mixes.....	38
Figure 4.2- Compressive strength of FRCA.....	39
Figure 4.3- Compressive Strength of FRBA.....	39
Figure 4.4(a)- Splitting Tensile Strength of FRCA.....	41
Figure 4.4(b)- Splitting Tensile Strength of FRBA.....	41

Figure 4.5(a)- Flexural Strength of FRCA.....	43
Figure 4.5(b)- Flexural Strength of FRBA.....	43
Figure 4.6(a)- MOE of FRCA 28-Days.....	44
Figure 4.6(b)- MOE of FRBA 28-Days.....	45
Figure 4.7(a)- Ultrasonic Pulse Velocity FRCA.....	46
Figure 4.7(b)- Ultrasonic Pulse Velocity FRBA.....	47
Figure 4.8- Rebound Hammer Test.....	48

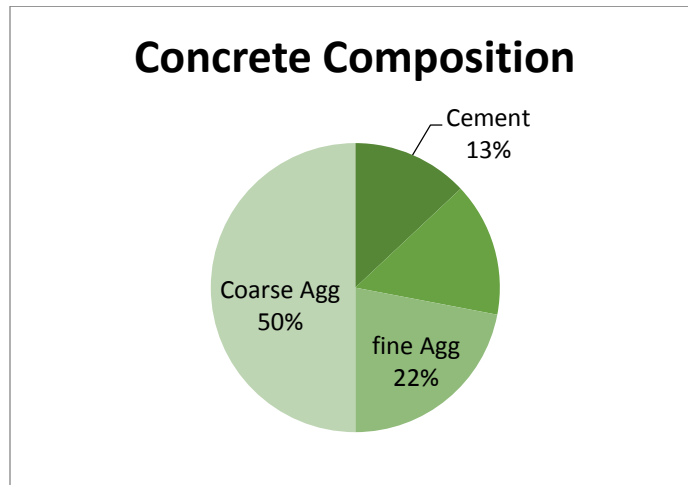
## CHAPTER-1

### INTRODUCTION

*This chapter discusses the details of concrete consumption and its effect of environment, the need for recycled materials to produce concrete, different wastes generated in the construction of buildings, use of these aggregates and introduction of the thesis.*

#### **1.1 CONCRETE CONSUMPTION AND ITS EFFECTS ON ENVIRONMENT**

Concrete is most commonly used construction material all over the world, over ten billion tonnes of concrete is produced every year. With that large amount of concrete produced concrete production plays a vital role in the economic development of the world. Concrete comprises of three major fractions- aggregates, binder and water hence is a composite material. Since 50 to 80 percent of concrete comprises of aggregates so aggregates play an important role in concrete performance and the overall consumption of natural aggregates in the production of concrete is very high.



**Fig 1.1:** General Composition of Concrete (Behra et al., 2014)

This use of a large amount of aggregates in concrete puts a lot of pressure on the ecosystem. The aggregate extractions by mining have harmful effects on the environment leading to several environmental problems such as soil erosion, retreating coastline, harming flora and fauna etc. The methods of extraction of these natural aggregates are time and cost consuming processes. Extraction by machines requires fuel and which further release obnoxious gasses which causes air pollution.

The production of fine aggregates from coarse aggregates is a high-cost process and raises difficulties concerning fresh concrete, given their high regularity. The increase in the rate of industrialization and urbanization due to the parallel growth in economy and population has made the use of concrete as the most non-sustainable material as it is consuming the maximum amount of natural resources.

Sustainability is a broad term describing meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. The issues of sustainability are of prime concerns these days as we use a large number of natural resources for producing materials such as concrete. To achieve sustainability issue in the construction area, researchers and companies are focusing on reduction, reuse, and recycling of the waste materials.

So, to take care of all these harmful effects Construction Industry requires alternate materials to fulfill the needs of construction. To facilitate this, Recycled aggregates can be used for concrete production.

## **1.2 Fine Recycled Concrete Aggregates**

### **1.2.1 Concrete Waste**

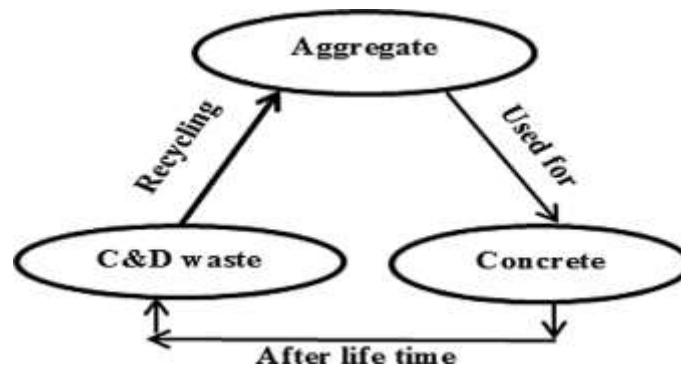
Concrete Waste can be categorized as follows:-

1. Demolition Waste- is waste debris from the destruction of a building. The debris varies from insulation, electrical wires, rebar, wood, concrete, and bricks. It also may contain lead, asbestos or different hazardous materials.
2. Concrete Leftovers-The leftovers of concrete batching plants come under this category. A large number of leftovers due to the difference in demand and supply are generated at batching plants.
3. Precast Concrete plants- Precast concrete is a construction product produced by casting concrete in a reusable mould these precast concrete are in great demand but with great demands comes greater wastage which leads to a lot of landfills.
4. Test Samples-Test samples from laboratories also generate a large amount of wastage which is left with no further utilization.

India is on the list of countries with the largest production of demolition waste. With the growing economy of India, it is expected that the demand for aggregates for construction activities will be doubled in the coming two decades. Currently, India has a severe shortage of infrastructural facilities. Nonetheless, India is constructing its foundation at a very fast rate. In this process of construction and reconstruction, it has become the second largest producer of cement in the world only after China. Though it is not even in the top ten when it comes to the production of recycled aggregate concrete. One of the main reason for it is the lack of proper source concrete in India. To meet these needs of the construction industry we need an alternative to natural aggregates with keeping in mind the sustainability issue in mind. This can be achieved by recycling Concrete Demolition waste.

### 1.2.2 RECYCLED CONCRETE AGGREGATES

Recycling is an act of processing used materials for further use in developing new value products. Recycled aggregates are the aggregates extracted through the processing of the debris generated from the demolition of concrete structures and other construction debris such as waste concrete, rejected precast concrete members, broken masonry, concrete road beds and asphalt pavement, leftover concrete from the ready-mix concrete plant and the waste generated from different laboratories. The resulting properties are different from the natural aggregates, but the newly formed aggregates can be accommodated easily to get desired mechanical properties.



**Fig. 1.2:** Schematic representation recycling technique (Behra et al. 2014)

The aggregates typically processed from concrete waste such as demolition waste, concrete leftovers from RMC plants and precast plants are Known as Recycled Concrete Aggregates.

The process extraction of Concrete recycled aggregates has three steps which are as follows:-

1. Evaluation of Source concrete-The first step in the production of RAC is to determine the quality of the source concrete. Properties and records of source concrete like strength, durability, and composition are looked into for deciding the proper source concrete.
2. Breaking of waste- The simple process involves crushing concrete into specified size and quality.
3. Removal of contaminants- Contaminants like reinforcing steel, foundation materials, asphalt concrete shoulders, soil, etc. are removed. It can be achieved by many methods including screening or air separation, demolition, using electromagnets, etc.

### 1.2.3 ADVANTAGES AND DISADVANTAGES OF RAC

Advantages of Recycled Aggregate:

1. Reduces the number of virgin aggregates to be created, hence less evacuation of natural resources.
2. While being crushed into smaller particles a large amount of carbon dioxide is absorbed. This reduces the amount of CO<sub>2</sub> in the atmosphere.
3. Cost saving – few research studies have shown a significant reduction in construction costs if RAC is used.
4. Conserves landfill space, reduces the need for new landfills and hence saving more costs.
5. Creates more employment opportunities in the recycling industry.

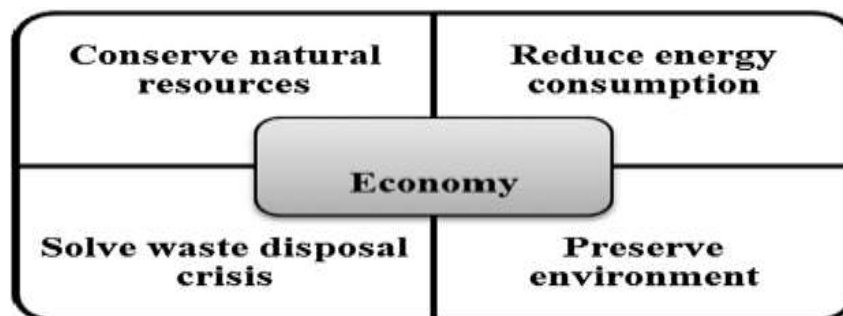


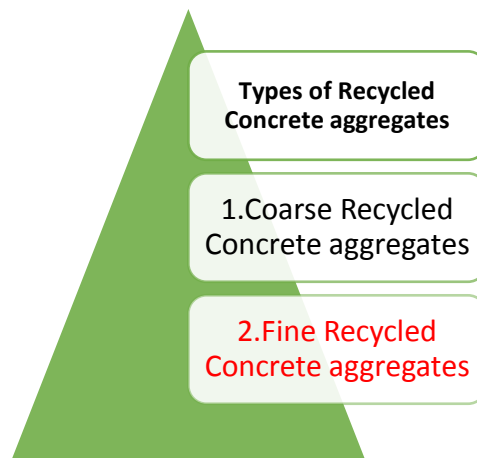
Fig 1.3: Benefits of recycling (Behra et al. 2014)

#### Disadvantages of Recycled Aggregate:

1. Downgrading the quality of concrete.
2. Increase in water absorption capacity ranging from 3% to 9%
3. Decreases in compressive strength of concrete (10-30%)
4. Reduces workability of concrete.
5. Lack of specifications and guidelines.
6. Less durability of RAC, however, few papers have shown an improvement in the durability by mixing it with special materials like fly ash

#### 1.2.4 Types of Recycled Concrete Aggregates

After screening the Concrete recycled aggregates can be divided into two types-:



