**International Journal of Engineering Research And Management (IJERM)**
**ISSN: 2349- 2058, Volume-08, Issue-01, January 2021**

# Behaviour of Recycled Coarse Aggregate Including Plain Cement Concrete

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*Abstract*— **In the era of construction, concrete has been the leading building material since it was discovered and found viable for future due to its durability, easy maintenance, wide range of properties and adaptability to any shape and size. Concrete is the composite mix of cement, aggregates, sand and water. Concrete gets hardened like stone on mixing water with cement and aggregates. Concrete have two type ingredients namely active and inactive. The active group consists of water and cement. The inactive part consists of sand and coarse aggregates. Concrete have high compressive strength and low tensile strength. To overcome this shortcoming, steel reinforcements are used along with the concrete. This type of concrete is called reinforced cement concrete (RCC).**

## INTRODUCTION

Concrete structures that are designed to have service lives of at least 50 years have to be demolished after 20 or 30 years because of deterioration caused by many agents. Old buildings require maintenance for better and higher economics gains. The rate of demolition has increased and there is a shortage in dumping space and also increase in cost of dumping. Instead of dumping this demolished concrete, use of demolished as recycled concrete would not only reduce the cost but also will conserve the non renewable energy sources. The use of demolished concrete will further result in reduction in use of natural aggregates. The usage of natural aggregates is causing damage to natural resources resulting in imbalance in environment. Recycled aggregates consist of crushed, graded inorganic particles obtained from the materials that have been used in constructions. Recycled aggregates are generally obtained from buildings, roads and bridges which are demolished due to completion of life, wars and earthquake.

Earthquakes and bombarding in wars causes a lot of destruction of buildings and roads causing generation of a lot of concrete waste. In Second World War, bombardment caused demolition of buildings and roads. Transportations and reconstruction were the restrains in economy. At the same time, disposal of concrete waste was also a big problem. The idea of reusing demolished concrete as aggregates gave a solution to this problem and hence was justified as alternative material source in 1976.

Worldwide aggregate use is estimated to be ten to eleven billion tonnes each year. Of this, approximately eight billion tonnes of aggregate (sand, gravel, and crushed rock) is being used in Portland cement concrete (PCC) every year [Naik 2005, Mehta 2001]. Also there is a critical reduction of natural aggregate and an increasing amount of demolished concrete [Hansen 1984]. It is estimated that 150 million ton of concrete waste is produced in the United States annually [Salem 2003]. In 2005, the American Society of Civil Engineers reported US infrastructure in poor condition with an estimated repair cost of $1.6 trillion over five years.

Manuscript received Dec, 2020

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## OBJECTIVES OF THE STUDY

The study on use of demolished concrete in pavement construction consists of conducting laboratory investigations on cement concrete prepared by using demolished concrete to estimate its suitability for pavement construction. The main objectives of study are:

1. To prepare mix design for M40 concrete with varying proportions of recycled aggregates.
2. To determine the compressive strength of the samples at the end of 7, 28, 56 and 90 days.
3. To determine the flexural strength of the samples at the end of 7,28, and 90 days
4. To determine the sulphate resistance strength of samples at the end of 7, 28 and 56 days.

The purpose of this research was to study the behavior of recycled coarse aggregates when it was included in Plain Cement Concrete. Slump test was performed on freshly mixed concrete, and compression test was performed on hardened concrete. 135 samples of concrete were prepared with RCA and natural aggregate, changing their mixture design parameters, including coarse aggregate proportion.

## LITERATURE REVIEW

A lot of investigations have been done for use of demolished concrete and it was found that the use of recycled aggregate is an appropriate solution to the problem of dumping and transportation of demolished concrete. It was found that the recycled aggregates are valuable building material in environmental, economical and technical aspects. Initially recycled aggregates were used as landfills but now a day they are also used for constructions for building and roads. Recycled aggregates have been used as concrete kerb and gutter mix in Australia [Shing Chai NGO,2004]. In the project of Lenthall Street in Sydney, 10 mm recycled aggregates and blended recycled sand are used for concrete kerb and gutter mix.

