COMPARATIVE STUDY BETWEEN NATURAL COARSE AGGREGATE (BRICK AND STONE) AND RECYCLED CONCRETE AGGREGATE (RCA) AND USE OF ADMIXTURE IN RCA FOR THE PURPOSE OF REGAINING THE INITIAL CONCRETE STRENGTH.

LT MD MONIRUL HASAN

LT S.A SHAH NEOWAZ FERDOUS

ABDUL HANNAN KHAN

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APPROVAL OF SUPERVISOR

The thesis titled "COMPARATIVE STUDY BETWEEN NATURAL COARSE AGGREGATE (BRICK AND STONE) AND RECYCLED CONCRETE AGGREGATE (RCA) AND USE OF ADMIXTURE IN RCA FOR THE PURPOSE OF REGAINING THE INITIAL CONCRETE STRENGTH." submitted by LT Md. Monirul Hasan (ID-201511152); LT S.A Shah Neowaz Ferdous (ID-201511171); Abdul Hannan Khan (ID-201411031) Session 2014-2015 has been accepted cordially in partial fulfillment for the degree of Bachelor of Science in Civil Engineering

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Major Mohammad Moinul Islam

Department of Civil Engineering

Military Institute Of Science and Technology

DECLARATION

Except required specific references related to this paper which has been included with this paper, overall studies and data in this thesis are the outcomes of the investigation carried out by the respective authors. Any part of this paper is not submitted elsewhere in return of achieving the award of any degree or diploma (except for publication).

LT Md Monirul Hasan

Student ID: 201511152

LT S.A Shah Neowaz Ferdous

Student ID: 201511171

Abdul Hannan Khan

Student ID: 201411031

Department of Civil Engineering

Military Institute of Science & Technology

Dhaka – 1212

ABSTRACT

In the present context of Bangladesh, it has been seen that most of the time after demolishing any concrete structure, demolished aggregates are hardly used or recycled for further construction work. This demolished aggregate has a reasonable amount of monetary value. But rather than being used for further construction work it turns into the garbage and pollutes our environment as well as become a burden for us. This happens due to most of the people have the idea that this recycled concrete hardly possesses any strength. Again, in Dhaka and major cities in our country, the requirement of the road has increased significantly inside the town area. Most of these roads are constructed demolishing the concrete structure and producing demolished concrete as well as increasing carrying cost of this demolished concrete. So in this thesis work it has been tried to show the relative comparison of natural coarse aggregate(NCA) and recycled concrete aggregate(RCA) as well as regaining strength by mixing admixture with recycled concrete aggregate(RCA) so that recycled concrete aggregate(RCA) can be potential substitute natural coarse aggregate(NCA). So that aggregate of demolished concrete structure can be recycled for further construction rather than dumping. This will in one hand reduce pollution as well as reduce the overall cost. .For the purpose of thesis work 1st class brick, 3rd class brick, and stone chips have been used. Using this natural course aggregate (NCA) cylinder block was cast with a simple ratio of 1:1.5:3. Then the compressive and tensile strength was checked after 28 days. Aggregate property tests like Aggregate crushing value(ACV),Aggregate impact value (AIV) , Elongation index(EI) , Flakiness index(FI), Los Angles abrasion test(LAAV),unit weight, specific gravity, Absorption capacity and void ratio test were done with both natural coarse aggregate(NCA) and recycled concrete aggregate(RCA) before casting of cylinder. This tests were done to draw a conclusion and compare between the natural coarse aggregate (NCA) and recycled concrete aggregate (RCA). For casting using recycled concrete aggregate (RCA) mix ratio of 1:1.5:3, water-cement ratio, brand and type of cement, sand, and grading of aggregate were kept same as casting using natural coarse aggregate (NCA). After recycling once admixture was mixed with recycled concrete aggregate (RCA) show how much strength can be regained. It is found that a significant amount of strength was regained and it is very compatible and close to the initial strength. Thus a cost comparison was also done using natural coarse aggregate (NCA) and recycled concrete aggregate (RCA) and found to be very fruitful to use recycled concrete aggregate (RCA). Finally using this dumped recycled concrete aggregate (RCA), developing country like Bangladesh can be benefited from the point of monetary value and environmental issue like saving the natural resource, reducing fuel consumption, low carbon emission, reuse of waste material and stepping one step forward in green building concept.

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ABBREVIATIONS

NCA	Natural Course Aggregate
RCA	Recycled Concrete Aggregate
AASHTO	American Association of State Highway and Transportation Officials
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Standard for Testing and Materials
BS	British Standard
EI	Elongation Index
FI	Flakiness Index
FA	Fine Aggregate
FM	Fineness Modulus
IRC	Indian Roads Congress
LAAV	Los Angeles Abrasion Value
OD	Oven Dry
OPC	Ordinary Portland Cement
RHD	Roads and Highways Division
SSD	Saturated Surface Dry
WBM	Water Bound Macadam
1^{st} RCA	1^{st} time recycled aggregate
2^{nd} RCA	2^{nd} time recycled aggregate

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CHAPTER ONE

INTRODUCTION

1.1 Background

In the field of construction industry concrete is one of the most important building material. About 6 billion tons of concrete are produced every year (ISO, 2005) which is huge in amount. So it has become a challenge for the industry to produce this much amount of concrete per year using natural resources which has a lot of environmental impacts as well. And the demand is increasing day by day. For this reason, developed countries increased their attention in this issue thinking about the environmental impact and they set taxes on the use of fresh aggregate. For a country like Bangladesh, a large amount of waste is produced from this construction sector after demolishing the structure. After demolishing the structure this concrete material is used in a landfill in most of the cases which pollute the environment as well as wastes of material which contain a monetary value. So the use of recycled concrete is always welcomed to the present context which can be the most suitable solution to reduce the waste as well as it can save our natural resource.

It is seen that in some cases in our country this demolished concrete is used as aggregate in embankment construction or in road construction but most of the cases it is used in landfills. The main reason is that the quality of recycled concrete aggregate (RCA) is lower compared to the natural aggregate which turns into an important issue to use this (RCA) as structural concrete construction.

After crushing the demolished aggregate lose its initial strength. Which is the main reason for the degradation of the quality of (RCA) compare to the fresh aggregate? Which ultimately results in strength reduction in concrete construction using recycled concrete. In this paperwork, it has been analyzed how much strength is reduced in the subsequent stage after using the recycled concrete as aggregate in concrete construction repeatedly. For showing the comparison both recycled stone chips and brick chips have been used those are recycled for twice which will show the comparative strength reduction in both the cases. If this strength can be regained this recycled concrete can be used in concrete construction again which can reduce the cost of the construction work. The huge demand of aggregate in construction work can be met by using this recycled concrete .which reduce the demand for industrial production of normal coarse aggregate (NCA). And it is going to be an environmentally friendly process. To regain the strength admixture has been used which will increase the workability in mix design with a low water-cement ratio. For both recycled stone and brick chips, the same admixture has been used keeping all the parameter, same to compare in which case how much strength can be regained.

1.2 Objectives of the Study

Basing on the background discussed in the above section, main research objectives are as follows:

1. To compare brick chips and stone chips as RCA in terms of strength required for concrete mixing as well as pavement design.
2. To compare between NCA and RCA of brick and stone and find how much strength can be regained by using admixture with recycled concrete.
3. To reach a final decision basing on the study where to use this recycled aggregate which can be environmentally and economically feasible.

1.3 Scopes

To obtain the objectives stated above, the scopes of this thesis are set as follows:

- Procuring aggregate of different types for comparing their strength.
- Casting concrete cylinder block using those normal aggregate.
- Reusing those aggregate for repeated casting in every cycle.
- Perform compressive and tensile tests on concrete cylinder block after 28 days in every cycle to compare the variation in compressive strength and tensile strength.
- Using admixture with recycled concrete for regaining the strength.
- Summarize every test results graphically for comparing the variation of strength for different types of aggregate.

1.4 Outline of the Thesis

Chronological development of whole thesis work has been divided into a number of chapters. The contents of the chapters are briefly presented below.

- Chapter One. Where introduction of this research work has been described briefly which includes of its background, objectives, and scopes of the study.

- Chapter Two. This chapter includes the literature regarding various types of aggregate, methods of mix design and influence of admixture in the mix design.

- Chapter Three. Which deals with the test methodologies. The standard procedures which were followed for each test are described in this chapter.

- Chapter Four. which represents the test result of the tests performed

- Chapter Five. Which represents the comparative test results graphically.

- Chapter Six. Which deals with the ultimate findings of whole thesis work and recommendation based on findings.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Concrete is a major part of a structural member. Brick chips and stones are used as coarse aggregate and sand and cement as binder materials. Out of those constituent materials of concrete, the aggregate can be recycled. And the strength of the concrete using recycled aggregate will largely depend on the strength of aggregate used. There is also some other parameter which will influence the strength of concrete like the type of binder material, type of fine aggregate, workability, type size and grading of coarse aggregate, admixture, water-cement ratio and most importantly mix design procedure.

2.2 Mix Design Procedure

For this study, one of the most used mix ratio of 1:1.5:3 has been used and the water-cement ratio was 0.42 for the mix. In the case of admixture, the mix ratio was the same but water-cement ratio was reduced to 0.35 and Master Rhio Build was used as an admixture. The admixture was mixed with a ratio of 600 ml per 100 kg cement.

2.3 Types of Aggregates Based on Source.

2.3.1. Natural Aggregates. The aggregate, which is produced naturally from a natural source like sand gravel etc.

2.3.2 Manufactured Aggregates. The aggregate, which is manufactured in factory manually or mechanically, is known as manufactured aggregate such as brick chips, crushed rocks etc. For the manufacture of aggregate fly ash, soil can be used.

2.3.3 Recycled Aggregates. The aggregate, which is found from the recycling of previously used concrete, is known as recycled concrete. Examples include aggregate recycled from the demolished concrete structure, aggregate from scrap tires and asphalt pavement etc.

2.3.4 Reused by-Product. Aggregate that is found from the by-product of an industrial process. Examples include various types of aggregates that are found from steel and iron manufacturers. In 2005, instead of disposing of as landfill 2.35 million tons of iron and steel slag were effectively used in a productive way in Australia.

2.4 Based on Strength types of Bricks

1st Class: These bricks are burnt in kilns, having standard shape and table molded.it has a sharp and straight edge and smooth surface with square shape. The clear ringing sound is emitted once it is being struck. These bricks are made of the good earth completely burnt and possess the qualities of good bricks. It has the crushing strength 1500 lbs per square inch.

2nd Class: These bricks are also burnt in kilns and ground-molded. The shape of this brick is slightly irregular and the surface is little rough. It may not have a sharp and uniform edge and it may have hair cracks. It should have a minimum of 70 kg per sq. cm crushing strength.

3rd Class: It is also ground molded, possesses uneven and distorted surfaces and edges. If it is struck it provide dull sound .it is having a light color and used in those areas where is normal. These bricks are mainly used for the temporary and minor structure.

4th class: These bricks are over burnt and having dark color mostly.it is having very low compressive strength. These bricks are mainly used on roads floors or in such concrete structure where less compressive strength is desired. It is mainly used as aggregate or gravel in substandard structure.

2.5 Types of Aggregates

On the basis of size, the aggregate can be following types.

2.5.1 Coarse Aggregate

Aggregates size bigger than 4.75 mm is called coarse aggregates. These mainly provide strength to concrete.

2.5.2 Fine Aggregate

Aggregates passing through 4.75mm sieve are known as fine aggregates. They are used for filling up the gap in between coarse aggregate.

2.6 Factors Influencing Mix Design

Concrete mix should possess certain desirable properties like workability, durability, strength etc. at the same time concrete mix should be prepared in such a way so that it becomes cost effective. Some of the important parameters, which control the proportion of ingredients in the mix, are shown below

2.6.1 Workability

The concrete mixture should be such so that certain workability is attained. It is mainly determined to cope up with means of compaction, placing condition and type of construction at the site. Some of the factors which control the workability are shape and size of the mold, properties of aggregate, amount of water-cement ratio, amount of reinforcement etc. But the most important factors which control the workability is a proportion of water content. Few other parameters which can also influence the workability are the maximum size of aggregate and its grading. The more workable concrete mixture should be used for a heavily reinforced section. Admixture can also alter the workability of the concrete mix.

2.6.2 Aggregate Cement Ratio

Some of the factors which influence the aggregate-cement ratio are grading of the aggregate, workability, shape size and texture of the aggregate. The selection of aggregate-cement ratio is done from the chart or table which is prepared from laboratory investigation. Aggregate cement ratio largely influences the strength of the concrete. A varying ratio of aggregate cement will provide varying strength. Concrete mix with a low water-cement ratio or low aggregate-cement ratio concrete contains high cement content. Absorption behavior of aggregate may reduce the effective water-cement ratio of the mix.

2.6.3 Type Size and Grading Of Aggregate

Grading of aggregate is one of the important factors which can influence the workability of the mixture. A concrete can be good if it contains different types of aggregate like crushed rock, irregular gravel which is preferably angular in shape. For the heavily reinforced concrete section maximum size of aggregate is restricted to 5 mm (Indian standard code practice IS: 456. Another investigation was done by Bloem where he has indicated that if the maximum size of the aggregate exceeds 40 mm improvement of the aggregate does not occur. Aggregate should be carefully graded so that void in between the coarse aggregate is filled up by the fillers so that maximum density can be attained

2.6.4 Durability

The durability of concrete depends on the type of exposure prevailing. If concrete is prepared with certain compaction and suitable ingredient under ordinary exposure it becomes durable. Most of the cases strength, workability, water cement ratio etc., these are taken into consideration rather than considering the durability of the concrete. The places where high durability is expected water-cement ratio should be reduced in those cases. Suitable air entrainment should be there in a concrete mix where the cycle of freezing and thawing exist. If fire-resistant concrete is expected natural aggregate should be used with a concrete mix like basalts, dolerites, limestone etc. hard coarse aggregate should be used in runways and spillways like gravel, granite to increase the compacted density which can resist erosion and abrasion effect.

2.6.5 Compressive strength

A satisfactory level of Compressive strength is the prime requirement from a concrete. Strength o the concrete depends on water-cement ratio, durability, impermeability, abrasion resistance etc. for designing a high strength concrete water-cement ratio depends on the maximum size of the aggregate, workability, water cement ratio etc. again compressive strength of concrete depends on the type of cement or filler material used and method of curing applied.