**Fig 1.4:** Types of Recycled Concrete Aggregates

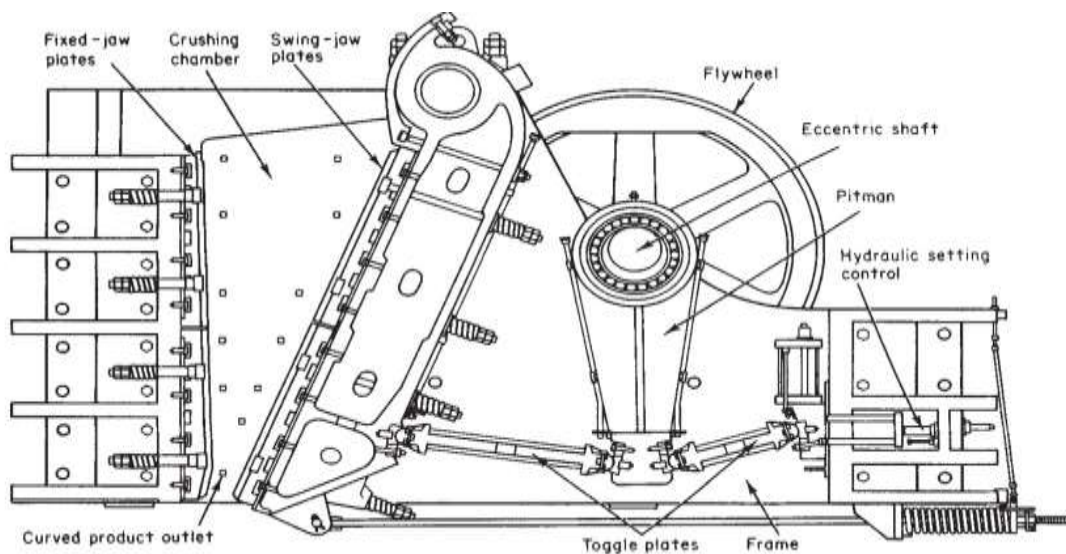
Coarse Recycled concrete Aggregates are aggregates which have the same particle size as that of natural coarse aggregates i.e.-20 to 35.5mm and are extracted from demolition and other concrete wastes.

Fine Recycled Concrete Aggregates are aggregates which have same practical size as that of natural Fine aggregates i.e.-less than 4.75mm and are extracted from demolition and other concrete wastes.

The incorporation of coarse recycled aggregates (CRA) in concrete is already accepted, although with restrictions, by the construction industry. In some countries, even full substitution is allowed in particular situations. However fine recycled aggregates (FRA) are firmly excluded from concrete and mortar production in almost all existing standards and regulations. But with recent studies, it has been proved that FRAs with acceptable features can also be used for the production process and Pre-treatments can be also be used for property improvement of Fine recycled aggregates and with recent development on the topic, it has been seen that FRA can be used with effecting the mechanical properties to a point where concrete turns out to be insufficient in terms of strength.

### 1.2.5 Processing of Demolition Debris

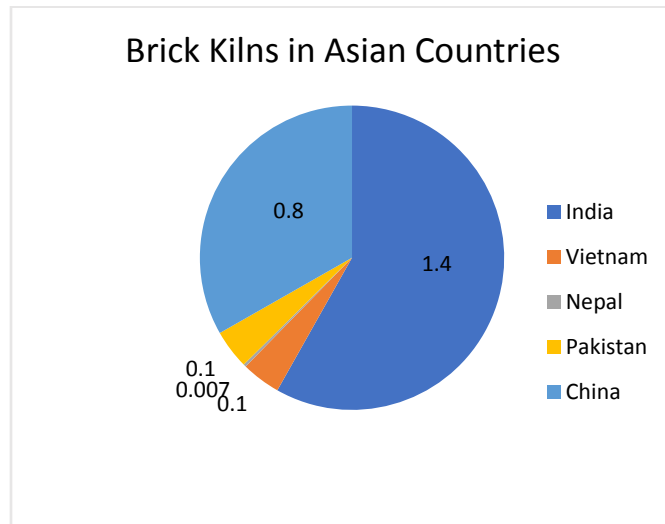
Jaw Crusher- A jaw crusher uses compressive force for breaking of the particle. This mechanical pressure is achieved by the two jaws of the crusher of which one is fixed while the other reciprocates.



**Fig 1.5:** Jaw Crusher (Sunco Machinery, 2013)

### 1.3 Brick Dust

Brick Dust is leftover part of crushed bricks which is available at Brick kilns, which is brick red in colour. Brick dust is generally used on Kacha roads in villages in Punjab region to make pavement soil-less clayey and make the movement of vehicles such as tractors, Bullock carts, and Bicycles etc. possible in rainy seasons. Brick dust is also used in playgrounds, gardens, and parks. Brick dust used in this study is taken from Jindal Brick Kiln situated near Village Kauli. Crushed Brick dust was not considered a recyclable material in many parts of the World but during the 1860s it was used as aggregates by Germany for reconstruction of the Structures after the Second World War. As concrete consumes a large amount of natural minerals every year to control this large consumption of natural aggregates we can put Brick dust to a better use by making it an alternative for these natural aggregates and conserve these natural minerals for future generation. The Number of Brickkiln in India alone are 1.4 lakh which produces around 240-260 billion Bricks every year. Data for Brick Kilns in Asian countries can be seen in Figure 1.6. With this large number of Brick kilns in Asia, the amount of Brick waste is also large which can be put to a good used by incorporation of this waste in concrete.



**Fig 1.6:** Number of Brick Kilns in Asian Countries (J.S Kamyotra, 2017)

### **1.3.1 Advantages of Brick Dust**

The use of Brick dust has following advantages-:

1. Reduces the use of Natural aggregates in concrete and helps to create a sustainable environment.
2. Reduction in cost of concrete by use of brick dust in concrete
3. Brick dust utilization will lead to a reduction in waste piles in Kilns.
4. More employment opportunities in the Recycling Industry.

### **1.3.2 Disadvantages of Brick Dust**

1. Downgrading the quality of concrete.
2. Increase in water absorption capacity ranging from 10% to 15%
3. Decreases in compressive strength of concrete (10-30%)
4. Reduces workability of concrete.

### **1.4 Objective of Thesis**

The objectives of the thesis are as follows -:

1. To study the effect of fine recycled concrete aggregates and brick dust when replaced with fine aggregates.
2. To compare the workability of concrete mixes incorporating fine recycled concrete aggregates and brick dust as partial replacement of natural fine aggregates in the concrete mix.
3. To compare the compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, ultrasonic pulse velocity of concrete incorporating fine recycled concrete aggregates and brick dust as partial replacement of natural aggregates.

## **1.5 Organization of the thesis**

- 1.** The first chapter is the introduction of the thesis and this chapter discusses the details of concrete consumption, different wastes produced in the construction of building and details of fine recycled concrete aggregates and brick dust.
- 2.** The second chapter is the literature review which discusses the existing literature on utilization of fine recycled concrete aggregates and brick dust.
- 3.** The third chapter is experimental studies and includes all the properties of materials used and procedures of tests performed.
- 4.** The fourth chapter is results and discussion which includes the test results of the concrete mixes prepared.
- 5.** The fifth chapter is the conclusion of the entire thesis.

## **CHAPTER-2**

### **LITERATURE REVIEW**

*This chapter deals with the existing literature on utilization of fine recycled concrete aggregates and brick dust as fine aggregates in new concrete and effect of this utilization on properties of concrete so formed.*

#### **2.1 General**

Fine recycled concrete aggregates and Brick dust aggregates have been used in Concrete as replacement of Fine natural aggregates. Due to the large-scale utilization of virgin aggregates, there is an urgent need of recycled aggregates to create an environment which can fulfill the needs of all present and future generations without harming the environment. Due to lack of landfills, high natural aggregates extraction cost, air pollution and forest degradation and ever-increasing dumping cost the utilization of recycled concrete and Brick dust as Recycled aggregates is an eco-friendly and sustainable alternative.

#### **2.2 Properties of Concrete Incorporating Fine Recycled concrete aggregates and Brick Dust**

Properties of concrete incorporating Fine recycled concrete aggregates and brick dust based on studies gathered from work done all over the world published by different journals are mentioned.

##### **2.2.1 Physical Properties**

**Evangelista and de Brito (2006)**- reported that the concrete used for recycling was solely made for the purpose and was of standard composition this was done so that the properties of concrete used for the entire process are known. The average compressive strength for this concrete after 28 days was 29.6 MPa. To keep the particle size of both natural aggregates and recycled aggregates the range of size chosen was 0.074mm to 1.19mm. It was also reported that density of Fine recycled aggregates was less than Natural aggregates and water absorption of fine recycled aggregates was more than that of Natural aggregates.

**Khatib (2005)**-Reported that the natural fine aggregates used belonged to Class M according to BS 882,1992 and Coarse natural aggregates were of 20 mm nominal size. Recycled aggregates contained Crushed brick and crushed concrete which were crushed in the laboratory and were recycled out of demolition waste. The particle size of these recycled aggregates was less than 5 mm in Diameter. The density of Recycled aggregates is less than the natural aggregates hence they have more water absorption. Water absorption of their aggregates was also calculated which was 6.2% for Crushed concrete and 14.8 % for crushed brick.

**Cong and Poon (2009)**-reported the properties of FRA as in table 2.3. For coarse aggregates Crushed natural granite was used by Cong and Poon and the size was 10mm and 20mm both taken in equal proportions. River sand was used as fine aggregate, it was taken from a local quarry. Fine recycled aggregates were obtained from a Concrete and demolition waste recycling plant. Fine recycled aggregates were less dense and had a greater water absorption capacity.

**P. Pereira et al. (2012)** -Total four types of natural aggregates were used out of which two were fine natural aggregated which were FNA1 and FNA2 and other two were coarse natural aggregates which were CNA1 and CNA2. All aggregates were characterized in terms of size grading particle density and water absorption. Fine recycled aggregates showed a greater water absorption than all the natural aggregates whereas in terms of density Fine recycled aggregates had the least density.

**Cheng-Chih Fan et al (2016)** - Reported the physical properties as shown in table 2.1. In the table, CAN stands for Coarse natural aggregates and FNA stands for Fine natural aggregates. R1 and R2 are two Fine recycled aggregates R1 was produced by crushing concrete waste and R2 was produced by repeated crushing until the required particle size is obtained.

**Table 2.1:** Physical Properties of the CAN, FNA, R1, and R2 (Fan et al. 2016)

SR No.	Physical Properties	CAN	FNA	R1	R2
1	Maximum Grain size (mm)	19	4.75	4.75	4.75
2	Saturated Surface dry density	2668	2653	2347	2404
3	Water absorption %	1.2	1.3	8.9	6.6
4	Fineness Modulus	6.9	2.9	3.3	3.1

Absorption- FRA has a higher water absorption rate than does FNA; therefore, a higher concentration of FRA will tend to increase the water absorption of the resulting concrete. Furthermore, the water absorption rate of R1 is higher than that of R2, which means that using

R1 in concrete results in greater water absorption than that obtained when using R2, when the two specimens shared the identical replacement ratio.