In road construction recycled aggregates are used as granular base course. They have proved better than the natural aggregates when used as granular base course. In case of wet sub grade areas, recycled aggregates stabilize the base and provide an improved working surface for pavement structure construction. Recycled aggregates are used as base, sub base course and sometimes for foundation purpose also. In USA, the use of recycling technology in a number of full scale

pavement rehabilitation projects has been accomplished since 1976 [Kumar,Satish,2002].
Market development study for recycled aggregates products [ Shing Chai NGO,2004] stated that recycled aggregates can be used in embankment fill. The embankment site is on the wet sub grade areas, recycled aggregates can stabilize the base and provide an improved working surface for the remaining work. In Hongkong they are used as paving blocks. Norwegian Building Research Institute mentioned that RCA can be used as backfill materials in pipe zones.
In Lowa [Kumar,Satish,2002] recycled concrete was first used in 1976 for the production of new concrete where a 41 years old pavement was crushed and demolished concrete was used for the construction of 1 mile long and 22.5 cm thick highway pavement. In other construction of 17 mile long and 20 cm thick highway pavement, crushed concrete was used in Lowa in 1978. The Minnesota department of transportation recycled 16 mile long plain concrete pavement into a new concrete pavement on trunk highway in 1980. In Netherland, recycled aggregates are used for partition walls in apartments. After the damage caused in Second World War, countries like Germany, England, Netherland and other European countries have tried to use recycled concrete in new construction and made a lot of investigations over it. Some countries have developed code of practice for the use of recycled aggregates. In India recycled aggregates are not much used, but its future seems bright and one can predict remarkable contribution of recycled aggregates.

## REVIEW OF LITERATURE

### Compressive Strength

The ability to resist compression loads is called Compressive strength. It is found that the use of RCA in the concrete mix decreases compressive strength compared to natural aggregate. But it is also found that, at 28 days, all mix designs usually exceed 50MPa compressive strength [Shayan 2003]. In one study it is found that the compressive strength of natural concrete was 58.6 MPa, and the RCA concrete ranged from 50.9 to 62.1 MPa. The compressive strength for 50% RCA concrete was higher than 100% RCA concrete [Poon 2002]. In other study it is found that the loss of compressive strength is in the range of 30-40% for the concrete made with RCA at 28-days [Katz 2003]. There was very less reduction in 28- and 56-day compressive strength when natural aggregate was partially replaced with RCA and a much greater reduction when RCA was used in full [Abou-Zeid 2005].
The compressive strength is most affected by the w/c ratio [Lin 2004]. Other influential parameters include fine recycled aggregate content, cleanness of aggregate, interaction between fine recycled aggregate content and crushed brick content, and interaction between w/c ratio and coarse RCA content [Lin 2004]. At a constant w/c ratio, air-dried RCA containing concrete had the highest compressive strength compared to oven-dried and saturated surface dry RCA [Poon 2003]. Particularly at lower w/c ratios, unwashed RCA reduces compressive strength. Compressive strength is 60% of virgin concrete at 0.38 w/c and 75% at 0.6 w/c [Chen 2003].
In a study it is found that there is a strong interaction between maximum aggregate size and water-cement ratio when compared with compressive strength development [Tavakoli 1996a]. Due to a lower w/c ratio Compressive strength may increase for RCA, 14% and 34% respectively in comparison of natural aggregates. However, compressive strength may decrease for RCA since it has a higher air entrainment, 25%, compared to virgin aggregate 23% [Salem 2003]. The most of strength loss for RCA concrete can be caused by the presence of material smaller than 2 mm because natural sand has greater strength than RCA fines. It is recommended that RCA fines should not be more than 50% of the sand content [Shayan 2003]. Bonding between the RCA and the cement can be affected by loose particles created during the crushing process. Treating the RCA by impregnation of silica fume resulted in an increase in compressive strength of approximately at 30% at 7-days and 15% at 28-days. If RCA is exposed to ultrasound then it results in a uniform increase of 7% compressive strength over time [Katz 2004]. Compressive strength of the final concrete is affected by the age at which RCA has been crushed. For example, crushing concrete into RCA after three days compared to one day resulted in a seven percent increase in compressive strength of the new RCA concrete at 7 days. The difference in compressive strength of the new RCA concrete increased to 13% at the age of 90 days [Katz 2003]. The compressive strength of the original crushed concrete affects the compressive strength of the RCA concrete [Tavakoli 1996a]. However, it is also found that RCA concrete can produce higher compressive strengths than the original concrete [Ajdukiewicz 2002]. For example, an 80 MPa concrete was produced from an original 60MPa concrete [Ajdukiewicz 2002]. There was the same basic trend in all strength development when laboratory made RCA and field demolished RCA were compared [Tavakoli 1996a]. Presence of admixtures in the original concrete had not much impact on the compressive strength of the new RCA concrete [Hansen 1984].Slag added RCA concrete develops strength over a longer period of time compared to normal concrete. [Sagoe-Crentsil 2001]. Some research showed that compressive strength is dependent on the amount of time the RCA spent in the stockpile after crushing [Rashwan 1997]. For example, concrete made with RCA that was in the stockpile one day had a 25% higher compressive strength than concrete made with RCA that was in the stockpile 28 days. Concrete made with RCA that was in the stockpile seven days had 7% lower compressive strength than concrete that was in the stockpile 28 days [Rashwan 1997]. If RCA concrete is exposed to 600 $^{0}$C temperature then it showed good performance with a loss in compressive strength of 20-25% [Abou-Zeid 2005]. In s study it is also found that RCA concrete fails due to passage of cracks through the RCA, however when virgin concrete fails it is usually due to bond failure at the aggregate-paste interface [Salem 2003]