2.7 Admixture and its effectiveness in the mix

Admixture can be one of the good options to increase the workability of the concrete mix with a low water-cement ratio. Using admixture can reduce the water-cement ratio without increasing the cement content. There is various type of admixture which can influence the strength of the concrete mix in any way. But most of the time superplasticizer is used which contain the retarding agent. There are also few admixtures which are commercially available to increase the strength of concrete. But it should be mixed in a definite proportion which is provided by the definite code. Excessive use of the dose may not be effective in the concrete mix to get the desired result.

CHAPTER THREE

METHODOLOGY

3.1 General

For the study, three type of aggregate were used. They are 1^{st} class brick, 3^{rd} class brick, and stone. The bricks were crushed manually and following aggregate property test was conducted.

- Fineness Modulus test
- Aggregate Impact Value (AIV)
- Aggregate Crushing Value (ACV)
- Specific Gravity
- Flakiness & Elongation Index
- Unit Weight & Voids
- Los Angeles Abrasion Value

After conducting these tests a concrete cylinder was cast. For casting, all the mix were done following 1:1.5:3 ratio. Concrete cylinders were prepared for each type of aggregates and both compressive and tensile strength test was carried out at 28 days.

After measuring the strength of all the cylinders each type of concrete with different Coarse aggregates was crushed manually. Then again the above-mentioned aggregate tests were conducted using this recycled concrete and for better assimilation, it is named as 1st time recycle concrete in this paper. Then the concrete cylinder was cast with this 1st time recycle concrete aggregate (RCA). The mix, brand of cement, the source of sand and downgrade ratio of coarse aggregate were kept unchanged as initial casting. In addition to this admixture was used with 1st time recycle concrete aggregate (RCA) following the same ratio and procedure only the water-cement ratio was reduced from 0.42 to 0.35. After this again cylinder ware tested for compression and tension and like previous manually crushed. This time, the aggregate obtained after crushing it is named as 2nd time recycle concrete (RCA) in this paper for better understanding. Again the aggregate property test was done with 2nd time recycled concrete aggregate (RCA). A similar way concrete cylinder was cast using 2nd time recycled concrete and after 28 days the compressive and tensile strength were measured.

3.2 Collection of Sample:

The bricks are collected from the brickfield near Gabtoli. Sylhet sand and also cement collected from Gabtoi. The stones and admixture were collected from concrete lab MIST. The cement used is Shah Portland cement.

3.3 Under grade Ratio

Mix design done for preparing the sample followed grade M20 where the ratio of 1:1.5:3 is used to prepare all the sample and also the grading of course aggregate were kept fixed by the following ratio:

Sieve No	Percentage (%)
25 mm	0
19.5 mm	25.4
12.5 mm	54
9.5 mm	12.7
4.75 mm	7.9

Table 3.1: The grading of course aggregate.

Water-cement ratio was kept fixed at 0.42:1 in all casting except the concrete with admixture where the water-cement ratio was 0.35:1 and 800 ml of Master Rheobuilt 623 were used for per 100 kg of cement

3.4 Laboratory Tests:

The tests have been performed following the ASTM and BS specifications. The standard procedures followed for each test are described here.

3.4.1 Fineness Modulus Test:

Objective: To determine the gradation and the number of fines produced by the aggregates to be used in construction.

Procedure: This test requires a set of standard sieves arranged sequentially one below the other. The standard sieves used for coarse aggregate are 37.5 mm, 19 mm, 9.5 mm, 4.75 mm (#4), 2.36 mm (#8), 1.18 mm (#16), 600 µm (#30), 300 µm (#50), 150 µm (#100) and a pan. Sieves used for fine aggregates are #4, #8, #16, #30, #50, #100, #200 and pan .A representative weighed sample was poured on the top sieve. The sieves were shaken well using a mechanical shaker. Then the amount retained on each sieve was carefully weighed [ASTM C136].

The Fineness Modulus (FM) of the sample was found out using the following formula:

$$FM = \frac{\sum(\text{Cumulative percentage retained on standard sieves})}{100}$$

A graph was plotted in a semi-log graph paper having sieve opening along x-axis and percent finer along the y-axis. The shape of the curve indicates the gradation of the aggregate, i.e. well-graded, uniformly graded or gap-graded.

Data Calculation & Graph:

Course Aggregate (NCA & RCA)

Sieve Size (mm)	Mass Retained (kg)	Percent Retained (%)	Cumulative Percent Retained (%)	Cumulative Percent Passing (%)
37.5	0	0.00	0.00	100.00
19.0	17.82	25.37	25.37	74.63
12.5	37.4	53.24	78.61	21.39
9.50	9.46	13.47	92.08	7.92
4.75	5.566	7.92	100.00	0.00
2.36		0.00	100.00	0.00
1.18		0.00	100.00	0.00
6.00		0.00	100.00	0.00
3.00		0.00	100.00	0.00
1.50		0.00	100.00	0.00
Pan				
Total	70.246	100.00	692.08	FM=6.92

Table 3.2: Sieve analysis of coarse aggregate

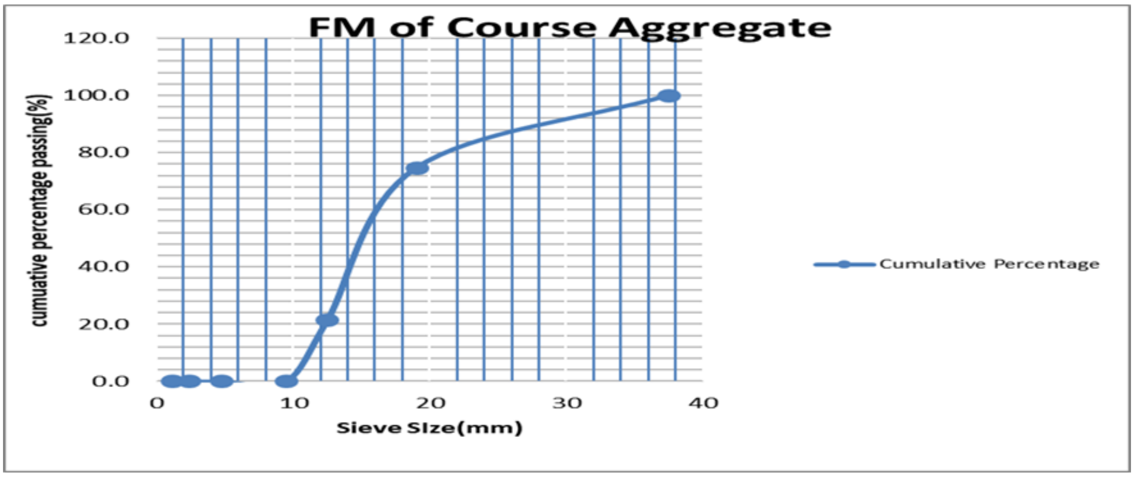

Fig 3.1: Grain Size Distribution Curve for Coarse Aggregate

Fine Aggregate

Sieve Size (mm)	Mass Retained (gm)	Percent Retained (%) (gm)	Cumulative Percent Retained (%)	Cumulative Percent Passing (%)
9.500	0	0	0.0	100.0
4.750	0	0	0.0	100.0
2.360	20	4	4.0	96.0
1.180	56	11.2	15.2	84.8
0.600	180	36	51.2	48.8
0.300	160	32	83.2	16.8
0.150	61	12.2	95.4	4.6
Pan	23	4.6	100.0	0.0
Total	500	100.00	249.00	
		FM =	2.49	

Table 3.3: Sieve analysis of Fine Aggregate

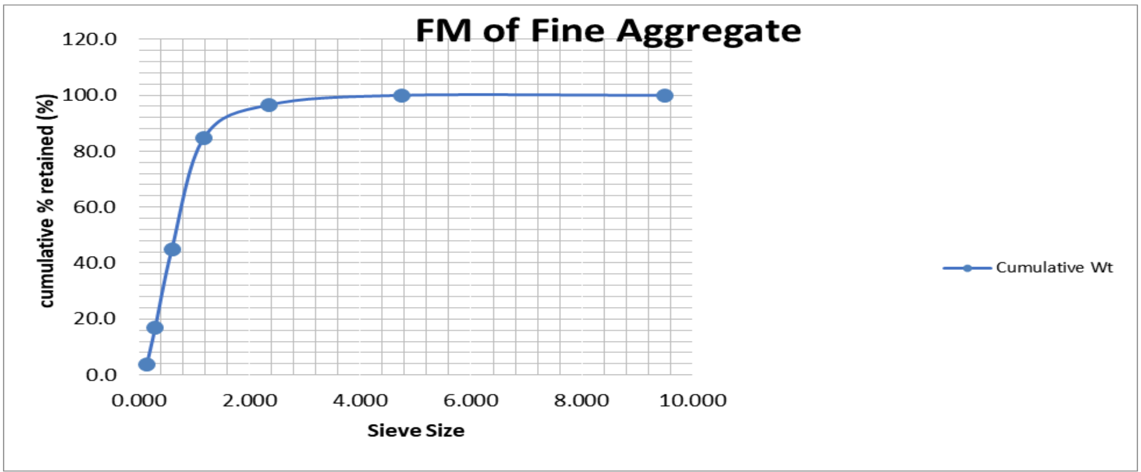

Fig 3.2: Grain Size Distribution Curve for Fine Aggregate.

Result: FM of Coarse aggregate was found 6.92% and fine aggregates were found 2.49%.Coarse and Fine aggregate were both gaps graded.

3.4.2 Aggregate Impact Value:

Objective: To get a relative measure of the resistance of an aggregate to sudden shock or impact.

Procedure: The required sieves sizes are 12.5 mm, 10 mm and 2.36 mm. For this test, the aggregates were dried in an oven for 4 hours. Then aggregates passing through 14 mm sieve and retained on 10 mm sieve were taken for AIV test. A cylindrical metal measure (dia. = 75 mm, depth = 50 mm) was filled up in three layers with aggregate, each layer was stroke 25 times with a tamping rod falling freely from a height of 50 mm. Aggregates were taken in standard mold and tamped in three-layer until overflow and excess aggregates were discarded from the top of the mold carefully. Then the aggregate was poured into a mold of (dia. = 102 mm, depth = 50 mm) AIV testing machine and was fixed in the impact testing machine. 15 blows were given at 1-sec interval with a hammer by dropping it from a height of 380±5 mm. The crushed aggregate was then transferred to a tray and sieved through a 2.36 mm sieve for 1 min.IS 2386 (Part IV) – 1963.

The AIV was obtained from the following formula:

$$AIV = \frac{B}{A} \text{ x } 100$$

Where A = initial weight of aggregate

B = weight of aggregate passing through 2.36 mm sieve.

The result was discarded in case of more than 1% loss of aggregate.

Data:

1st Class Brick

Type	Total (gm)	Mold (gm)	Passing 2.36 Mm (gm)	AIV (%)
NCA	1320.6	1071	94.3	38
1st RCA	1338.3	1071	70.1	27
2nd RCA	1343.7	1071	96.2	36

3rd Class Brick

Type	Total (gm)	Mold (gm)	Passing 2.36 Mm (gm)	AIV (%)
NCA	1316	1071	105.6	44
1st RCA	1339	1071	92.2	36
2nd RCA	1321	1071	95.2	39

Stone

Type	Total (gm)	Mold (gm)	Passing 2.36 Mm (gm)	AIV (%)
NCA	1404.5	1071	43.6	14
1st RCA	1367.5	1071	74.5	26
2nd RCA	1353.3	1071	80.3	29

Table 3.4: Aggregate Impact Value

3.4.3 Aggregate Crushing Value

Objective: To get a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load.

Procedure: This test is similar to the AIV test except the dimensions of cylindrical metal measure are different (dia. = 115 mm, depth = 180 mm). After tamping the aggregate as before, it was poured into another cylinder with the base plate and tamped again in three layers. Then the cylinder along with the base plate and a plunger was placed in a compression testing machine. 400 KN force was applied for 10 minutes at a uniform rate. The rest of the procedure including the calculation is exactly the same as that of the AIV test [BS 812-110].

Data:

1st Class Brick

Type	Total (gm)	Mold (gm)	Passing 2.36 mm (gm)	ACV (%)
NCA	3807.3	1623	643.2	30
1st RCA	3793.9	1623	512.2	24
2nd RCA	3782.5	1623	679.3	32

3rd Class Brick

Type	Total (gm)	Mold (gm)	Passing 2.36 mm (gm)	ACV (%)
NCA	3605.3	1623	821.3	42
1st RCA	3601.3	1623	933	48
2nd RCA	3599.1	1623	1003.2	51

Stone

Type	Total (gm)	Mold (gm)	Passing 2.36 mm (gm)	ACV (%)
NCA	4230.3	1623	436.2	17
1st RCA	4205.5	1623	562.3	22
2nd RCA	4196.2	1623	653.2	26

Table 3.5: Aggregate Crushing Value

3.4.4 Flakiness Index:

Objective: To identify whether an aggregate is flaky or not in order to know its strength.

Procedure: The required sieves for this test are 63 mm, 50 mm, 37.5 mm, 28 mm, 20 mm, 14 mm, 10 mm and 6.3 mm. The aggregates were kept in surface dry condition. They were sieved through all the sieves and the portions retained on 63 mm and passing through 6.3 mm were discarded. Each size fraction was weighed. Then aggregates were passed through appropriate slots of a thickness gauge. The aggregates passing through the slots were considered as flaky. The individual amount of aggregates passing through each slot was then weighed [BS 812-105.1]. Flakiness Index was obtained using the following formula:

$FI = M_3/M_2 \times 100$

Where M_2 = sum of net mass retained on each sieve

M_3 = total weight of flaky particles.

<u>FI Value</u>

Type	1st Class Brick (%)	3rd Class Brick (%)	Stone (%)
NCA	19.4	23.3	17.9
1st RCA	8.4	16.4	8.9
2nd RCA	15.4	17.2	10.4

Table 3.6: Result of FI

3.4.5 Elongation Index:

Objective: To determine whether an aggregate is elongated or not in order to know its strength.