### 2.1.2 Mix compositions used

**Khatib (2005)**- Nine different mixes were made to examine the influence of incorporating fine recycled concrete aggregates and crushed brick aggregated on the properties of concrete. The control mix proportion of 1:2:4. Mixes with replacement proportion of 25%, 50%, 75% and 100% were made. Water-cement ratio for all the mixes was kept constant. Water Cement ration for all the mixes was 0.5.

**Table 2.2-** Details of concrete mix ( $\text{kg}/\text{m}^3$ )

Mix	Mix compositions used					Crushed brick	Coarse aggregate
	Mix ID	Cement	Water	Sand	Crushed concrete		
M1	Control	325	162	649	0	0	1298
M2	CC25	322	161	483	161	0	1288
M3	CC50	320	159	320	320	0	1277
M4	CC75	317	158	158	475	0	1267
M5	CC100	315	157	0	629	0	1257
M6	CB25	319	159	478	0	159	1275
M7	CB50	314	156	314	0	314	1253
M8	CB75	308	154	154	0	462	1232
M9	CB100	303	151	0	0	606	1211

**Evangelista and Brito (2006)**-mixes were designed for the common target slump of 80mm. It was expected that FRA would have more water absorption than FNA so the water-cement ratio of the mixes containing FNA was increased to keep workability constant. Five replacements were made i.e. 10%, 20%, 30%, 50% and 100%.

**Dabieb and Kenai (2007)**- Mixes were designed using Fine Recycled Crushed brick as replacement of Fine Natural Aggregates. The mix proportions used for the control mix are 1:2.14:3.19. The replacement percentages used were 0%, 25%, 50%, 75% and 100%. Water-cement ratio was chosen to keep the values of a slump between 60mm to 70mm.

**Kou and Poon (2009)** - Two series of concrete mixes were prepared. In the concrete mixes, natural river sand was replaced by FRA at replacement levels of 0%, 25%, 50%, 75% and 100% by mass, respectively, and the cement content was fixed at 386 kg/m. Cement to natural aggregates ratio used was 1:2. In Series I, the concrete mixes were designed at the fixed water-cement ratio of 0.53. In Series II, the concrete mixes were designed to have a near constant slump in the range of 60–80 mm; and as such, the free water content (and hence the water-cement ratio) varied.

**Pereira et al. (2012)** – Two types of superplasticizers were used i.e. SP1 and SP2, Five mixes with each superplasticizer were made. Out of the five mixes, one was the control mix which had no Recycled aggregate other four had 10%, 30%, 50% and 100% replacement of natural aggregates by Recycled aggregates. All the mixes have the same cement content and water content is reduced as due to use of superplasticizer and increase of aggregates.

**Fan et al. (2016)** -Two types of fine recycled aggregates (FRA: R1, R2) were produced. Fine recycled aggregate (R1) was produced simultaneously with recycled coarse aggregate production by crushing concrete waste. Fine recycled aggregate (R2) was produced by repeating the crushing process until required particle size. Two types of water-cement ratios were used i.e. 0.35 and 0.55. The mixes with water-cement ratios of 0.35 showed poor workability so superplasticizer was used. The replacement of different mixes was 25%, 50%, and 100%.

### **2.2.3 Workability**

**Khatib (2005)**-The mixes show a good workability without the use of admixture and the slump values vary from 170 mm to 190 mm for concrete containing crushed concrete and from 85 mm to 155 mm for concrete containing crushed brick.

**Pereira et al (2012)** – all mixes met the target workability apart from concrete without superplasticizer and 100% replacement of FNA by FRA. The lower slump achieved for this particular case means that the optimal water/cement ratio should be slightly higher than that used. The performance of this mix, therefore, tends to deviate from that of the other mixes.

**Fan et al. (2016)**- The specimen containing R1 presented less slump than did R2 when the two specimens shared identical replacement ratios. This can be attributed to the fact that FRA has a rougher surface texture and greater angularity, which increases the friction among the particles. Thus, as the FRA replacement ratio was increased, the higher concentration of fine aggregate in the cement paste produced more friction between the particles, thereby reducing slump in the concrete.

#### 2.2.4 Density

**Khatib (2005)**- The density of the mixes at 1, 7, 28 and 90 days of curing was calculated. There is a decrease in the density of the concrete in which natural aggregates are replaced by recycled aggregates. The value of density ranges from 2263 to 2427 kg/m<sup>3</sup>.

**Pereira et al (2012)** -The mixes with recycled aggregates showed a decrease in density with increasing the incorporation percentage of FRCA.

**Fan et al. (2016)**- The density of FRA was lower than that of FNA; therefore, increasing the ratio of FRA to FNA reduced the density of the resulting concrete mixes. Graphs show that R2 mixes have greater density this is because R1 has greater water absorption than R2.

#### 2.2.5 Compressive strength-

**Khatib (2005)** – Cubes of 100 mm size were used to determine the compressive strength of the concrete. Cube compressive strength was checked at 1, 7, 28 and 90 days. Compressive strength decreased in concrete containing Crushed concrete and crushed brick. The reduction in strength by incorporating Crushed concrete varies from 15% to 27%.

**Table 2.3:** Compressive strength of concrete (Khatib 2005)

		Compressive strength results			
Mix	Mix ID	Compressive strength (MPa)			
		1-DAY	7-DAYS	28-DAYS	90-DAYS
M1	Control	11.7	35.6	46.7	51.1
M2	CC25	9.2	25.8	35.3	43.6
M3	CC50	8.9	25.8	35.2	42.1
M4	CC75	8.6	25.5	35.1	39.9
M5	CC100	8.4	25.2	30	37.8

M6	CB25	11.2	30.4	39.2	50.9
M7	CB50	10.3	28.5	37.7	48.9
M8	CB75	9	26.6	36.1	45.4
M9	CB100	8	25.8	33.2	46.7

**Evangelista and Brito (2006)** reported Compressive strength tests were carried out on 150 mm cubes. Results of Compressive strength were for three stages, combined results for the second and third stage were represented. First stage and Second/third stage differ by mixing method. In second and third stage mixing was carried out for 10 more minutes. Compressive strength results were not affected by the ratio was 30% after the replacement ratio was increased there was a decrease in compressive strength.

**Dabieb and Kenai (2007)**- Reported that the compressive strength decreased with increase in brick aggregates in the concrete. This reduction in the compressive strength could be due to high water absorption of the brick aggregates. Substitution of fine brick aggregates should be done with caution as it could affect the compressive strength of concrete.

**Kou and Poon (2009)** –Reported when using the same W/C ratio, generally, the compressive strength of the FRA concrete decreased at all the ages with an increase in the FRA contents in both series. This may be due to the high initial free water content used in the mixes rendered bleeding and poorer interfacial bonding between the aggregates and the cement pastes.

**Pereira et al (2012)** – Reported that after 28 days curing all FRCs showed a decrease in compressive strength due to the incorporation of FRA, with figures of 4.8%, 15.4% and 3.3% for the WS, SP1 and SP2 families, respectively. These reductions are insignificant for the superplasticizer-free and SP2 concrete mixes and it can even be said that the compressive strength remains approximately constant. The addition of superplasticizer in the mixes led to compressive strength gains of up to 34.8% and 69.5% for the SP1 and SP2 families respectively. These strength gains increase with the water reducing the capacity of the superplasticizer, due to a reduction in the water/cement ratio.

**Fan et al. (2016)** - tested the compressive strength of concrete specimens at 7, 14, and 28 days and reported that there was a decline in the compressive strength of the specimens cast with an increase in replacement ratio.

### 2.2.6 Split Tensile Strength

**Evangelista and Brito (2006)**- For Split tensile strength cylinders with diameter 150mm and length 300 mm were used, these cylinders were wet cured for 31 days and were tested. The tensile strength is not as affected by the cement content as the compressive strength, so the tensile strength does not particularly benefit from the additional cement that is incorporated along with the FNA. Therefore, a decrease in split tensile strength is natural and occurs as the replacement ratio is increased, due to the more porous structure of the recycled aggregates.

**Table 2.4:** Split tensile strength Results (Evangelista and Brito, 2006)

Split Tensile Strength results		
Mix	$f_{ctm}$	% decrease
RC	3.85	
C30R	3.65	-5.2
C100 R	2.95	-30.5

**Pereira et al. (2012)**- The splitting tensile strength tests were performed on cylinders with diameter 150 mm and length 300 mm. With an exception of 30% replacement, all other FRAC has a reduction in split tensile strength with increase in replacement ratio.

### 2.2.7 Modulus of Elasticity

**Evangelista and Brito (2006)**-The modulus of elasticity of concrete is dependent upon the stiffness of coarse aggregates, the porosity of bond and stiffness of mortar. It is possible that for small replacement of aggregates the overall stiffness is influenced. There was a slight reduction in the modulus of elasticity for concrete with 30% replacement ratio and for 100% replacement the reduction in Modulus of elasticity was very high.

**Table 2.5:** Modulus of Elasticity (Evangelista and Brito, 2006)

Modulus of elasticity		
Mix	E (GPa)	Reduction %
RC	35.5	
C30R	34.2	-3.7
C100 R	28.9	-18.5

**Dabieb and Kenai (2007)**- The modulus of elasticity varies in the same way as the compressive strength and decreases with the percentage of substitution of crushed brick aggregates. A reduction up to 30%, 40% and 50% of the modulus of elasticity was observed for coarse, fine and both fine and coarse crushed bricks concrete, respectively, as compared to natural aggregates concrete.

**Pereira et al (2012)** - The mixes with superplasticizers showed a significant increase in the modulus of elasticity value. The concrete mix having FRAC showed an improvement of 20.7% for Superplasticizer 1 and 33.0% for Superplasticizer 2. On the other hand, the mixes prepared without the use of superplasticizer showed a reduction in the modulus of elasticity value.

### **2.2.8 Abrasion Resistance**

**Evangelista and Brito (2006)**- Reported that the mixes prepared with FRCA had greater abrasion resistance than the mixes prepared with FNA. That may be due to the bond of cement paste with the aggregates which is better when recycled aggregates are used.

**Pereira et al. (2012)** – Reported that the test results showed the unfavorable influence of FRCA on the abrasion resistance of Concrete. The addition of superplasticizers led to increases in abrasion resistance of up to 23.7% and 33.2% for mixes with SP 1 and with SP 2. These results contradict those of Evangelista and de Brito who found wear resistance gains in mixes with 100% FRA.

**2.2.9 Ultrasonic Pulse Velocity**- Higher velocities indicate good quality and continuity of the material, while slower velocities may indicate concrete with many cracks or voids.