Procedure: The sieves required for this test are 50 mm, 37.5 mm, 28 mm, 20 mm, 14 mm, 10 mm and 6.3 mm. The procedure is similar to that of FI test. The aggregates retained on 50 mm and those passing through 6.3 mm were discarded. Aggregates were passed through appropriate slots of a length gauge for their corresponding sieve sizes. Length of the gauge is the1.8 times of average of sieve size that the aggregate passes and the sieve aggregate retains. [BS 812-105.2]. The aggregates which did not pass were considered as elongated. Elongation Index was obtained using the following formula:

$EI = M_3/M_2 \times 100$

Where M_2 = sum of the net mass of aggregate taken for a test

M_3 = total weight of elongated particles not passing the gauge

EI Value

Type	**1st Class Brick (%)**	**3rd Class Brick (%)**	**Stone (%)**
NCA	32.6	38.7	26.9
1st RCA	15.4	32.4	9.1
2nd RCA	14.2	13.1	14.4

Table 3.7: Result of EI

3.4.6 Specific Gravity:

Objective: To determine the quality and water absorption capacity of aggregate in order to know the amount of water requirement of a concrete mixture made using these aggregates.

Procedure: Aggregate samples were oven-dried at 110^0C for 24 hrs and then cooled at room temperature for 1-3 hrs. The samples were then immersed in water for 24 hrs to make it SSD. The weight of the SSD sample was taken. Then it was placed in a wire basket and immersed in water immediately. The immersed weight was taken. Then the sample was oven-dried again and its weight was taken [ASTM C127]. Specific gravity and water absorption capacity of the sample were found out using the following formulae:

Bulk Sp. Gravity (OD) = $\frac{A}{B-C}$

Bulk Sp. Gravity (SSD) = $\frac{B}{B-C}$

Apparent Sp. Gravity = $\frac{A}{A-C}$

Absorption Capacity = $\frac{B-A}{A} \times 100\%$

Where, A = weight of OD sample

B = weight of SSD sample

C = weight of SSD sample in water.

Data

Specific Gravity (Oven Dry)

Type	1st Class Brick	3rd Class Brick	Stone
NCA	1.88	1.81	2.63
1st RCA	2.06	1.99	2.47
2nd RCA	2.07	2.01	2.39

Table-3.8: Result of Specific Gravity (OD) of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

Specific Gravity (Saturated Surface Dry)

Type	1st Class Brick	3rd Class Brick	Stone
NCA	1.97	1.91	2.68
1st RCA	2.17	2.14	2.56
2nd RCA	2.18	2.17	2.50

Table -3.9: Result of Specific Gravity (SSD) of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

Apparent Specific Gravity

Type	**1st Class Brick**	**3rd Class Brick**	**Stone**
NCA	2.07	2.02	2.76
1st RCA	2.31	2.34	2.73
2nd RCA	2.33	2.39	2.67

Table -3.10: Comparison of Apparent Specific Gravity of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

3.4.7 Unit Weight and Voids:

Objective: To determine the percentage of voids present in the aggregate and the effort required for compaction of concrete to be used in construction.

Procedure: There is a standard bucket for this test. At first, weight and volume of the empty bucket were taken. Unit weight can be measured in two ways – loose or compact. For measuring loose unit weight, the bucket was simply filled with aggregate and weighed. For compact unit weight, the bucket was filled with aggregate in three equal layers, each layer being tamped 25 times with a tamping rod. Then it was weighed. The aggregates were oven-dried prior to the test [ASTM C29].

$$\text{Unit Wt.} = \frac{\text{Weight of aggregate}}{\text{volume of a bucket}} \ (\text{kg/m}^3)$$

$$\%\ \text{voids} = \frac{G-Y}{G} \times 100\%$$

Where, G = sp. gravity of aggregate (OD)

Y = unit wt. (kg/L)

Result:

Unit Weight

Type	1^{st} Class Brick (Kg/m^3)	3^{rd} Class Brick (Kg/m^3)	Stone (Kg/m^3)
NCA	1160	1013	1645
1^{st} RCA	1192	1250	1526
2^{nd} RCA	1265	1197	1432

Table -3.11: Result of Unit Weight of 1^{st} Class, 3rd Class Brick and Stone as NCA and RCA.

Void Ratio

Type	1^{st} Class Brick (%)	3^{rd} Class Brick (%)	Stone (%)
NCA	38.3	44.04	37.46
1^{st} RCA	42.14	37.19	28.22
2^{nd} RCA	38.89	40.45	40.09

Table -3.12: Result of Void (%) 1^{st} Class, 3rd Class Brick and Stone as NCA and RCA.

3.4.8 Los Angeles Abrasion Test:

Objective: To determine the resistance of an aggregate to abrasion, which is an indication of the toughness of the aggregate.

Procedure: The sieves used for this test are 37.5 mm, 25 mm, 19 mm, 12.5 mm, 9.5 mm, 6.3 mm, 4.75 mm and 2.36 mm. Aggregates were rinsed and oven-dried at 110 ± 5^0C. The number of spheres to be used was selected as per Table-1, ASTM C131. In our case, the aggregates fell under the class B, so 11 spheres were used. The aggregates along with the spheres were put in the LAA machine and rotated. After completion of the rotation, the aggregates were taken out and sieved through a #12 sieve. The aggregates passing through the #12 sieve were weighed [ASTM C131]. Then LAAV was obtained from the following formula:

$$\text{LAAV} = \frac{\text{Wt.passing through \#12 sieve}}{\text{Total wt.of agg.}} \times 100\%$$

<u>Graph</u>:

Type	**1^{st} Class Brick (%)**	**3^{rd} Class Brick (%)**	**Stone (%)**
NCA	31	42	26.5
1^{st} RCA	41	64	33.6
2^{nd} RCA	63	81	45

Table-3.13: Result of LAAV of 1^{st} Class, 3rd Class Brick and Stone as NCA and RCA.

3.5 Compressive Strength Test of Concrete Cylinder:

Objective: To determine the compressive strength of the concrete cylinder in order to gain knowledge about the ultimate compressive strength of concrete to be used in construction.

Procedure: Concrete was made from three types of aggregate, 1st Class bricks, Picket bricks, and stone chips. In total, three kinds of concrete were made. And with each of these three aggregates, three types of concrete were made. Each of these three types of concrete was crushed by hand and used as coarse aggregate for concrete mix. For next iteration of concrete mixes coarse aggregate found from crushing each individual type of concrete were used for respective concrete preparation. Again this concrete was tested and crushed and again used for concreting but this time admixture was used for all type of concretes. The ratio of Cement: FA: CA was 1:1.5:3 for all type of aggregates and the w/c ratio was taken as 0.418. The sand used for this purpose was Sylhet sand. Portland cement from local manufacturers was (Crown Cement) used. Cylinders were cast in steel molds having internal diameter 6 in. and internal depth 8 in. All the molds were greased properly prior to casting. Concrete was poured in them and tamped properly and left to set. After 24 hours, the cylinders were unmolded and immersed in water for curing.28-day compressive strength tests were done. For testing, cylinders were taken out of the water and left for at least 4 hrs. Then their dimensions and weight are measured. Each cylinder was placed longitudinally in the compression testing machine and the required input was given. Force was applied by the machine until the cylinder cracked. The results were obtained digitally from the machine. Three cylinders were tested for each day and the average result was taken [ASTM C39].

Compressive Strength

Casting / Type	1st Casting (NCA) (Psi)	2nd Casting (1st RCA) (Psi)	3rd Casting (2nd RCA) (Psi)	Casting with RCA and Admixture (Psi)
1st Class Brick	4155	3374	2816	4324
3rd Class Brick	1664	1874	1309	2869
Stone	3808	3515	2816	5317

Table 3.14: Result of Compression Test

3.6 Tensile Strength Test of Concrete Cylinder:

Objective: To get a measure of the tensile strength of concrete.

Procedure: The same concrete used for the compressive strength test was also used for this test. Split & cone test was carried out for tensile strength measurement. Cylinders were placed laterally in the compression testing machine and force was applied. The cylinders broke across their vertical diameter. The split tensile strength was obtained directly from the machine. The average of three-cylinder results was taken as the final result. The 28-day strength tests were performed [ASTM C496]

<u>Tensile Strength</u>

Casting Type	1st Casting (NCA) (Psi)	2nd Casting (1st RCA) (Psi)	3rd Casting (2nd RCA) (Psi)	Casting with RCA and Admixture (Psi)
1st Class Brick	474	391	382	453
3rd Class Brick	286.6	273.3	262	293
Stone	345	340	324	376

Table 3.15: Result of Tensile Test

CHAPTER FOUR

SUMMARY OF RESULTS

4.1 Aggregate Property Test Results:

This table represents the different aggregate property test:

Name of test	**1st Class brick**			**3rd class brick**			**Stone**		
	NCA	**1st RCA**	**2nd RCA**	**NCA**	**1st RCA**	**2nd RCA**	**NCA**	**1st RCA**	**2nd RCA**
ACV	29.6	24.7	31.2	43	27	35	16.7	21.9	26.4
AIV	38	27	36	44	29	39	13.4	26	29
LAAV (%)	31	41	53	41	53	61	26.5	33.6	45
FI (%)	19.4	8.4	15.4	23.3	16.4	17.2	17.9	8.9	10.4
EI (%)	32.6	15.4	14.2	38.7	32.4	13.1	26.9	9.1	14.4
Specific gravity (SSD)	1.97	2.17	2.18	1.91	2.14	2.17	2.68	2.56	2.5
Specific gravity (OD)	1.88	2.06	2.07	1.81	1.99	2.01	2.63	2.47	2.39
Unit Weight kg/m³	1160	1192	1265	1013	1250	1197	1645	1526	1432
Apparent Specific Gravity Value	2.07	2.31	2.33	2.02	2.34	2.39	2.76	2.73	2.67
Void (%)	38.3	42.14	38.89	44.04	37.19	40.45	37.46	38.22	40.09

Table-4.1: Aggregate Property Test Results

4.2 Cylinder Strength Test Results:

Compressive and tensile strengths of the cylinders made with different kinds of aggregates are presented below:

Types of test	1st class brick			3rd class brick			Stone		
	1st Casting (NCA)	2nd Casting (RCA)	3rd Casting (RCA)	1st Casting (NCA)	2nd Casting (RCA)	3rd Casting (RCA)	1st Casting (NCA)	2nd Casting (RCA)	3rd Casting (RCA)
Average Compression Strength (psi)	4156	3374	3057	1645	1875	1595	3605	3615	3159
Average Tensile Strength (psi)	345	340	324	285.6	273.3	263.2	474	391	382

Table-4.2: Cylinder Strength Test Results

4.3 Comparison of Aggregate Property Test

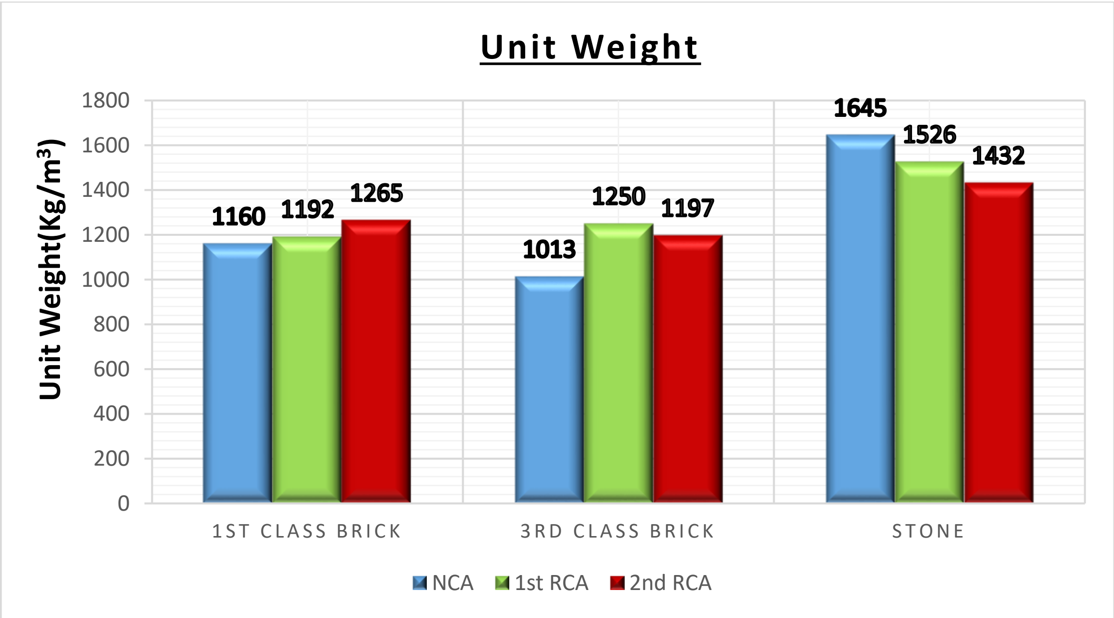

Fig-4.1: Result of Unit Weight of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

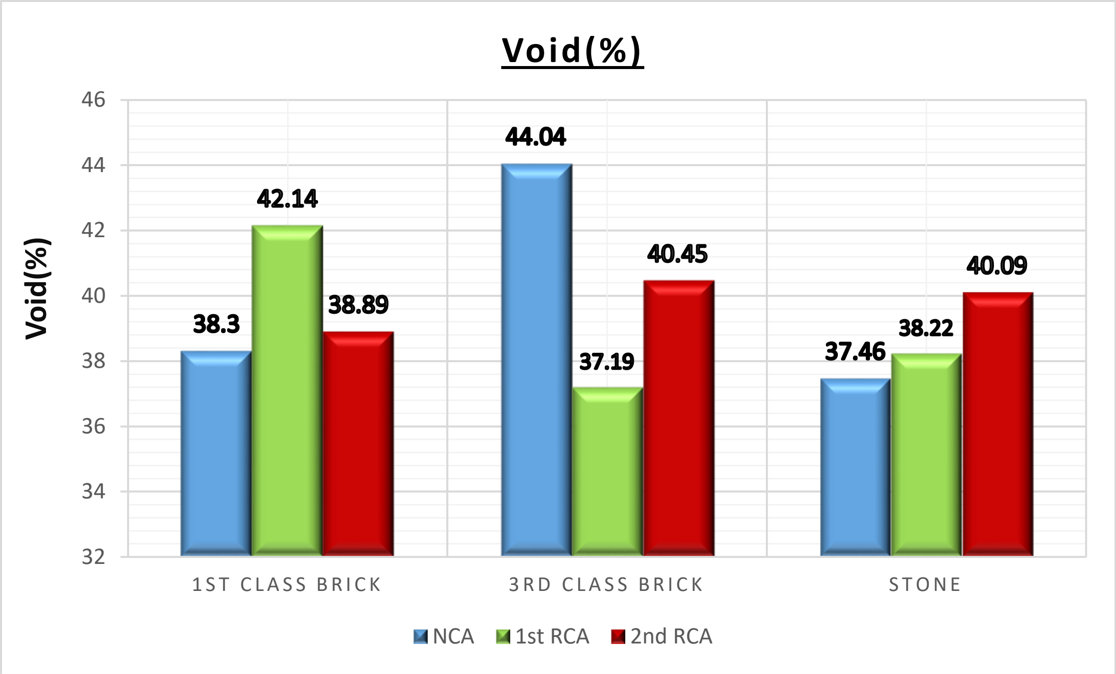

Fig-4.2: Result of Void (%) 1st Class, 3rd Class Brick, and Stone as NCA and RCA.