**Khatib (2005)**- Reported an increase in Ultrasonic Pulse velocity between 1 and 7 days of curing for every concrete. The increase in Ultrasonic pulse velocity slowed down between 7 and 90 days of curing. Concretes containing Crushed concrete and crushed brick shows a reduction in Ultrasonic pulse velocity at all curing ages.

**Fan et al. (2016)** -The UPV declines with an increase in replacement ratio. With  $W/C = 0.35$  and a replacement ratio of 25% and 100%, concrete produced using R1 lost 3.87% and 12.16% of its UPV, respectively. Concrete produced using R2 had higher UPV than did specimens using R1 when the two specimens shared the identical replacement ratio. As indicated by Fan et al. [17], R1 and R2 are more porous than FNA; therefore, higher concentrations of R1 or R2 increase the porosity of concrete, which in turn reduce UPV. Furthermore, R1 is more porous than R2; therefore, using R1 in the production of concrete results in lower UPV than that obtained when using R2.

## CHAPTER-3

### Experimental Studies

*This Chapter includes all the properties of the materials used, the procedure to obtain these materials and details of the tests performed on the mixes prepared.*

#### **3.1 Materials Used**

The materials used in this research are Cement, Natural Fine aggregates, Natural Coarse aggregates, Fine Recycled concrete aggregates and Brick Dust.

##### **3.1.1 Cement**

Cement is a binder material which is used for its adhesion property in concrete production. Ordinary Portland cement of Grade 43 manufactured by Ambuja Cement Ltd. has been used in all the mixes prepared. The Properties of the cement has been mentioned in table 3.1.

**Table 3.1: Physical Properties of cement**

Physical Properties of Cement			
Sr no.	Properties	Experimentally	As Per IS 1489 1991
1	Standard Consistency	34	
2	Fineness of Cement as retained on 90 sieves in %	0.5	Minimum-0.1
3	Setting Time (in minutes)		
	Initial Setting Time	130	Minimum-30 mins
	Final Setting Time	460	Maximum-600 mins
4	Specific Gravity	3.08	

### 3.1.2 Fine Aggregates

Three types of fine aggregates were used in the entire process, all three are mentioned below:-

1. Fine Natural Aggregates.
2. Fine Recycled Concrete Aggregates.
3. Brick Dust /Kiln Dust.

Fine natural aggregated used were available in the lab and were from a nearby crusher plant. The Physical Properties of these Natural aggregates are as given in table 3.2.

**Table 3.2: Physical Properties of Fine Natural Aggregates**

Physical Properties of Natural Fine Aggregates		
Sr no.	Properties	Experimentally
1	Specific Gravity	2.67
2	Bulk Density Loose (kg/ltr)	0.5
3	Fineness modulus	2.65
4	Water Absorption	1.80%
5	Grading Zone (Based on % passing 0.6mm)	2

Fine natural aggregates were sieved with a set of sieves for sieve analysis and determination of fineness modulus results of which can be seen in table 3.3.

**Table 3.3: Sieve Analysis of Fine natural Aggregates.**

Sieve Analysis Fine Natural Aggregates							
Sieves	Weight Retained(g)			Mean(g)	% Wt. Retained	Cumulative % retained	% Passing
	1	2	3				
4.75	37.5	42	46.5	42	4.24	4.24	95.76
2.36	162	170	151	161	16.26	20.5	79.5
1.18	243	241.5	229	237.83	24.03	44.53	55.47
600	165	155	161	160.34	16.2	60.73	39.27

300	320	307	305	310.67	31.38	92.11	7.89
150	60	73	92.5	75.17	7.6	99.71	0.29
Pan	2.5	1.5	4.5	2.84	0.29	100	
				989.85		<b>321.82</b>	
				Fineness Modulus		3.2182	

### 3.1.3 Fine Recycled Concrete Aggregates

These are the aggregates which are recycled from used concrete. There can be different sources for these aggregates such as – building demolition waste, batching plant waste, precast concrete waste and laboratory waste etc. The source used extract Fine recycled concrete aggregates here is laboratory waste which is available in abundance and is recycled to make concrete. Figure 3.1 shows the laboratory waste used.



**Fig 3.1:** Laboratory waste used for producing FRCA



**Fig 3.2:** Jaw Crusher used to crush concrete waste from the laboratory.

Fine recycled concrete aggregates were produced using a Jaw Crusher. Figure 3.2 shows the jaw crusher used in the lab for producing Fine recycled concrete aggregates. The aggregates crushed by jaw crusher were further sieved. First, the aggregates crushed were sieved by 10 mm sieve all the aggregates which were retained were discarded and were thrown away, after sieving it with 10mm sieve the aggregates were passed through 4.75 mm sieve and were retained on 150  $\mu$ m sieve and these aggregates were used as Fine recycled concrete aggregates. Fig 27 shows a picture of these aggregates. Table 3.4 shows the physical properties of Fine recycled concrete aggregates and Table 3.5 shows Sieve analysis of FRCA.



**Fig 3.3:** Fine Recycled Concrete Aggregates

**Table 3.4:** Physical Properties of Fine Recycled Concrete Aggregates

Physical Properties of Fine Recycled Concrete Aggregates		
Sr no.	Properties	Experimentally
1	Specific Gravity	2.67
2	Fineness modulus	3.65
3	Water Absorption	7.06

**Table 3.5:** Sieve Analysis of FRCA

Sieve analysis Fine Recycled concrete aggregates							
Sieves	Weight Retained (g)			Mean (g)	% Wt. Retained	Cumulative % retained	% Passing
	1	2	3				
4.75	28.5	25.5	27.5	27.17	2.717	2.717	97.283
2.36	282.5	260	277	273.17	27.317	30.034	69.966
1.18	316	320	311.5	315.83	31.583	61.617	38.383
600	160	152.5	143.5	152	15.2	76.817	23.183
300	167	187.5	177.5	177.33	17.733	94.55	5.45

150	41	48.5	55.5	48.33	4.833	99.383	0.617
Pan	5	6	7.5	6.17	0.617	100	
				1000		<b>365.118</b>	
				Fineness Modulus		3.65118	

### 3.1.4 Brick Dust

Brick dust locally called as Keri was taken from Jindal Brick Kiln situated near Village Kauli. This Brick Kiln Dust is usually used for unpaved roads in villages. It's is rusty red in colour. Figure 3.4 shows Brick Kiln Dust. Same Procedure to sieve Brick dust was used as it was used for Fine recycled concrete aggregates. The Brick Kiln dust passing through 4.75 mm sieve and retained on the 150µm sieve was used in the concrete mixes prepared.



**Fig 3.4:** Brick Dust

The Physical Properties of brick dust can be seen in Table 3.6 and sieve analysis can be seen in Table 3.7.

**Table 3.6:** Physical properties of Brick Dust

Physical Properties of Brick Dust		
Sr no.	Properties	Experimentally
1	Specific Gravity	1.94
2	Fineness modulus	2.67
3	Water Absorption	15.13

**Table 3.7:** Sieve Analysis of Brick Kiln Dust

Sieve analysis Brick Dust							
Sieve s	Weight Retained(g)			Mean(g )	% Wt. Retained	Cumulative % Retained	% Passing
	1	2	3				
4.75	156.5	145.5	154	152	15.2	15.2	97.8
2.36	65.5	72	75.5	71	7.1	22.3	77.7
1.18	153	167.5	155	158.5	15.85	38.15	61.85
600	117	124	120	120.5	12.05	50.2	49.8
300	68	77.5	69.5	71.67	7.17	57.37	42.63
150	277.5	266	266	266.67	26.67	84.04	15.96
Pan	162.5	159	159	159.66	15.96	100	
				1000		<b>267.26</b>	
				Fineness Modulus		2.6726	

### 3.1.5 Natural Coarse Aggregates

Locally available crushed stone having a size in the range of 10mm to 20 mm is generally used as coarse aggregate. Coarse aggregates in the lab were available in two sizes i.e. is 10 mm and 20 mm so for concrete a mix of both sizes were used. In which 60% was 20 mm and 40 % was 10 mm. Physical Properties of Natural Coarse aggregates are shown in Table 3.10.

Coarse aggregates were sieved before they were used in the mix to ensure the size of aggregates used. Table 3.8 and Table 3.9 shows the gradation of 20mm and 10 mm Coarse aggregates.

**Table 3.8:** Gradation of 20 mm Natural Coarse Aggregates

Gradation of 20 mm Coarse Aggregates				
Sieve Size	Weight Retained(g)	% Weight Retained	Cumulative % Weight Retained	% Passing
40 mm	0	0	0	100
20 mm	42	0.42	0.42	99.58
10 mm	7156	71.56	71.98	28.02
4.75 mm	2355	23.55	95.53	4.47
Pan	444	4.44		
Total			167.93	

$$\text{Fineness Modulus} = (167.93+500) / 100 = \mathbf{6.67}$$

**Table 3.9:** Gradation of 10 mm Natural Coarse Aggregates

Gradation of 10 mm Coarse Aggregates				
Sieve Size	Weight Retained(g)	% Weight Retained	Cumulative % Weight Retained	% Passing
40 mm	0	0	0	100
20 mm	0	0	0	100
10 mm	897	8.97	8.97	91.03
4.75 mm	8202	82.02	90.99	9.01
Pan	900	9		
Total			99.96	

$$\text{Fineness Modulus} = (99.96+500) / 100 = \mathbf{5.99}$$

Sr. No.	Property	20 mm	10 mm
---------	----------	-------	-------

1	Specific Gravity	2.6	2.6
2	Water Absorption	2.86	1.47
3	Fineness Modulus	6.67	5.99

**Table 3.10:** Physical Properties of Natural Coarse Aggregates.

**3.1.6 Water** – Water is an important ingredient in concrete the quality and quantity of water in the mix should be precisely taken care of. In the present investigation, Tap water is used for the preparation of mix.

### **3.2 Concrete Mix**

Concrete Mix was designed using IS 10262:2009 (Code of Practice for Mix design of Concrete), Several trials were made to design a base mix of M25 concrete. After the desired strength was attained Mix design was used to make 5 Concrete mixes which are mentioned in Table 3.11. For each mix, the water-cement ratio was kept constant to 0.55. Out of the five mixes made there was the replacement of Natural Fine Aggregates with Fine Recycled concrete Aggregates and Brick Dust. The replacement percentage of Natural Fine aggregates by both materials was 25% and 50%. The Mix made by replacement of natural fine aggregates by Fine recycled aggregates had the same colour as of the control mix and the mix prepared by replacement of Fine Natural aggregates by Brick dust had a Rusty Brown colour. Mixing of materials was done using a concrete mixing machine which is shown in fig 3.5. The machine was thoroughly cleaned by chipping dry concrete from the drum. After the dry concrete was chipped out it was cleaned by rotating water in the drum for a few minutes and later drying it for some time. The quantity of Concrete mix was calculated according to the no of specimens to be cast.



**Fig 3.5:** Concrete Mixing Machine.

**Table 3.11:** Mixes Prepared

Mix	Cement Kg/m <sup>3</sup>	Coarse Aggregate (20mm) Kg/m <sup>3</sup>	Coarse aggregate (10mm) Kg/m <sup>3</sup>	Fine Aggregate Kg/m <sup>3</sup>	FRCA Kg/m <sup>3</sup>	FRBA Kg/m <sup>3</sup>	Water Kg/m <sup>3</sup>	Water Cement Ratio
Control	360	640	427	698	0	0	199	0.55
FRCA 25	360	640	427	522.5	174.5	0	199	0.55
FRCA 50	360	640	427	349	349	0	199	0.55
FRBA 25	360	640	427	522.5	0	174.5	199	0.55
FRBA 50	360	640	427	349	0	349	199	0.55

### 3.3 Specimen Casting and Curing

- Before the casting of specimens, all the moulds were cleaned, oiled and tightened properly.
- Tightening of the moulds was done precisely so as the dimensions of the specimens cast are accurate and there are no spaces for the leakage of the slurry.

- Mixing was done for 10-12 mins till the mix had a uniform texture. For each mix 6 cubes of 150 mm, 6 cylinders of 100 mm diameter and 200 mm depth, 3 cylinders of 150 mm diameter and 300 mm depth and 3 Beams of 700mm x 150mm x150 mm were cast.
- Concrete Specimens were taken out of the moulds after 24 Hours of casting. Specimens were cured for 7 days and 28 days in water curing tanks according to the testing procedures.

### **3.4 Tests Conducted**

#### **3.4.1 Test for Properties of Fresh Concrete – Slump Test**

##### **Workability Test**

Slump test is used for the determination of the consistency of fresh concrete. The slump is a measure of the sinking of unsupported fresh concrete due to its flow to the sides.

IS1199:1959 is used for slump test procedures and determination of slump values.

##### **Procedure**

- Firstly, the cone into which concrete is to be poured is cleaned and oiled.
- After oiling the mix prepared is poured in the cone in 4 layers each being one-fourth of the cone, after pouring each layer is tamped 25 times with a tamping rod.
- After filling the concrete in cone strike off the extra concrete over the top with tamping rod.

- Remove the cone slowly in the vertical direction and measure the settlement of the concrete using tamping rod and scale.



**Fig 3.6:** Slump Test Apparatus

### 3.4.2 Tests for Mechanical Properties of Concrete

#### **Compressive Strength**

Compressive Strength of Concrete is determined using cube specimen of 150 mm. The compressive strength of the concrete is determined at 7-days and 28-days of curing. The code used for compressive strength test procedures is IS 516:1959.

#### **Procedure**

- For each Mix 6 cubes are cast out of which 3 cubes are tested after 7-days of curing and other 3 are tested after 28-days of curing.
- Cubes to be tested are taken out of the water tank and are kept in open for at least 4 hours.
- After the cubes are dried for 4- hours they are cleaned with cloth so that there is no water on the surface.

- For testing, a Compression Testing Machine is used. CTM used is of 5000 KN capacity and is manufactured by Aimil Ltd.
- CTM is set on the pace of 5KN per second and dimensions of the cubes to be tested are entered.
- Cube is placed on the machine and load is applied, the machine automatically stops loading once peak load is reached. CTM can be seen in Figure 3.7.
- Average of Peak load of 3 Cubes is taken and results are compiled.



**Fig 3.7:** Compression Testing Machine

### **Splitting Tensile Strength**

Splitting Tensile Strength of Concrete is its ability to resist force which tends to pull it apart. The Code used for Splitting Tensile Strength calculation procedures is IS 5816:1999. CTM machine was used for Load application shown in fig 32. Splitting Tensile Strength test was done using cylinders of 100mm diameter and 200mm length. Splitting Tensile Strength was tested at 7-Days and 28-Days.

### Procedure

- For each Mix, 6 cylinders are cast out of which 3 cylinders are tested after 7-days of curing and other 3 are tested after 28-days of curing.
- Cylinders to be tested are taken out of the water tank and are kept in open for at least 4 hours.
- After the cylinders are dried for 4- hours they are cleaned with cloth so that there is no water on the surface.
- For testing, a Compression Testing Machine is used. CTM used is of 5000 KN capacity and is manufactured by Aimil Ltd.
- CTM is set on the pace of 1KN per second and dimensions of the cubes to be tested are entered.
- The cylinder is placed on the machine and load is applied, the machine automatically stops loading once peak load is reached. CTM is shown in Figure 3.8.
- Peak load data of 3 cylinders is noted for further calculations.
- Calculation of Splitting tensile strength of cylinder is done using the formula in IS5816:1999 -:

$$f_{st} = \frac{2P}{\pi ld}$$

$f_{st}$ = Splitting tensile strength,  $P$ =Peak load,  $l$ =length of cylinder and  $d$ =Diameter of cylinder.



**Fig 3.8:** Splitting Tensile Strength using CTM

### **Flexural Strength**

The Specimens used for Modulus of Rupture Test were beams of Dimension 700x150x150. Specimens of age 28-Days were tested for Modulus of Rupture test.

### **Procedure**

- For each mix, 3 beams are cast and are tested after 28-days of curing.
- Testing of beams is done using Universal Testing machine of make Hung Ta. The universal testing machine is shown in figure 3.8.
- Beams are taken out of curing tank 8 hours before testing is to be done. Beams are wiped with a cloth to make sure there is no surface water.

- Lines are drawn on 50mm, 250mm, 450mm and 650mm on one face of each beam. 50mm and 650mm are marked for supports under the beam and 250mm and 450mm are marked as loads application points on the top face.
- The beam is placed on 2 Point load assembly as shown in Figure 3.8 Dimensions of the beam are added to the software and software is set to two-point load test setting.
- The load is applied on the beam and peak load value is noted. This peak load value is used to calculate the modulus of rupture by formulas given in IS 516:1999.

Formula Used-  $f_b = \frac{PL}{bd^2}$  ,when  $a > 20$  cm

$$f_b = \frac{3Pa}{bd^2} , \text{ when } a < 20 \text{ cm}$$

P- Peak load, L-Length of Specimen, b-width of the specimen, d- depth of specimen and a- distance between the line of fracture and nearer support.



**Figure 3.9:** Universal Testing Machine

**Modulus of Elasticity**

The Specimens used for Modulus of Elasticity were cylinders of diameter 150 mm and length 300 mm and age of specimens is 28-days. Modulus of Elasticity tests was performed using CTM make Aimil Ltd.

### **Procedure**

- For each mix, three cylinders were used for calculating the modulus of elasticity.
- Cylinders are taken out of the curing tank and are dried for 4 hours before testing. Cylinders are cleaned with a cloth if there is any surface water on the cylinder.
- Three frames assembly is attached to the cylinder, frame assembly has a digital dial gauge and an LVDT which measure lateral and axial compression in mm. Frame assemblies can be seen in figure 3.10. Digital Dial gauge and LVDT are connected to a desktop which has software to calculate Modulus of elasticity.
- After attaching the frame assemble the cylinder is placed on CTM, using software dimensions of the cylinder are added and the load is applied.
- The software gives the force and compression data which is used to evaluate Modulus of elasticity.



**Fig 3.10:** Frame Assembly for Modulus of Elasticity test.

### **Ultrasonic Pulse Velocity**

Ultrasonic pulse velocity is a non-destructive test and is done to check the quality of concrete. Ultrasonic pulse velocity test is performed on cubes used for 28-days compressive strength. Ultrasonic Pulse velocity tells about the voids in the concrete.

### **Procedure**

- Ultrasonic Pulse Velocity apparatus consists of two transducers one being a transmitter and other the receiver, set of wires and Ultrasonic Device. Components of Ultrasonic device can be seen in Figure 3.11.
- The ultrasonic gel is applied on the transducers and both transducers are placed at the two ends of the cube. The dimension of the cube is entered so as the machine knows the distance between the transducers.
- Transmission of Ultrasonic pulse is done by hitting Run button on the device.
- Ultrasonic Pulse device calculates Velocity using the distance between the transducers and time taken for the pulse to travel this distance.
- Ultrasonic Pulse velocity is calculated for 3 cubes of the same mix and their average is taken as the Ultrasonic Pulse velocity of concrete.



**Fig 3.11:** Ultrasonic Pulse Velocity Test Apparatus

### **Rebound Hammer Test**

Rebound Hammer test is done using Schmidt Rebound hammer. It works on the principle that Rebound of an elastic mass depends upon the hardness of the surface. This test helps to compare the results of Compressive strength using CTM and Rebound Hammer.

### **Procedure**

- Rebound Hamer is a Non-Destructive test, this test is done on cubes which are used for 28-days compressive strength testing.
- Cubes are placed on CTM and a load of about 20KN is applied so that CTM holds the cube when rebound hammer impinges on the surface.
- Rebound Hammer impinges on five points on each cube. These points are shown in Figure 3.12.
- After the Impingement, the Rebound Hammer device gives the compressive strength of the concrete specimen.



**Fig 3.12:** Rebound Hammer test apparatus

## **CHAPTER-4**

## RESULTS AND DISCUSSION

*This Chapter includes fresh and hardened properties of different concrete mixes prepared and All the test results are discussed in this chapter.*

### **Tests Conducted**

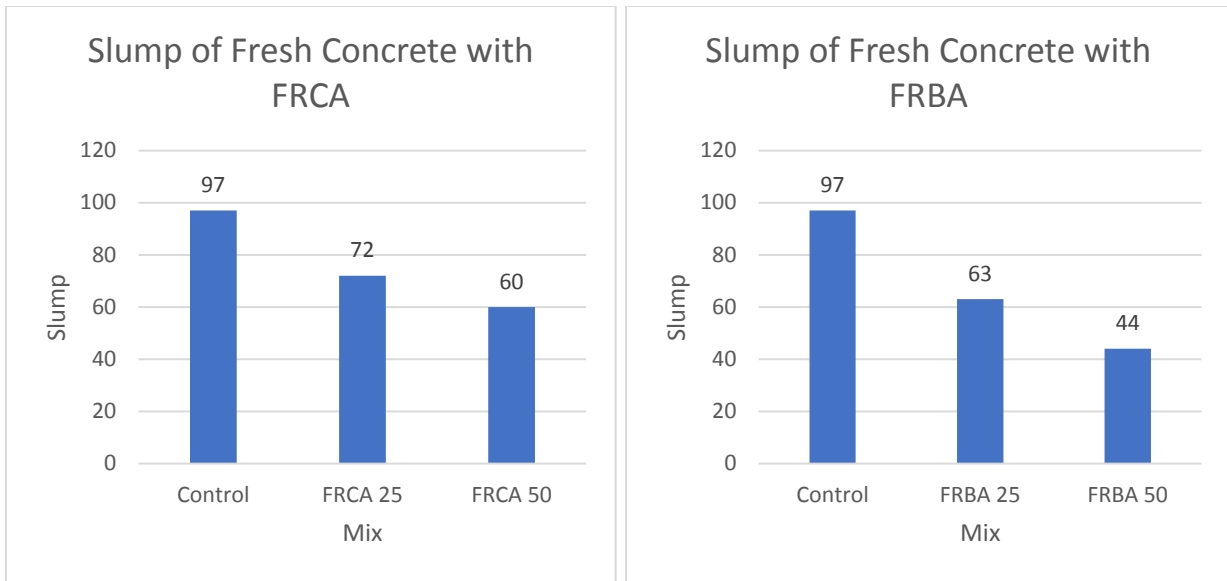
1. Test for Fresh Concrete
  - Slump Test
2. Test for Hardened Concrete Properties
  - Compressive Strength Test
  - Tensile Strength Test
  - Flexural Strength Test
  - Modulus of Elasticity Test
  - Ultrasonic Pulse Velocity
  - Rebound Hammer test

### **4.1 Workability**

Slump value of all the mixes are shown in table 4.1 and represented using charts as shown in Fig 4.1(a) and 4.1(b).