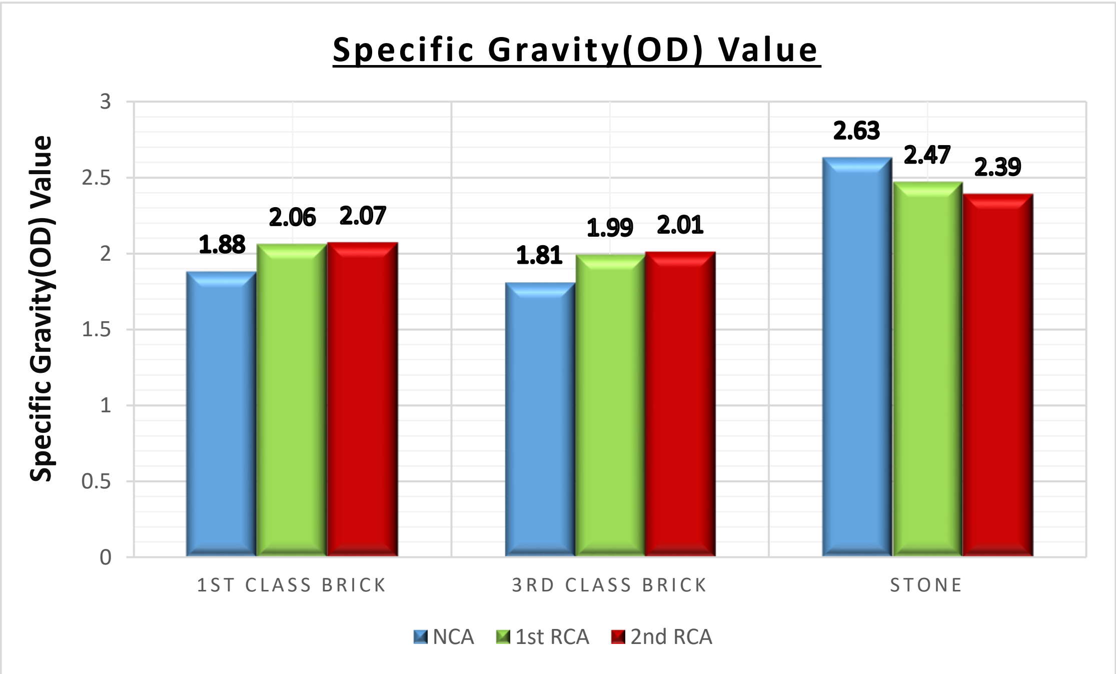

Fig-4.3: Result of Specific Gravity (OD) of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

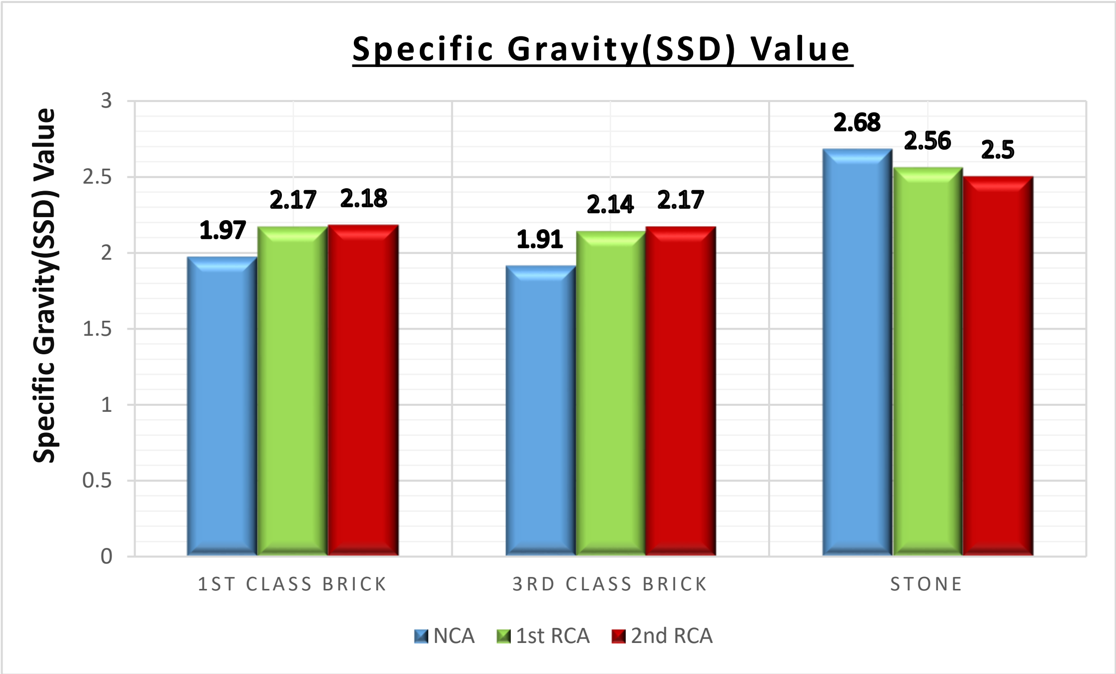

Fig-4.4: Result of Specific Gravity (SSD) of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

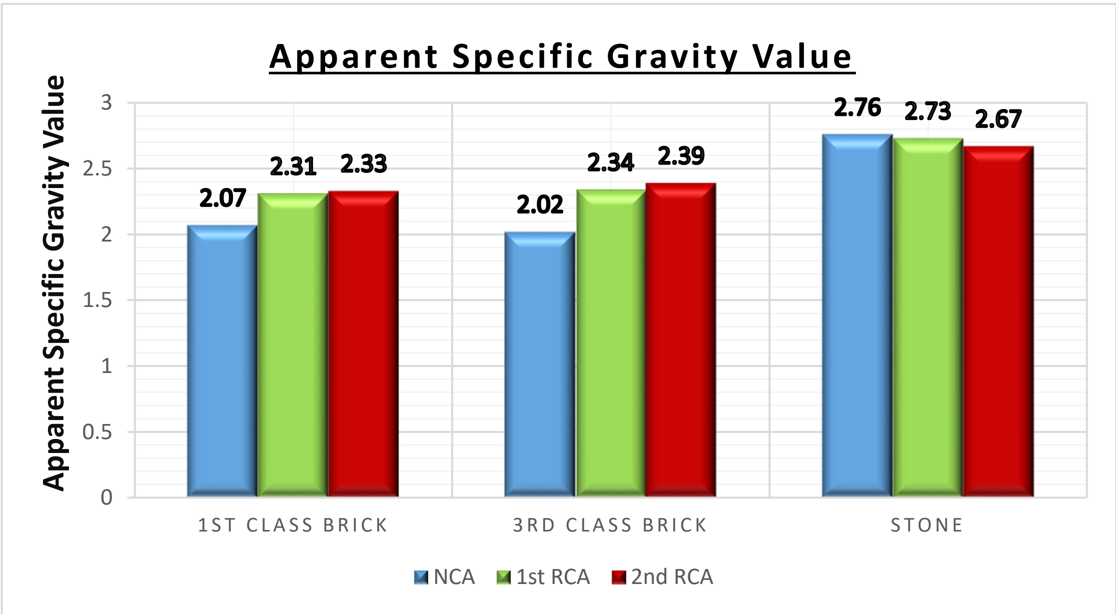

Fig-4.5: Comparison of Apparent Specific Gravity of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

CHAPTER FIVE

COMPARISON OF TEST RESULTS

5.1 Comparison of Strength of Aggregate in NCA and RCA.

The aggregate properties of 1st class brick, 3rd class brick, and stone used to prepare the cylinders are presented as below:

5.1.1 Comparison in AIV

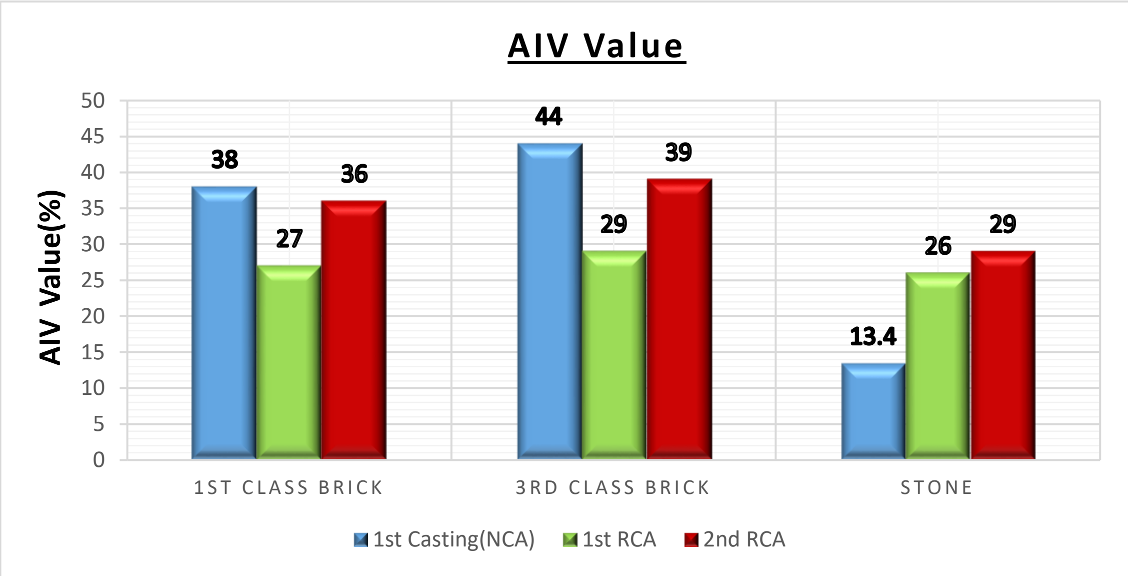

Fig-5.1: Comparison of AIV of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

Comments:

1. The AIV value decreased in RCA in case of bricks recycled for the first time but it increased in case of RCA after recycling for the second time in comparison with first time RCA as AIV<30%.
2. In the case of stone, it showed the opposite pattern and increased gradually in RCA.
3. The strength of stone NCA is more than stone RCA. But the strength of brick NCA is less than brick RCA.
4. The stone RCA and brick RCA, recycled for the first time can be used for road surface course

5.1.2 Comparison in ACV

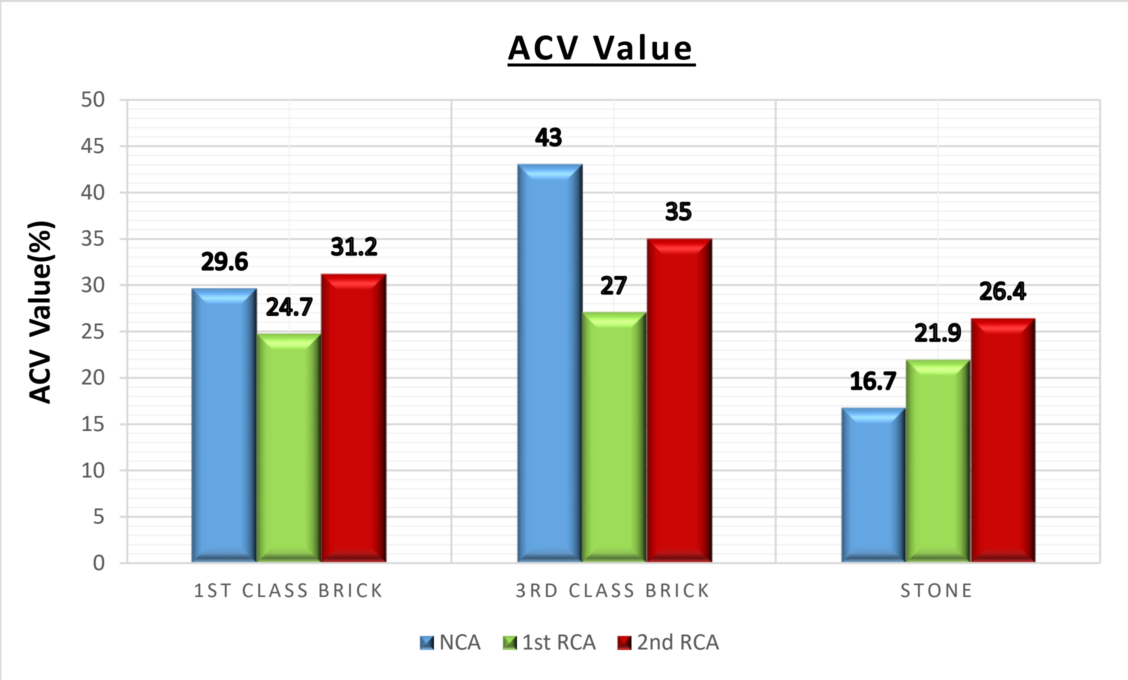

Fig-5.2: Comparison of ACV of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

Comments:

1. The ACV of brick RCA decreased after first recycling but increased after second recycling.
2. The ACV of stone increased gradually in RCA
3. Brick RCA of 1st class brick and stone can be used in the concrete pavement (ACV 20~30%)
4. Brick RCA of 3rd Class brick can be used in pavement wearing. (ACV<45%)