**Table 4.1(a):** Slump values of all the mixes

Mix	Slump Value (mm)
Control	97
FRCA 25	72
FRCA 50	60
FRBA 25	63
FRBA 50	44



**Fig 4.1:** Slump Value of concrete mixes

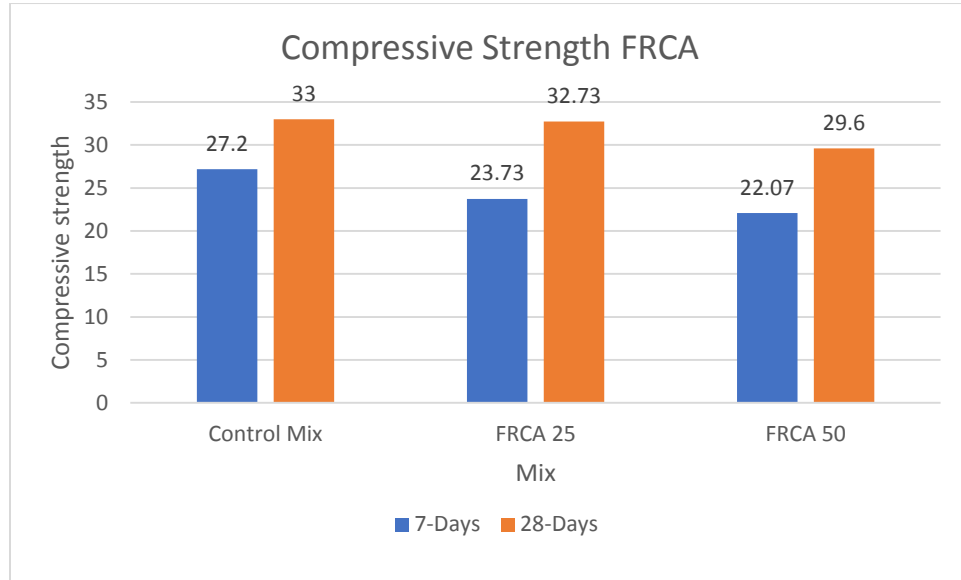
Slump Value of the Control mix is 97mm which is desired value as per mix design. Slump Value of concrete mix with replacement by FRCA and FRBA decreases as FRCA and FRBA have greater water absorption than Natural Aggregates. The water absorption is most in FRBA, so it has the least value in 50% replacement.

#### 4.2 Compressive Strength

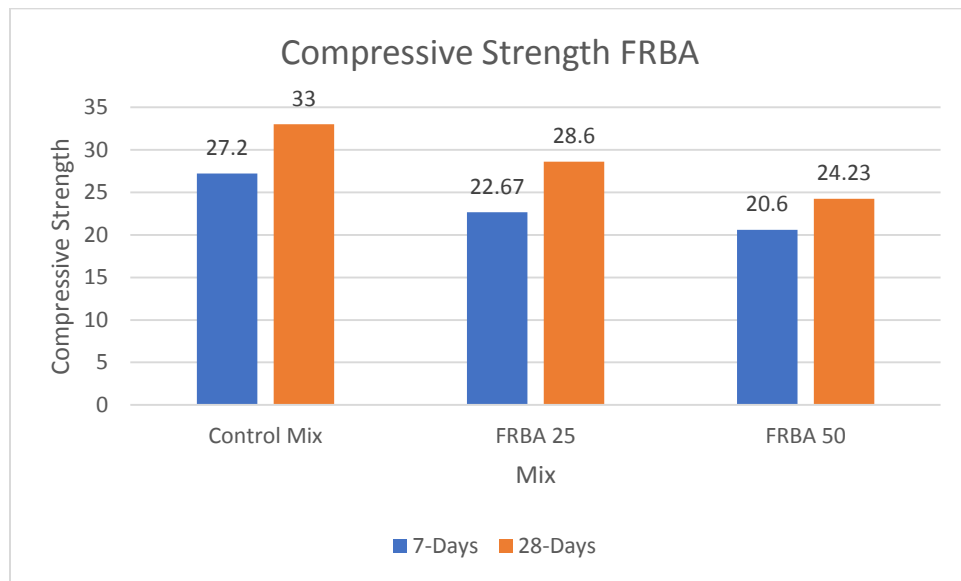
Compressive Strength results are shown in Table 4.2, Figure 4.2 and Figure 4.3.

**Table 4.2:** Compressive Strength test results

MIX	COMPRESSIVE STRENGTH		Average Compressive Strength (N/mm <sup>2</sup> )	
	7 days	28 days	7 days	28 days
Control Mix	27 27.2 27.4	34.6 34.2 30.2	27.2	33
FRCA 25	22.2 24.6 24.4	29.8 37 31.4	23.73	32.73
FRCA 50	20.8 25 20.4	30.4 28.6 29.8	22.06	29.6
FRBA 25	22.8 23 22.2	35 22.4 28.4	22.67	28.6
FRBA 50	16 23 22.8	24.4 23 25	20.6	24.13



**Fig 4.2:** Compressive strength FRCA



**Fig 4.3:** Compressive Strength FRBA

The 28-days compressive strength of concrete mix with 25% replacement of Natural Fine aggregate by Fine recycled concrete aggregates decreases by 0.81% which is a very small value whereas with 50% replacement compressive strength decreases 10.3%. The 7-days compressive strength of concrete mix with 25% replacement of Natural Fine aggregate by Fine recycled concrete aggregates decreases by 12.75% which is a very small value whereas with 50% replacement compressive strength decreases 18.88%.

The 28-days compressive strength of the concrete mix with 25% replacement of Natural Fine aggregate by Fine Recycled Brick dust decreases by 13.33% whereas with 50% replacement compressive strength decreases 26.88%. The 7-days compressive strength of the concrete mix

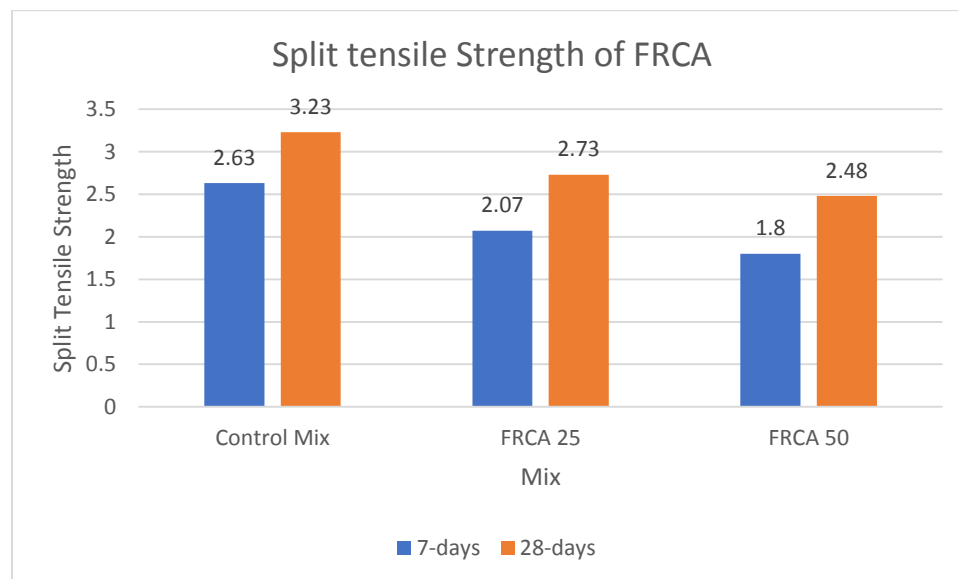
with 25% replacement of Natural Fine aggregate by Fine recycled Brick Dust decreases by 16.65% whereas with 24.46% replacement compressive strength decreases 10.3%.

### 4.3 Splitting Tensile Strength

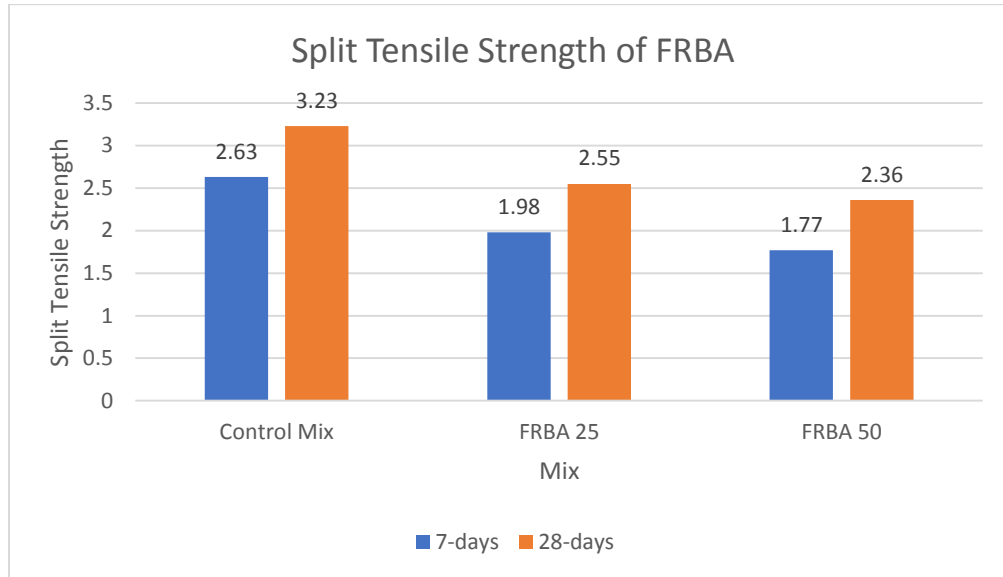
Results of Splitting Tensile Strength can be seen in table 4.3 and Fig 4.4 (a) and 4.4 (b).