5.1.3 Comparison in EI

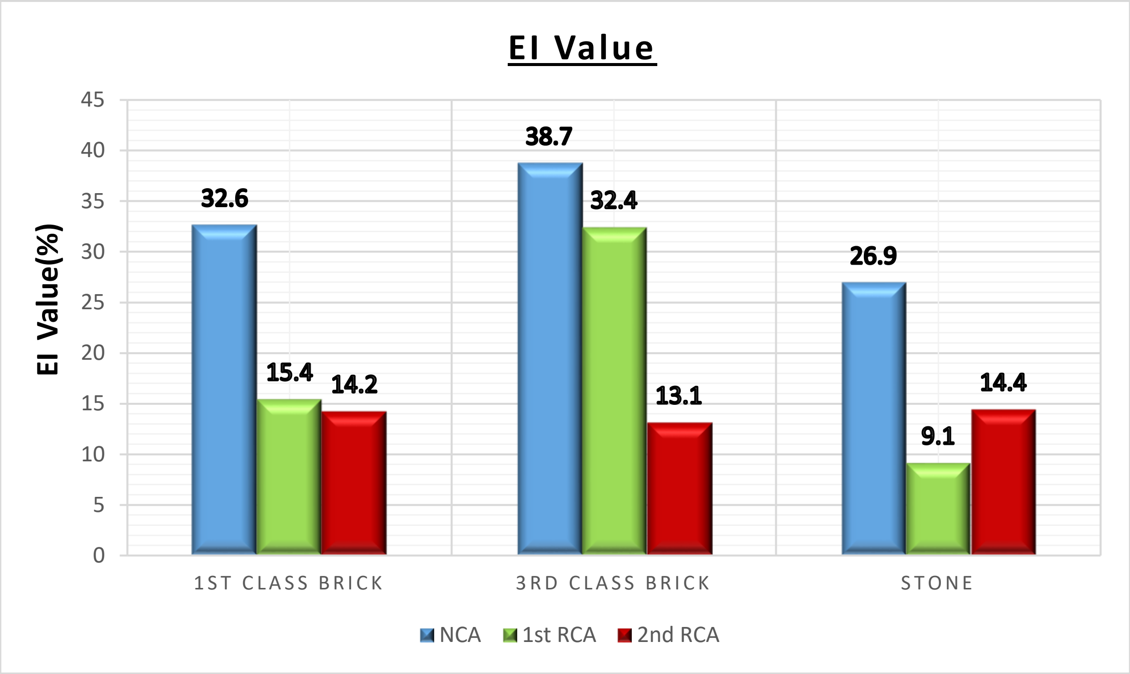

Fig-5.3: Comparison of EI of 1st Class, 3rd Class Brick and Stone as NCA and RCA

Comments:

1. The EI value of both brick and stone RCA is decreasing after 1st and 2nd recycling.
2. The aggregate having EI >45% is unsuitable for construction work, thus both brick and stone RCA can be used for the construction.
3. Elongated aggregate is also not suitable for the road construction due to it will break in heavy traffic load. Thus both the RCA of brick and stone can be used for road construction (EI < 45%, BS 1241)

5.1.4 Comparison in FI

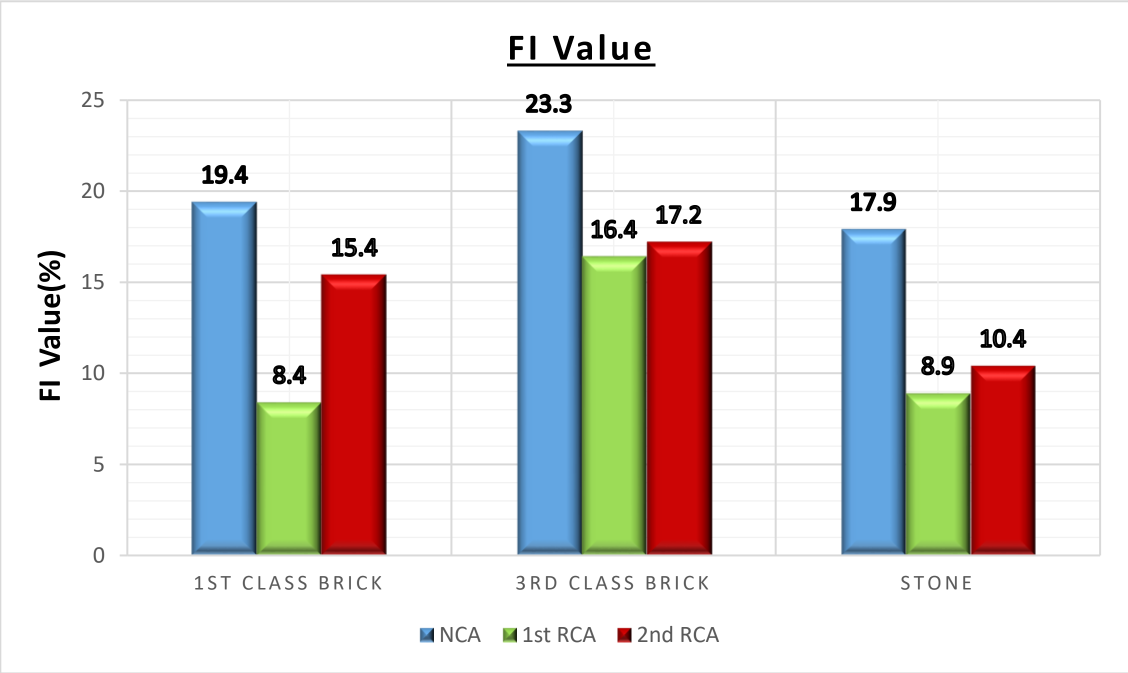

Fig-5.4: Comparison of FI of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

Comments:

1. The FI value decreased in brick RCA and stone RCA after 1st time recycling but increased after the second time and still, the value is less than brick NCA
2. The aggregate having FI less than 30% is suitable for concrete mix, thus both brick and stone RCA satisfy this condition.
3. The brick and stone RCA both are suitable for road construction since the value is less than 30%(BS 1241)

5.1.5 Comparison in LAAV

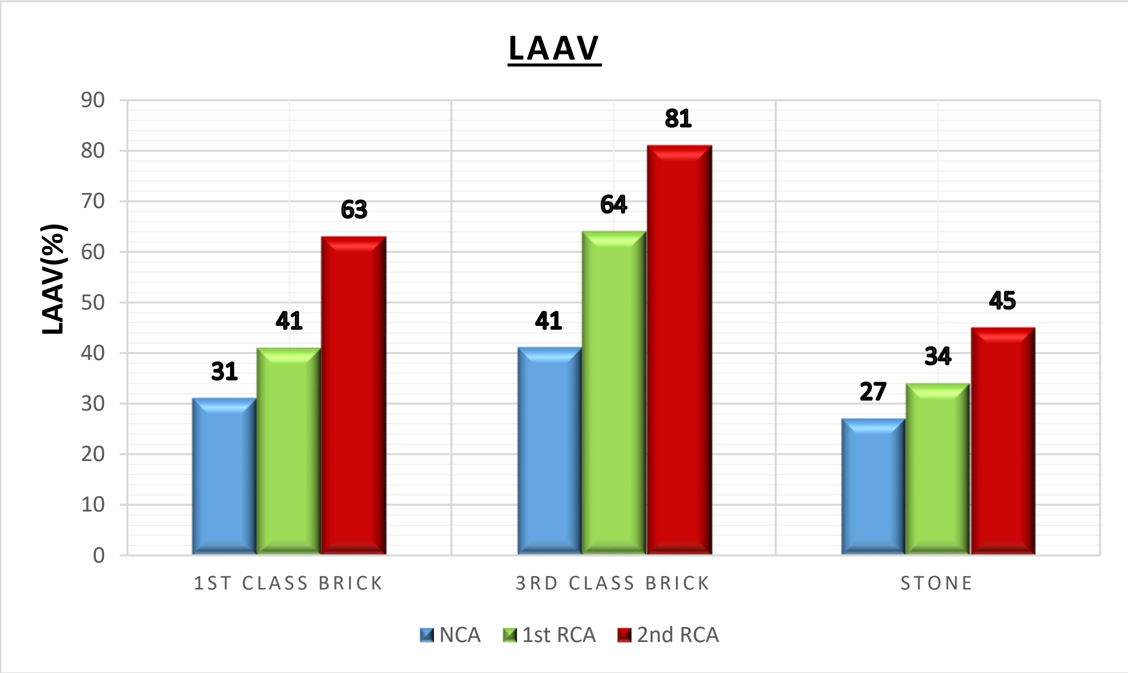

Fig-5.5: Comparison of LAAV of 1st Class, 3rd Class Brick and Stone as NCA and RCA.

Comments:

1. The LAAV value of both brick and stone RCA increase gradually.
2. According to AASHTO 90 LAAV for the base course should be less than 40% and for sub base course it should be less than 50%. According to road design standard of the rural road by LGED and JICA the LAAV should not exceed 40% for base course.
3. Thus RCA of Stone and 1st time recycled brick can be used as base and subbase and the RCA of 2nd time recycled can be used as sub-base in road construction.

5.2 Comparison in Cylinder Compressive Test

5.2.1 Comparison in 1st Class Brick

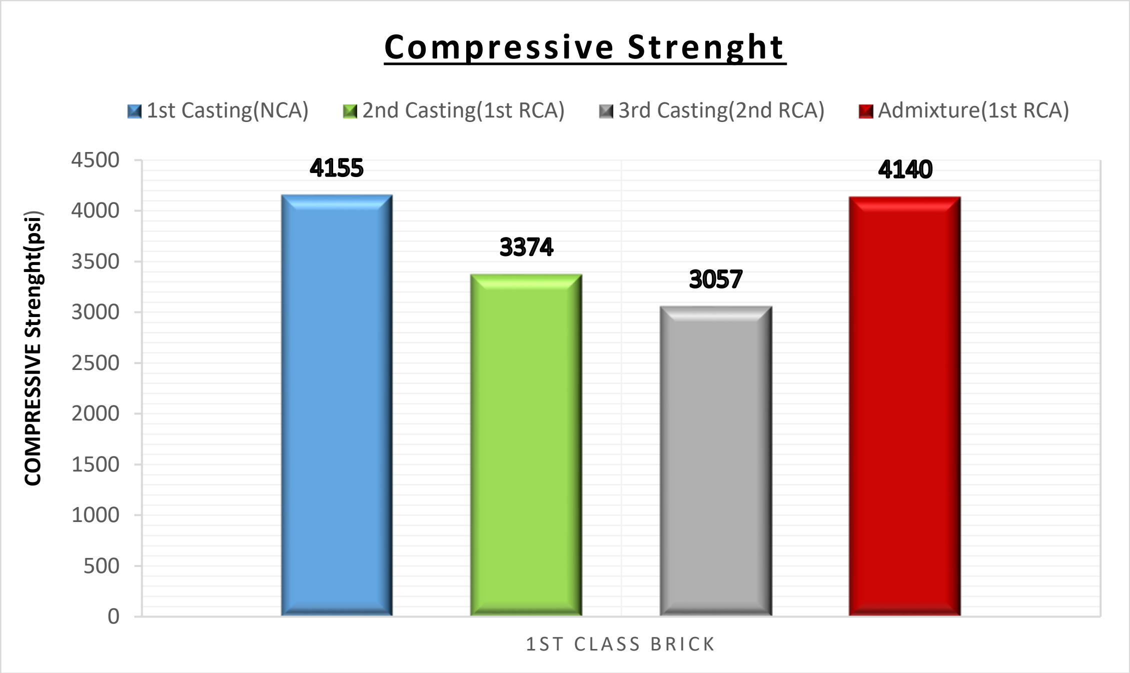

Fig-5.6: Comparison of Compressive Strength of 1st Class Brick as NCA and RCA.

Comments:

1. The compressive strength of concrete block with brick RCA gradually decrease with the number of recycling.
2. The strength is regained by the use of admixture (Master Rheobuilt 623) and 99% strength is regained using the admixture.
3. So RCA can be used in construction with admixture in case of first-class brick.

5.2.2 Comparison in 3rd Class Brick

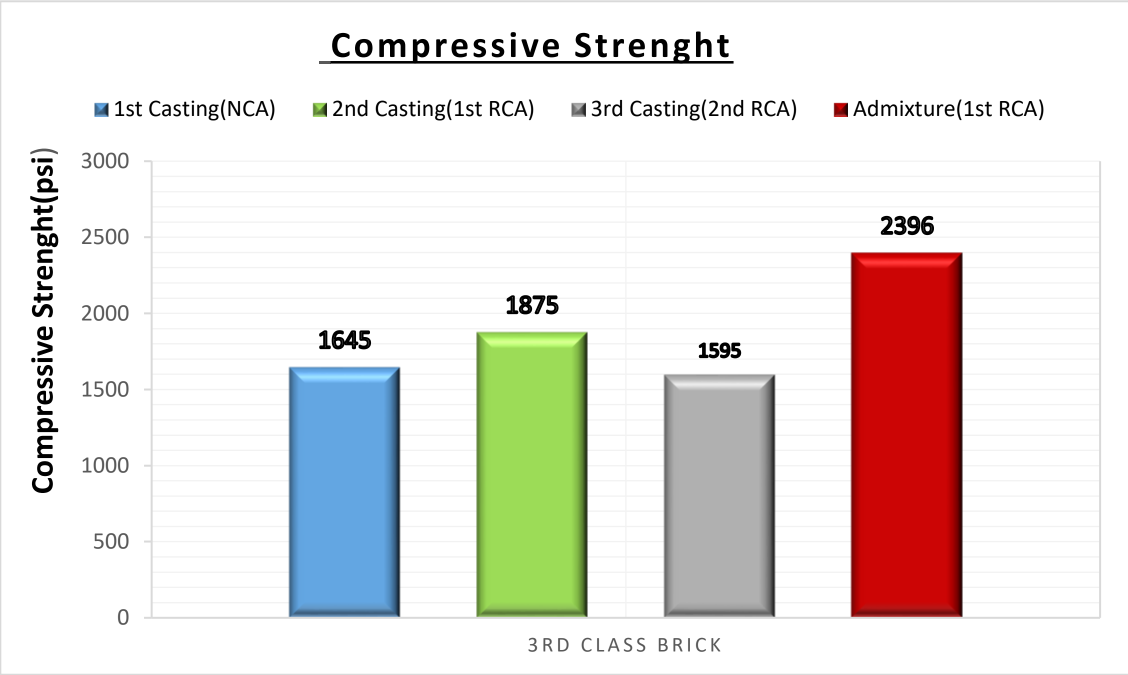

Fig-5.7: Comparison of Compressive Strength of 3rd Class Brick as NCA and RCA.

Comments:

1. The compressive strength of concrete block with 3rd brick RCA initially gained better strength than NCA concrete due to the addition of cement increased the aggregate strength. But during 2nd recycling, the strength reduced by approx. 5%

2. The strength is regained by the use of admixture (Master Rheobuilt 623) and it is more than the initial concrete with NCA.

5.2.3 Comparison in Stone

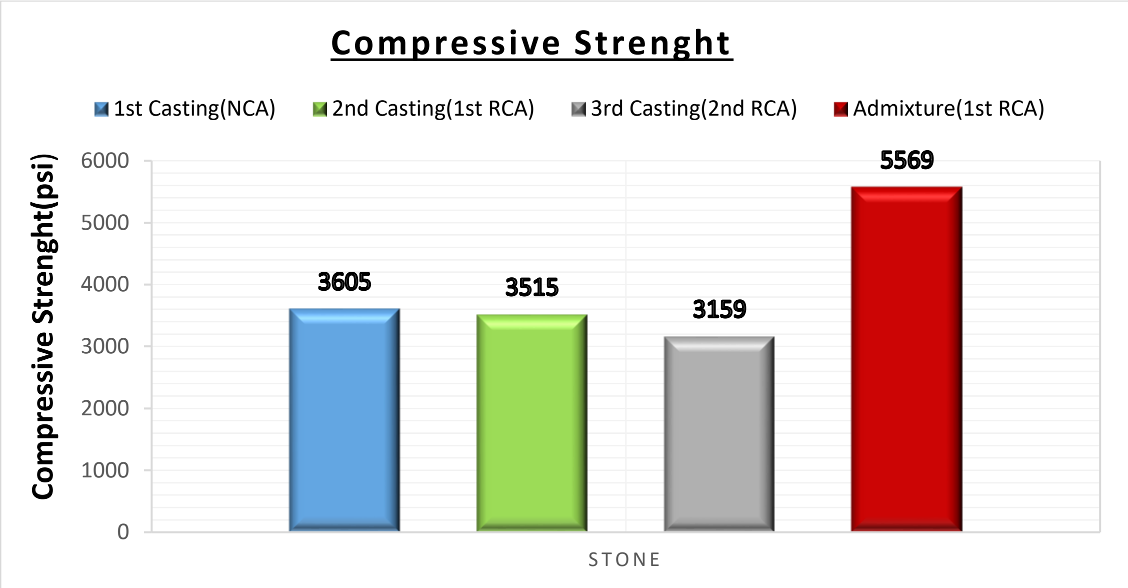

Fig-5.8: Comparison of Compressive Strength of Stone as NCA and RCA.

Comments:

1. The compressive strength of the stone block decreased the number of recycling but the rate of strength reduction is less compared to 1st class brick. (Reduction rate average=5%)
2. Again the strength regained by the use of admixture is much more than NCA concrete block (increased 55%).
3. So the RCA of stone performs better than RCA of brick.

5.3 Comparison in Cylinder Tensile Test

5.3.1 Comparison in 1st Class Brick

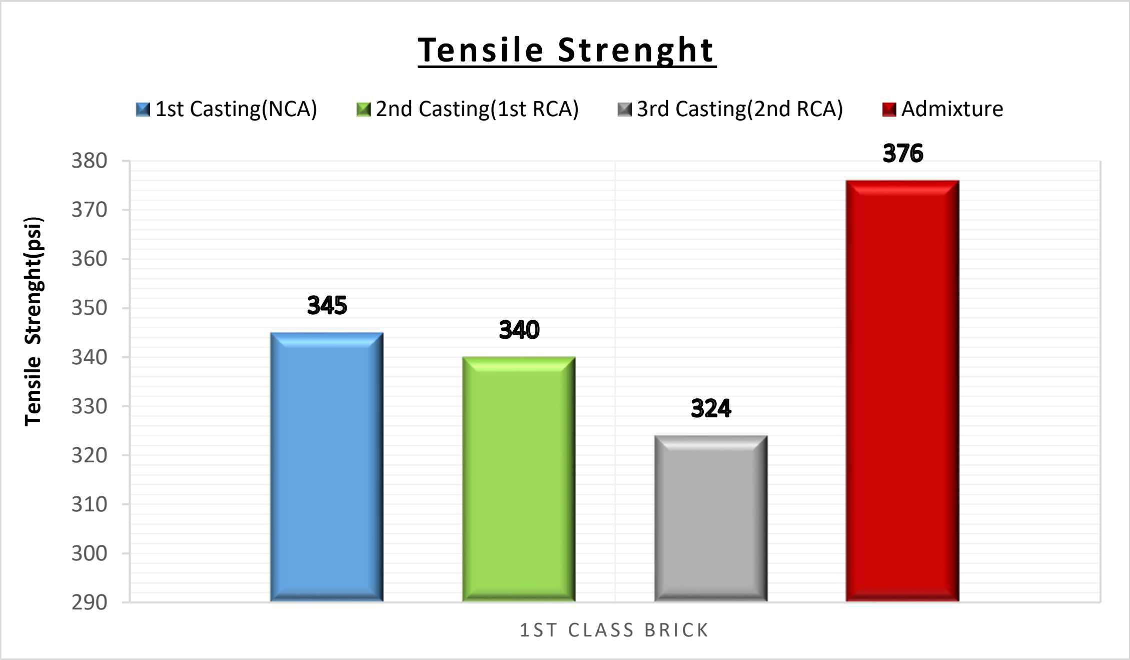

Fig-5.9: Comparison of Tensile Strength of 1st Class Brick as NCA and RCA.

Comments:

1. The tensile of concrete block with NCA decrease gradually with times of recycling.(Average reduction rate=1.05%)
2. Use of admixture gained the strength of RCA block by 8.9%.

5.3.2 Comparison in 3rd Class Brick

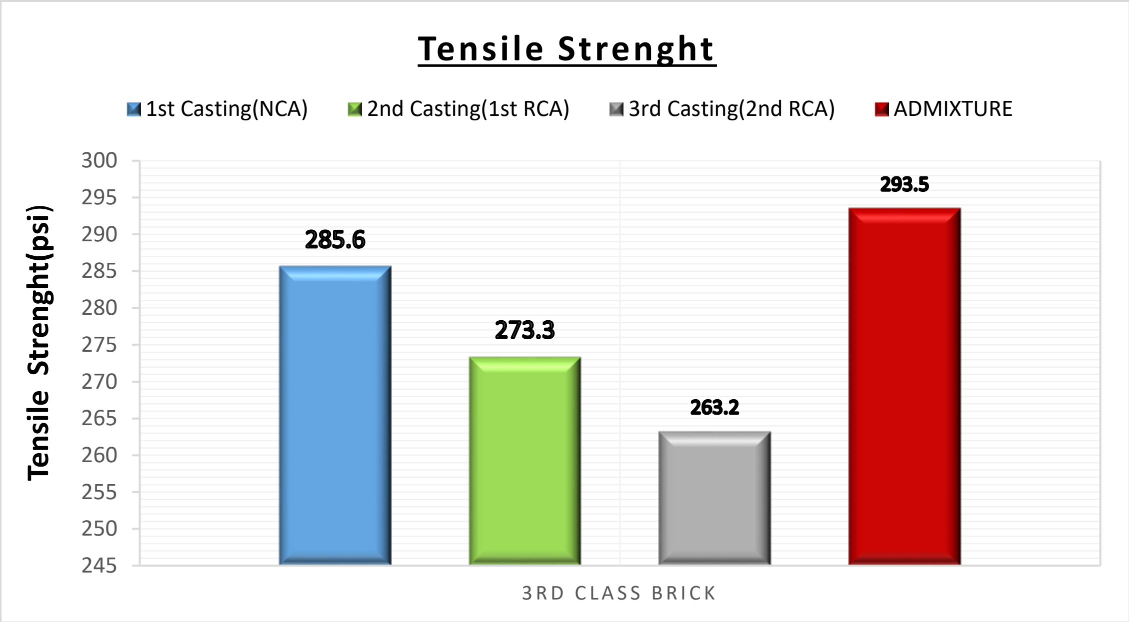

Fig-5.10: Comparison of Tensile Strength of 3rd Class Brick as NCA and RCA.

Comments:

1. The tensile of concrete block with NCA decrease gradually with times of recycling in 3rd class brick (Average reduction rate=3%)
2. Use of admixture gained the strength of RCA block by 2.77%.

5.3.3 Comparison in Stone

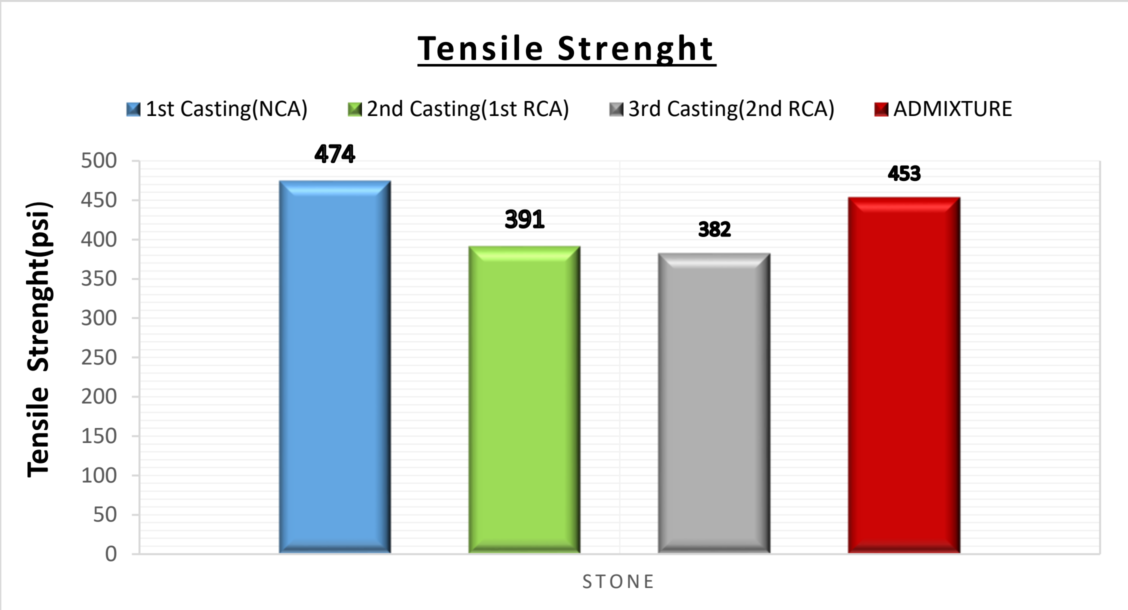

Fig-5.11: Comparison of Tensile Strength of Stone as NCA and RCA.

Comments:

1. The tensile of concrete block with NCA decrease gradually with times of recycling in 3rd class brick (Average reduction rate=9%)
2. Use of admixture gained the strength of RCA concrete block by 95%.of initial NCA concrete block.

5.4 Comparison among 1st Class Brick, 3rd Class Brick, and Stone

5.4.1 Compressive Strength

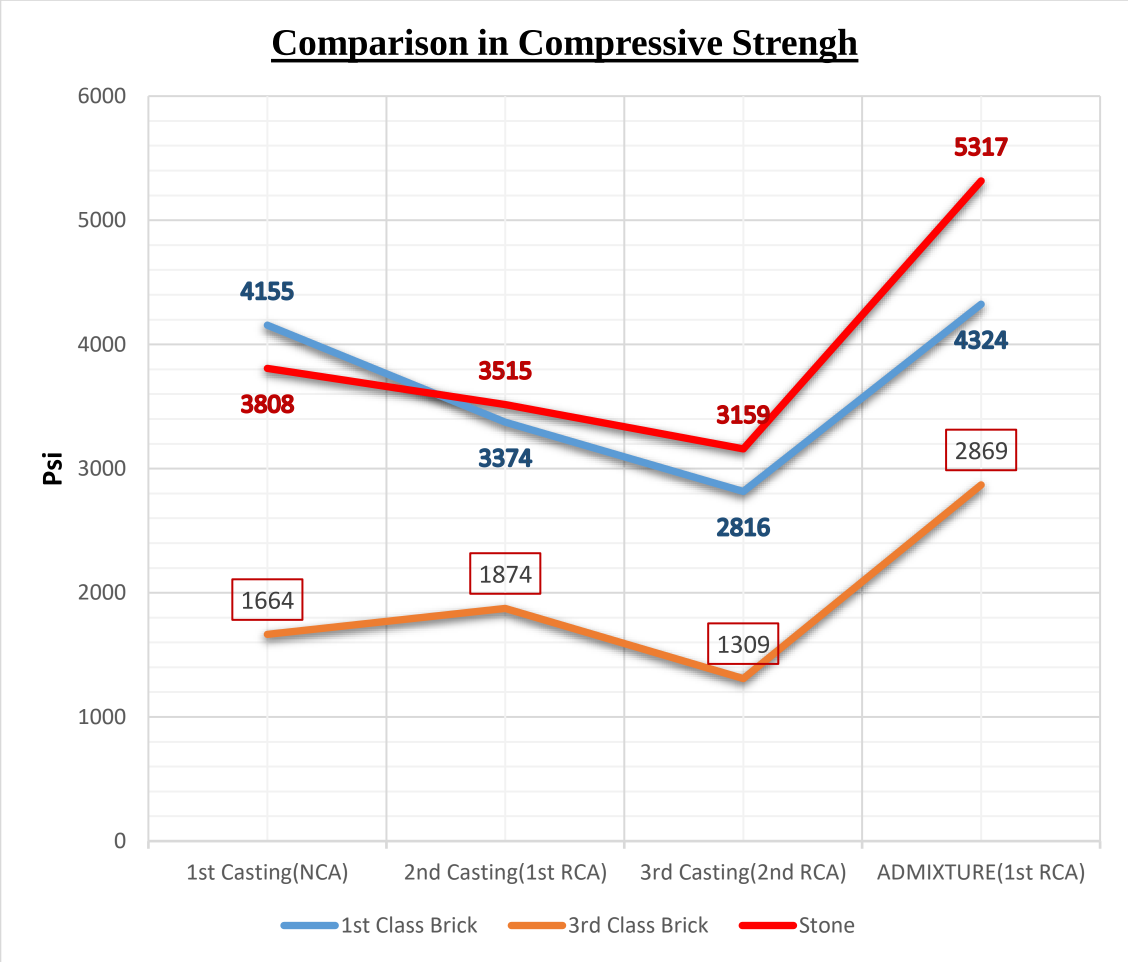

Fig-5.12: Comparison of Compressive Strength of 1st Class, 3rd Class Brick, and Stone

Comments:

1. The compression strength curve shows the similar behavior of 1st class brick and stone where the strength gradually decreased and regained with the addition of admixture.