**Table 4.3:** Splitting Tensile Strength Test results

MIX	7-Days		28-Days		Average Tensile Strength	
	Peak Load (KN)	Tensile Strength	Peak Load (KN)	Tensile Strength	7 days	28 days
Control Mix	86	2.74	122.8	3.9	2.63	3.23
	73.2	2.33	81	2.57		
	89.4	2.84	102	3.24		
FRCA 25	61.4	1.95	98	3.12	2.07	2.73
	74.2	2.36	73.2	2.33		
	59.2	1.88	86	2.74		
FRCA 50	51.8	1.65	94.2	2.99	1.83	2.48
	63.4	2.01	78	2.48		
	54.6	1.74	61.8	1.97		
FRBA 25	74.2	2.36	65	2.07	1.98	2.55
	50	1.59	89.2	2.84		
	61.8	1.97	86	2.74		
FRBA 50	67.6	2.15	85.4	2.72	1.77	2.36
	49	1.59	70.8	2.25		
	49	1.59	66.2	2.11		



**Fig 4.4 (a):** Splitting tensile strength FRCA



**Fig 4.4 (b):** Splitting tensile strength FRBA

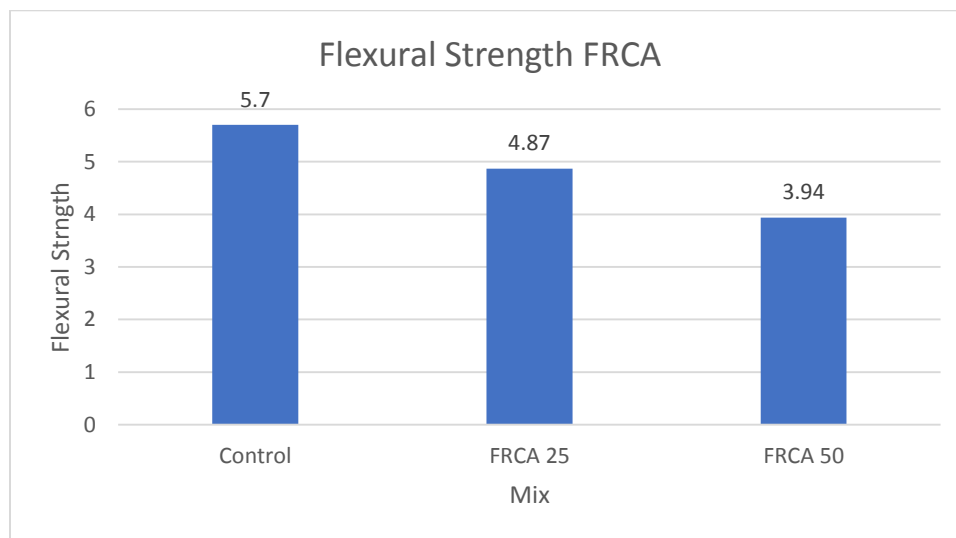
The 28-days Splitting tensile strength of the concrete mix with 25% replacement of natural fine aggregate by Fine recycled concrete aggregates decreases by 15.47% whereas with 50% replacement compressive strength decreases 23.22%. The 7-days Splitting tensile strength of the concrete mix with 25% replacement of natural fine aggregate by Fine recycled concrete aggregates decreases by 21.29% whereas with 50% replacement splitting tensile strength decreases 30.41%. The 28-days Splitting tensile strength of the concrete mix with 25% replacement of Natural Fine aggregate by Fine recycled Brick Dust decreases by 24.71% whereas with 50% replacement compressive strength decreases 32.69%. The 7-days Splitting tensile strength of the concrete mix with 25% replacement of Natural Fine aggregate by Fine recycled Brick Dust decreases by 21.05% whereas with 50% replacement Splitting tensile strength decreases 26.93%.

#### 4.4 Flexural Strength Test

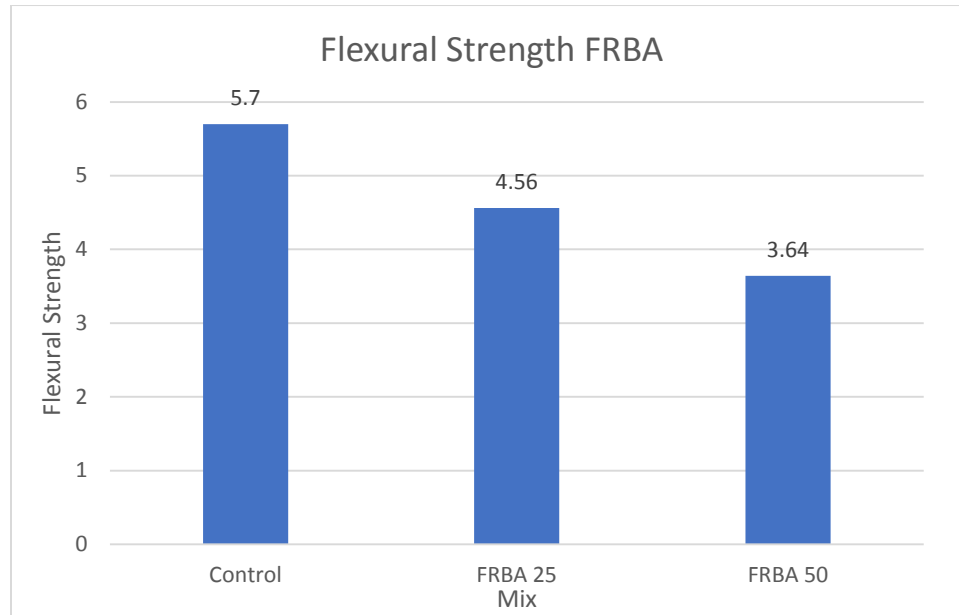
Flexural Strength test results are shown in table 4.4 and Figure 4.5(a) and 4.5(b).

Flexural Strength 28-Days			
Mix	Peak Load	Modulus of Rupture	Average Flexural Strength
Control	28.77	5.96	5.7
	26.42	5.47	
	27.34	5.67	
FRCA 25	24.45	5.07	4.87
	22.67	4.72	
	23.24	4.82	
FRCA 50	20.73	4.3	3.94
	14.54	3.01	
	21.78	4.51	
FRBA 25	21.91	4.54	4.56
	21.34	4.42	
	22.67	4.72	
FRBA 50	18.35	4.24	3.64
	16.73	3.47	
	15.56	3.23	

**Table 4.4:** Flexural Strength test results



**Fig 4.5 (a):** Flexural Strength of FRCA



**Fig 4.5(b): Flexural Strength of FRBA.**

Flexural Strength at 28-days of concrete with 25% of fine recycled concrete aggregates decreases by 14.46% whereas for 50% replacement flexural strength decreases by 30.87%. Flexural Strength at 28-days of concrete with 25% of Fine recycled Brick Dust decreases by 20% whereas for 50% replacement flexural strength decreases by 36.14%.

#### 4.5 Modulus of Elasticity

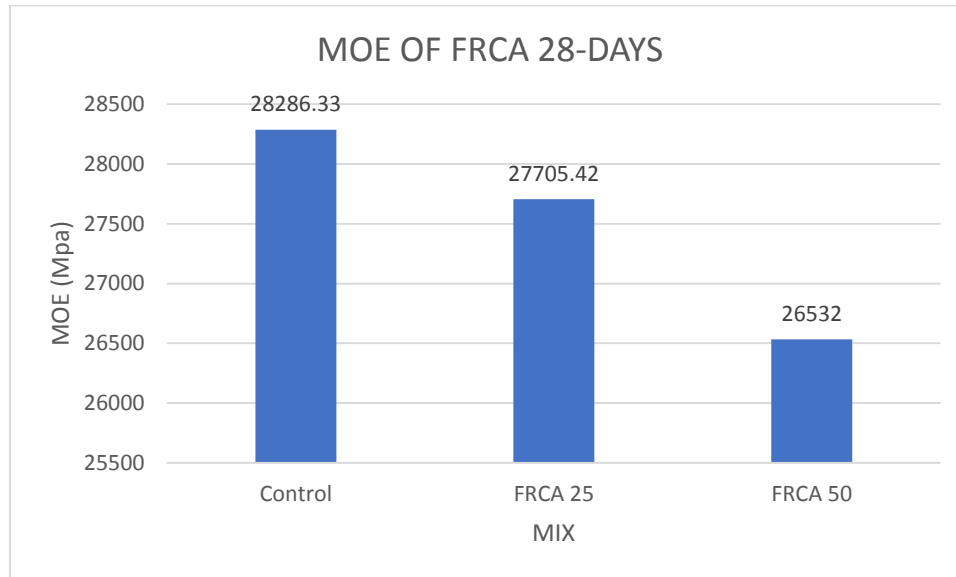
Results of the Modulus of Elasticity test are shown in Table 4.5 and Figure 4.6(a) and figure 4.6(b).