2. In case of 3rd class brick, the compressive strength initially increased and then decreased in 2nd time recycle. Addition of admixture increased the strength but the overall compressive strength is below 2500 psi in all case.

3. The reduction rate of concrete RCA block is more than RCA stone block

4. The strength gained due to admixture is much more in RCA stone block than that of brick RCA.

5.4.2 Tensile Strength

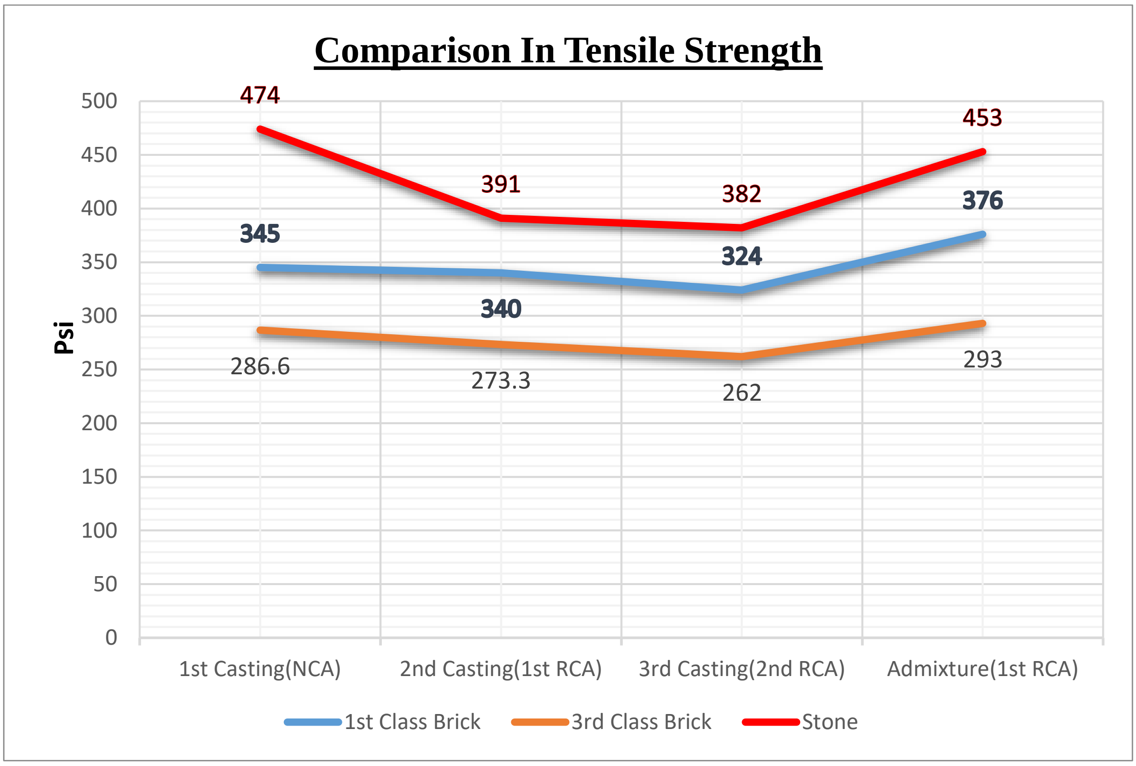

Fig-5.13: Comparison of Tensile Strength of 1st Class, 3rd Class Brick, and Stone.

Comments:

1. The tensile strength behavior in all three cases shows the same pattern where the strength reduced in use of RCA.

2. The strength regained in all the case with the addition of admixture

3. Overall variation due to NCA and RCA in 1st class brick is 24%, 3rd class brick is 9% and stone is 6%.

5.5 Cost Comparison

5.5.1 Cost in 1st Class Brick

For estimating the cost per cft of concrete, the price of materials was taken corresponding to November 2018. Firstly the material cost was collected and the cost per cubic feet was calculated. This cost is actual or market cost of per cft of concrete. Then 100% of NCA used in initial estimating was replaced by cost less RCA. In this way, 80%, 60% and 40% of NCA were replaced by RCA and cost were calculated. This cost is shown in chart 5.14, 5.16 and 5.18. For easy assimilation and understanding chart 5.15, 5.17 and 5.19 was added which are showing the % value of saving for using the RCA.