**Table 4.5: Modulus of Elasticity test Results**

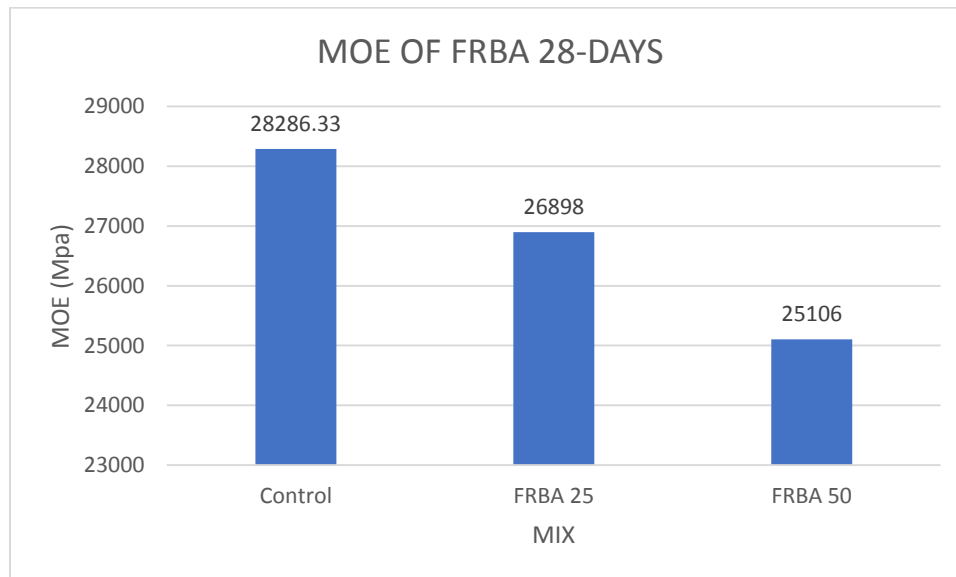
28-Day Modulus of Elasticity		
Mix	MOE (Mpa)	Average MOE (Mpa)
Control	28973	28286.33
	29112	
	26774	
FRCA 25	28369	27705.42
	27650	
	27097	
FRCA 50	26445	26532
	27146	
	26006	
FRBA 25	26576	26898
	27366	
	26752	
FRBA 50	24886	

24690  
25743

25106



**Fig 4.6(a):** MOE of FRCA 28-days



**Fig 4.6(b):** MOE of FRBA 28-days

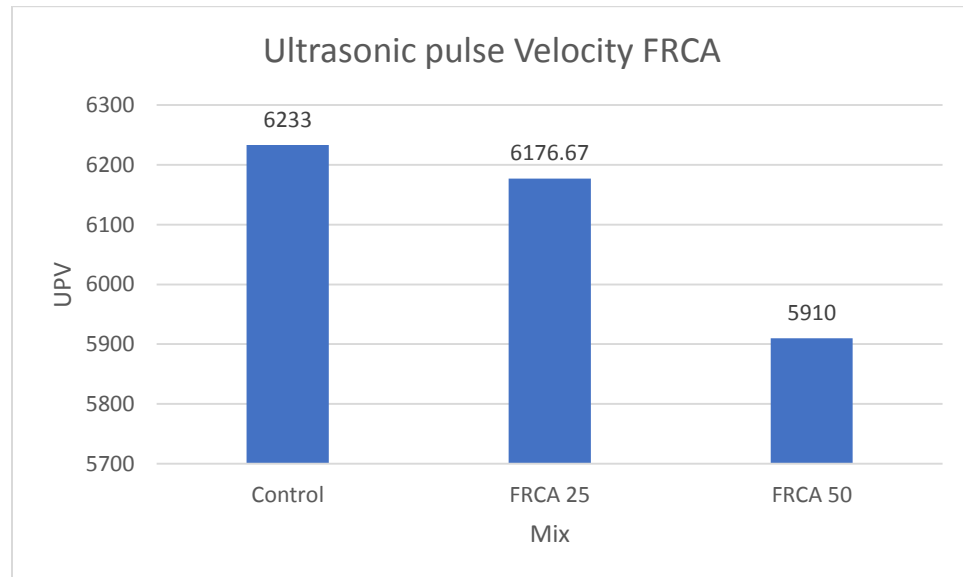
Modulus of elasticity for control mix at 28-days is 28286MPa, whereas for FRCA25 it is 27705.42MPa which is 2% less than the control mix and for FRCA50 it is 6% less than the control mix. Similarly, for FRBA there is a reduction in MOE but the reduction is more in FRBA than in FRCA, For FRBA the reduction is 5% whereas for FRBA50 reduction is 11.24%.

#### 4.6 Ultrasonic Pulse Velocity

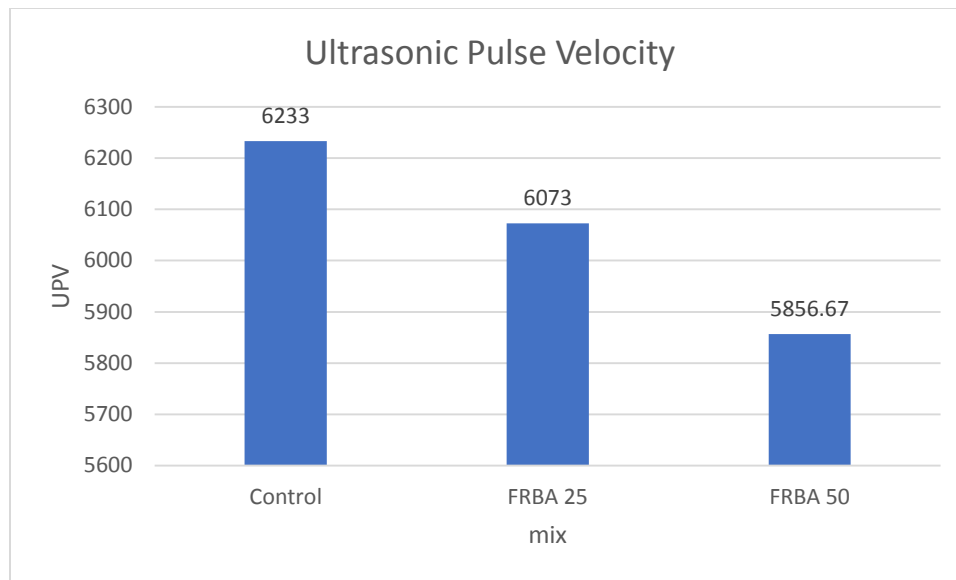
The results of ultrasonic Velocity can be seen in Table 4.7 and Figure 4.8.

**Table 4.7:** Results of Ultrasonic Pulse Velocity

Ultrasonic Pulse Velocity		
Mix	Ultrasonic pulse velocity 28-Days (m/sec)	
	28-days	Average
Control	6300 6200 6200	6233
FRCA 25	5820 6100 6610	6176.67
FRCA 50	5980 6000 5750	5910
FRBA 25	6150 6070 6000	6073
FRBA 50	5920 6000 5650	5856.67



**Fig 4.8(a):** Ultrasonic Pulse Velocity FRC



**Fig 4.8(b):** Ultrasonic Pulse Velocity FRBA

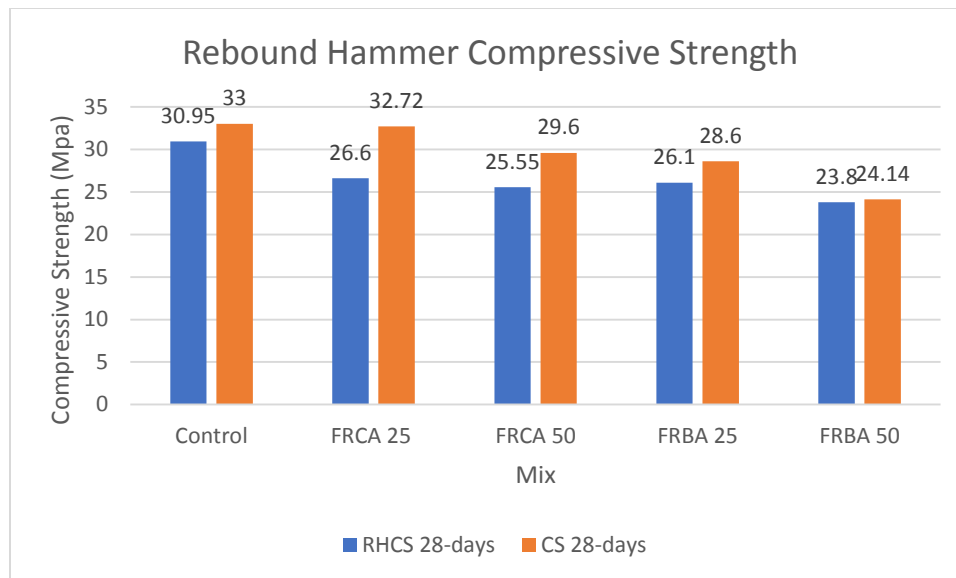
The Average Ultrasonic Pulse velocity of concrete made with natural aggregates is 6233m/s or 6.2Km/sec on comparing it with concrete with the replacement of natural fine aggregates with FRCA it decreases the decrease is about 0.9% at 25% replacement and 5.18% at 50% replacement. When fine natural aggregates are replaced with fine recycled brick dust aggregates the reduction is 2.56% at 25% replacement and 6.04% at 50% replacement which is more than FRCA.

#### 4.7 Rebound Hammer Test

Rebound Hammer 28-days Test Results are shown in Table 4.8 and Figure 4.9.

**Table 4.8:** Rebound Hammer Test Results

28-Days Rebound Hammer Test		
Mix	Rebound Hammer Results (MPa)	CTM Compressive Strength (MPa)
Control	30.95	33
FRCA 25	28.6	32.73
FRCA 50	25.55	29.6
FRBA 25	26.1	28.6
FRBA 50	24.8	24.14



**Fig 4.9:** 28-days Rebound Hammer Test Results

Figure 4.9 Blue bars represent Rebound Hammer strength and orange bar represent Compressive strength at 28 days.

## CHAPTER-5

### CONCLUSION

*This chapter deals with the conclusions from Results obtained from this study.*

#### **5.1 Conclusion**

1. Workability of concrete with recycled aggregates decreased with an increase in replacement ratios this is because of the water absorption by recycled aggregates which in case of Fine recycled concrete aggregates is 7.06% and in case of brick dust is 15.13%.
2. Compressive strength value for concrete incorporating Fine recycled concrete aggregates at replacement ratio of 25% and 50% were reduced by 0.81% and 10.3% while for Fine Recycled brick aggregates reduction was 13.33% and 26.8%. There was less reduction in concrete incorporating FRCA this must be due to cementing action of un hydrated cement particles in FRCA. The reduction in FRBA is more than that of FRCA as there was a greater water absorption by FRBA.
3. Splitting tensile strength of concrete incorporating FRCA with replacement ratios of 25% and 50% was reduced by 15.47% and 23.22% while for FRBA reduction was 21.29% and 30.41%. Reduction in splitting tensile strength is due to the porous structure of Recycled Aggregates.
4. Flexural strength value for concrete incorporating Fine recycled concrete aggregates at replacement ratio of 25% and 50% were reduced by 14.46% and 30.87% while for Fine Recycled brick aggregates reduction was 20% and 36.14%.
5. Modulus of elasticity of concrete incorporating FRCA with replacement ratios of 25% and 50% was reduced by 2% and 6% while for FRBA reduction was 5% and 11.21%. Modulus of elasticity is deeply related to the stiffness of coarse aggregates, the stiffness of mortar and porosity. When the natural aggregates are replaced with recycled aggregates there is a decrease in overall stiffness and porosity is also increased hence the modulus of elasticity decreases with the replacement of Fine natural aggregates.
6. Ultrasonic pulse velocity of concrete incorporating FRCA with replacement ratios of 25% and 50% was reduced by 0.9% and 5.18% while for FRBA reduction was 2.56% and 6.04%. This reduction in the ultrasonic pulse velocity is due to the increase in the voids when natural aggregates are replaced with recycled aggregates.

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