5.5.1 Cost in 1st Class Brick

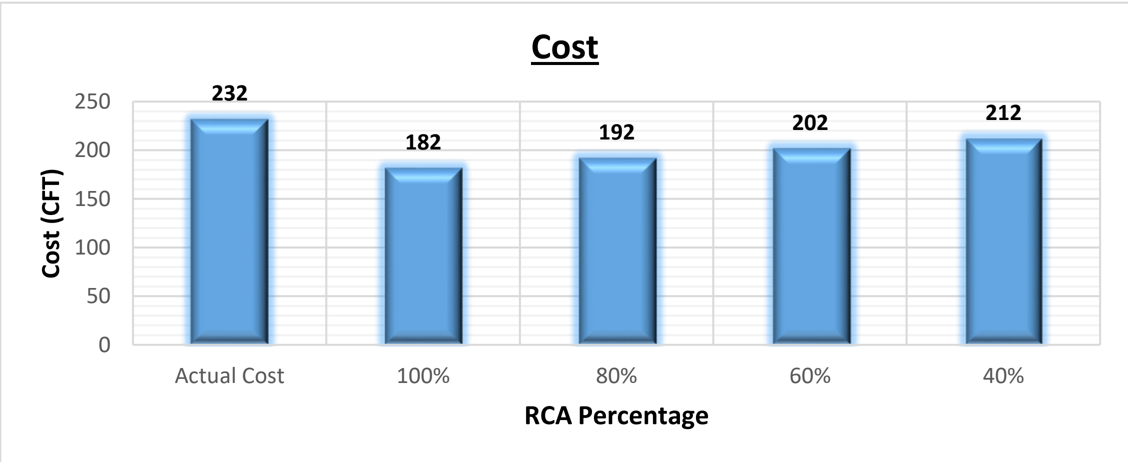

Fig.5.14: Cost comparison in 1st Class Brick by % of replacement of RCA

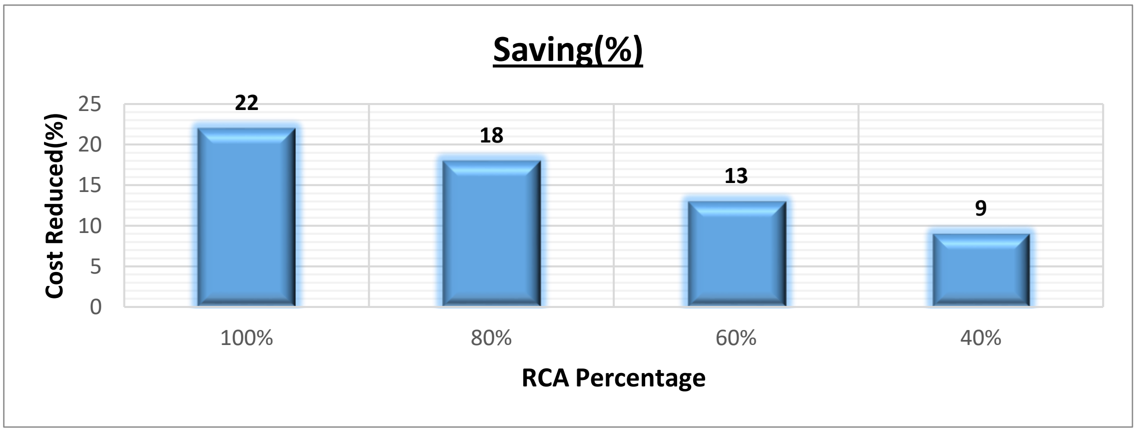

Fig.5.15: Percentage of saving by replacement of % of RCA

5.5.2 Cost in 3rd Class Brick

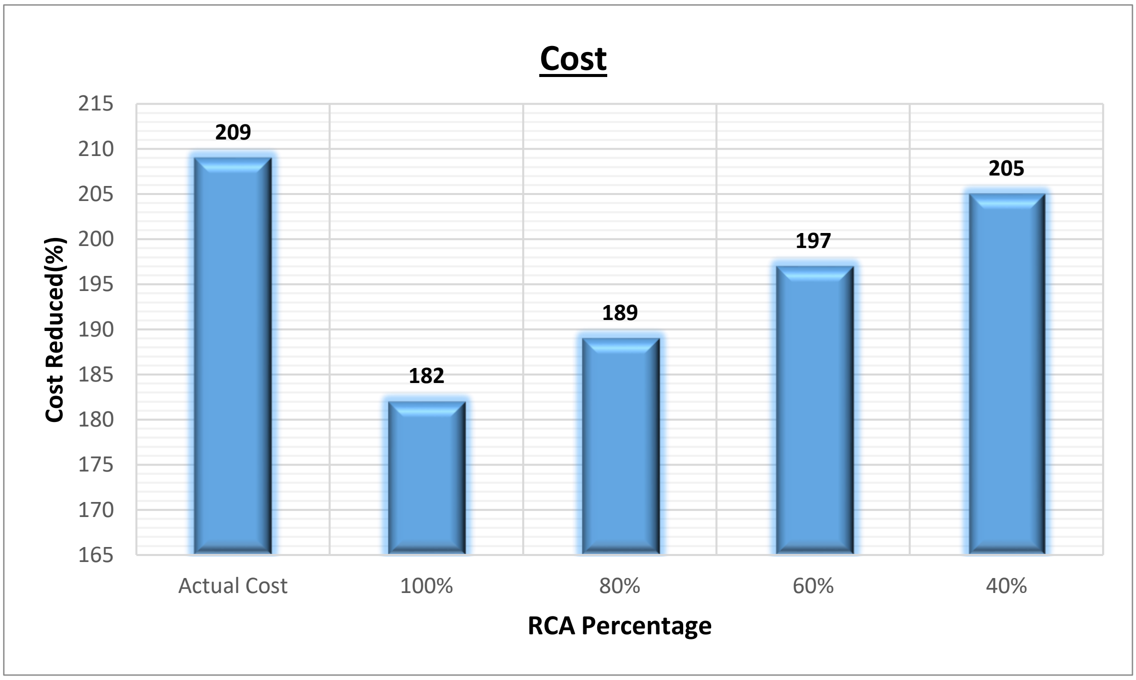

Fig.5.16: Cost comparison in 3rd Class Brick by % of replacement of RCA

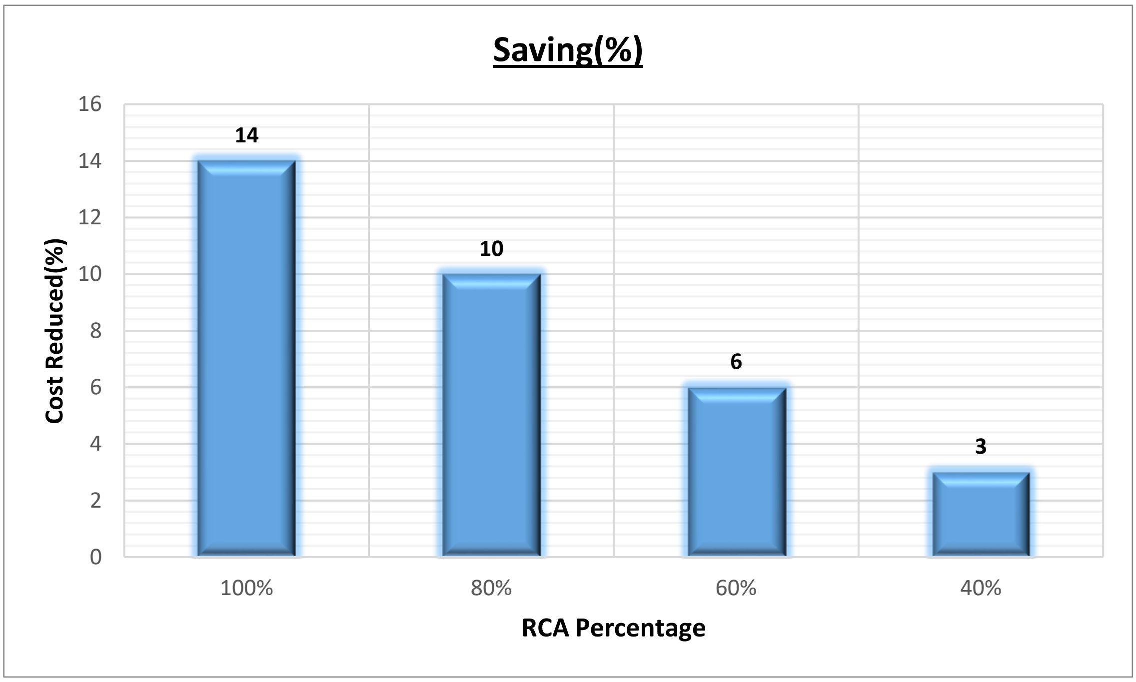

Fig.5.17: Percentage of saving by replacement of % of RCA

5.5.3 Cost in Stone

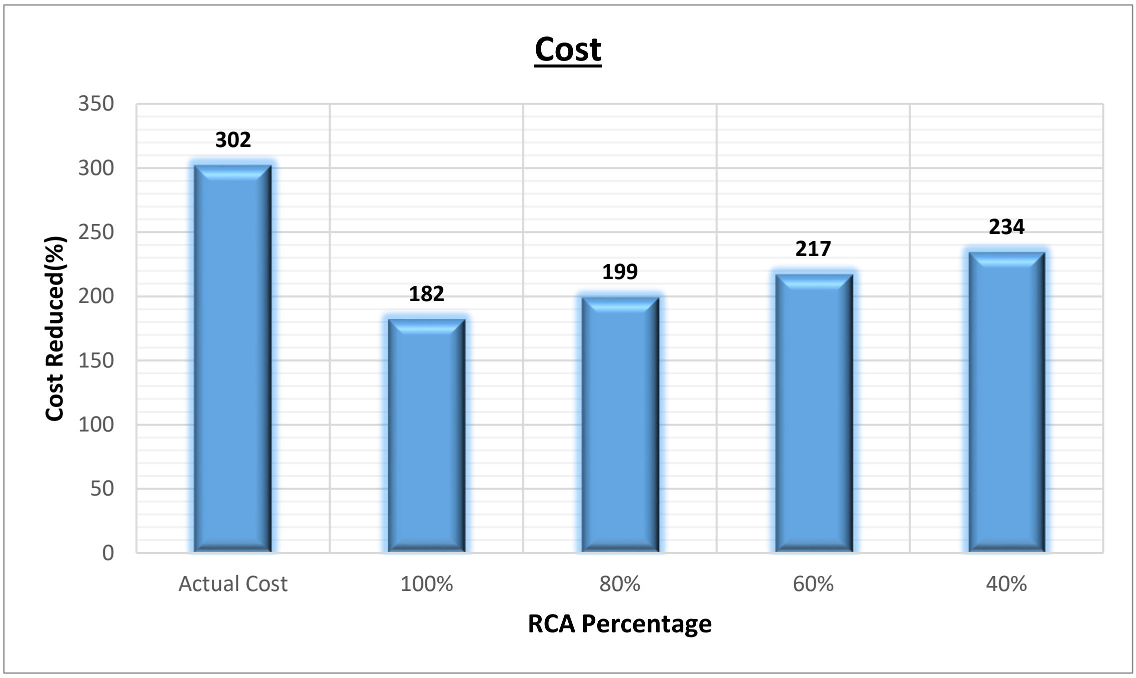

Fig.5.18: Cost comparison in Stone by % of replacement of RCA

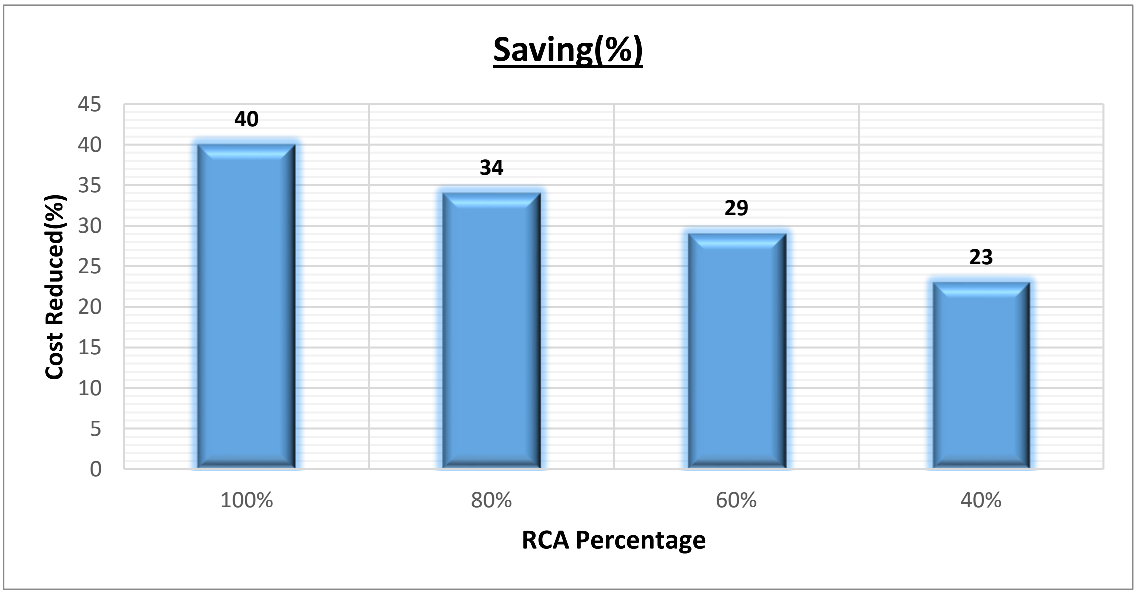

Fig.5.19: Percentage of saving by replacement of % of RCA

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Findings from the study:

Base on the aggregate test properties and strength of the NCA and RCA of brick and stone chips, the findings of the study are as follow

1. Both brick and stone chips showed a similar pattern in subsequent recycling and the strength reduced gradually in 1st class brick and stone. The aggregate properties also deteriorate in stone and brick chips except in brick RCA, the ACV and AIV value decreased than NCA. Overall results states that stone chips serve better than brick chips as RCA in all the aggregate test. The RCA of Stone has better strength in both compression and tensile test than RCA of 1st class brick. Therefore, it is preferable to use stone in a temporary structure, which may be further be reconstructed. In case of 3rd case brick RCA, it fails many of the tests and preferably should not be used as RCA

2. Both NCA is better in compression strength than RCA. To achieve higher strength and workability admixture was used with 1st RCA of both brick and stone aggregate and 95% of initial strength could be achieved in case of 1st class brick and 167% of initial strength achieved in stone RCA, which refers that stone is much better RCA than 1st class brick RCA. But both 1st class and stone RCA can be used in construction and pavement design since both passes in property test. In case of 3rd class brick, RCA strength increased but lack in other parameters. Thus not suitable as RCA.

3. The overall cost reduction in the use of 1st class brick is 22% while it is 40% in case of stone if 100% RCA is used. But practically 100 % RCA may not be available and if 40% replacement is possible then cost will be reduced to 9% in 1st class brick and 23% in stone which is very economic for construction.

6.2 Limitations of this study:

Despite controlling the required process for the individual test there were limitations. They are as follow:

1. The study may be limited in two brick and one stone sample and with a fixed mix ratio. This narrowed the result of the study to a particular source of the sample but for the final conclusion, a wide variety of samples should be taken

2. The number of samples cast was limited as well as there was human error. The instruments required for a long time like oven cannot be operated for 24 hours to get the actual dry weight.

3. The use of admixture was limited in one sample only. And the composition for mix design was also one since the study objective required fixed mix design in all sample casted

4. There were many test properties like modulus of elasticity, ductility and brittle behavior of the concrete could not be achieved due to time limitation

5. The cost comparison is time dependent and may change nature in the future.

6. The main limitation was the time. Due to time limitation, the actual or exact RCA strength was obtained. As a building will retain a minimum time after construction there may be a change in an aggregate property of RCA.

6.3 Conclusion:

At present more importance is given in environmental aspects of construction as well cost is the most concern part of construction works. But both cannot be satisfied together because eco-friendly construction involves cost. So this study involved to compromise two opposite aspects and can deduce an approximate solution that is a use of RCA. The study showed that stone RCA is comparatively better than brick RCA and use of admixture can regain the strength. RCA of 3rd class brick is not suitable for construction. So construction of less important elements of building like slab secondary beam, exterior beams can be designed with RCA to reduce the cost as well as ensure the strength. It is also environmentally good and aggregate sources are less used. RCA in pavement design can reduce cost as the buildings demolished to construct the road can be economically used or else this RCA needs to be transported as garbage and aggregate from other source need to be used which involves double cost. Finally, the use of RCA extensively can dissolve the misunderstanding between general mass that is RCA is not just a waste rather proper use RCA can save cost and also environmental friendly.

6.4 Recommendations for future study:

Recycled concrete is a vast field of works since the construction volume at present days are increasing hugely as well as the source is limited to this study is actually nothing but the demand of time and further future study can be carried on following aspects:

1. Use of different available brick and stone sample of our country for study.
2. Study on recycled aggregate based on time variation.
3. Recycling of composite structure and its feasibility
4. The behavior of NCA and RCA in a marine environment like cox bazar.
5. The behavior of RCA under fire.
6. Associating RCA with green building concept so that a building constructed in such that even after demolition it can be used as effective RCA

REFERENCES

ASTM C29/C29M-17a Standard Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate.

ASTM C39/C39M-17b Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

ASTM C127-15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate.

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BS 812-105.1:1989. Testing Aggregates. Methods for Determination of Particle Shape. Flakiness Index.

BS 812-105.2:1990. Testing Aggregates. Methods for Determination of Particle Shape. Elongation Index of Coarse Aggregate.

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BS 812-112:1990. Testing Aggregates. Methods for Determination of Aggregate Impact Value (AIV).

Local Government Engineering Department, Local Government Engineering Department (LGED) and Japan International Cooperation Agency.

BS 1241 Tarmacadam and tar carpets (gravel aggregate)

APPENDIX

➢ Aggregate Impact Value (AIV)

Type	Sample Name	Mass of container (g)	Mass of container + Agg (g)	Mass of Agg, A (g)	Mass of Agg passing 2.36 mm sieve, B (g)	AIV= (B/A)*100
1st Class Brick	NCA	1071	1320	249	95	38
	1st RCA	1071	1339	268	73	27
	2nd RCA	1071	1341	270	98	36
2nd Class Brick	NCA	1071	1342	271	120	44
	1st RCA	1071	1338	267	78	29
	2nd RCA	1071	1321	250	98	39
Stone	NCA	1071	1405	334	45	13.3
	1st RCA	1071	1368	297	78	26
	2nd RCA	1071	1363	292	85	29

➢ Aggregate Crushing Value (ACV)

Type	Sample Name	Mass of container (g)	Mass of container + Agg (g)	Mass of Agg, A (g)	Mass of Agg passing 2.36 mm sieve, B (g)	ACV= (B/A)*100
1st Class Brick	NCA	1623	3750	2127	630	29.6
	1st RCA	1623	3763	2140	529	24.7
	2nd RCA	1623	3771	2148	671	31.2
2nd Class Brick	NCA	1623	3723	2100	903	43
	1st RCA	1623	3735	2112	571	27
	2nd RCA	1623	3742	2119	742	35
Stone	NCA	1623	4223	2600	435	16.7
	1st RCA	1623	4203	2580	566	21.9
	2nd RCA	1623	4183	2560	676	26.4

➢ Specific Gravity

Type	Casting	OD (gm)	SSD (gm)	SSD Submerged	Specific Gravity (OD)	Specific Gravity (SSD)	Specific Gravity (Apparent)
1st Class Brick	NCA	1262	1323	651	1.88	1.97	2.07
	1st RCA	1252	1317	709	2.06	2.17	2.31
	2nd RCA	1302	1371	741	2.07	2.18	2.33
3rd Class Brick	NCA	1250	1321	629	1.81	1.91	2.02
	1st RCA	1030	1108	588	1.99	2.14	2.34
	2nd RCA	1123	1213	652	2.01	2.17	2.39
Stone	NCA	1050	1069	669	2.63	2.68	2.76
	1st RCA	1120	1164	709	2.47	2.56	2.73
	2nd RCA	1113	1161	695	2.39	2.5	2.67

➢ Elongation Index

Type	Sieve Size(Retained)							EI
	Sample Name	25.4-19 mm	19-12.7 mm	12.7-9.5 mm	9.5-6.35 mm	6.35-Pan mm	Total	
		gm	gm	gm	gm	gm	gm	
1st Class Brick	NCA	970	390	202	50	18	1630	32.6
	1st RCA	50	451	102.5	155	12	770.5	15.41
	2nd RCA	0	560	110	31	9	710	14.2
3rd Class Brick	NCA	901	512	386	91	49	1939	38.78
	1st RCA	763	465	195	152.5	43	1618	32.37
	2nd RCA	0	400	102.5	105	45	652.5	13.05
Stone	NCA	0	760	649	236	0	1645	32.9
	1st RCA	0	275	145	35	0	455	9.1
	2nd RCA	0	230	460	31	0	721	14.42

Flakiness Index

Type	Sample Name	Sieve Size(Retained)						FI
		25.4-19 mm	19-12.7 mm	12.7-9.5 mm	9.5-6.35 mm	6.35-Pan mm	Total	
		gm	gm	gm	gm	gm	gm	
1st Class Brick	NCA	561	191	131	70	18	971	19.42
	1st RCA	180	40	75	115	5	415	8.3
	2nd RCA	406	165	172	27	0	770	15.4
3rd Class Brick	NCA	302	401	356	71	31	1161	23.22
	1st RCA	481	201	65	42	31	820	16.4
	2nd RCA	255	545	40	21	0	861	17.22
Stone	NCA	0	210	465	201	20	896	17.92
	1st RCA	220	165	35	25	0	445	8.9
	2nd RCA	61	278	172	21	0	532	10.64

- **Voids Ratio**

Type	Sample Name	Unit Weight A(kg/L)	Specific Gravity(Oven Dry) B	Void(%)= ((B-A)/B)*100
1st Class Brick	NCA	1.645	2.63	37.46
	1st RCA	1.526	2.47	38.22
	2nd RCA	1.432	2.39	40.09
3rd Class Brick	NCA	1.192	2.06	42.14
	1st RCA	1.16	1.88	38.3
	2nd RCA	1.265	2.07	38.89
Stone	NCA	1.197	2.01	40.45
	1st RCA	1.013	1.81	44.04
	2nd RCA	1.25	1.99	37.19

➢ Los Angeles Abrasion Value

Type	Sample Name	Sample Weight W_1 gm	Weight passing 1.7mm IS sieve W_2 gm	Abrasion Value = (W2 / W1) X 100
1st Class Brick	NCA	5000	1550	31
	1st RCA	5000	2050	41
	2nd RCA	5000	3150	63
3rd Class Brick	NCA	5000	2050	41
	1st RCA	5000	3200	64
	2nd RCA	5000	4050	81
Stone	NCA	5000	1350	27
	1st RCA	5000	1700	34
	2nd RCA	5000	2250	45