In 2002,Buyle-bodin, F.et. al. showed a comparison between the behavior of RAC and natural aggregates. The affect of both the composition and the curing conditions was discussed. It was observed that durability of RAC is controlled by flow properties of high total W/C ratio and air permeability. The diffusion of $CO_2$ is faster, that leads to a weaker resistance of RAC to environmental attacks.
In 2003, Hendricks, F. et.al developed the approach called design for recycling can be used to optimize design of constructions for later use and the design for disassembly can be used for demolition. For the technical aspects two models

were developed concerning degradation processes and the high graded applications. These models were based on life cycle assessment method.

In 2006, Poon C.S.et.al studied the environmental effects of using recycled aggregates. Concrete mixes were prepared with varying proportions of recycled aggregates. The proportion of recycled aggregates was kept varying from 0% to 100%. Target strength was kept 35 MPa. The investigations were made on affect of recycled aggregates on slump value and bleeding. The effects of delaying the bleeding tests and using fly ash on the bleeding of concrete have been examined. From this study it was found that the use of recycled aggregates caused higher rate of bleeding. The slump of concrete mixes or without recycled aggregates was increased due to replacement of cement by 25% fly ash. It reduced bleeding rate and bleeding capacity with only minor negative effects on concrete strength at or before 28 days, but it gave positive effects on strength at age of 90 days.

In 2006 , Rao, Aakash,et.al. investigated the effect of recycled aggregates concrete that can be used in lower end application of concrete. It was found that RCA can be used for making normal structural concrete with the addition of fly ash, condensed silica fume etc.

In 2007, Zhang, Xue-bing et.al. generated a formula for additional water requirement in recycled aggregate concrete. They found that the specific absorption of coarse aggregates increases as the time of water absorbing goes on. The speed of water absorption was greatest in first 10 minutes. Then it decreased and changed very little. The specific absorption and water absorption speed of RCA are greater than those of crushed stones and pebble, within the same time.

In 2008, Tabsh,Sami W.et.al investigated the strength concrete with use of recycled aggregates. The main objectives of study were the sources of recycled aggregates and the strength of recycled concrete . Test results showed that the losses as 50% for toughness and 12% for soundness test which are within acceptable limits. From this study it was found that recycled aggregates concrete required more water than the virgin concrete to maintain the same slump without use of admixture. It was also found that the strength was reduced to 10-25% with the use of recycled aggregates.

In a study by **P. Kathirvel et.al on effect of sulphate on self compacting concrete it was concluded that compressive** strength of replacement of 10% Lime was 5 percent higher than the control specimens. It was found that addition of limestone powder increases the sulphate resistance up to 10% which is 0.5 percent higher than that of virgin concrete. Density was reduced to 1.5 percent lesser for replacement of cement by 10% lime when compared to of concrete without replacement of cement by limestone. The reduction in density was 1 percent lesser for replacement of cement by 10% quarry dust when compared to of concrete without replacement of cement by quarry dust. The reduction in density was 1 percent lesser for both replacement of cement by 10% lime and quarry dust powder. The result of the study indicated that the replacement of cement with 10% lime improved the durability of Self–compacting concrete. The losses in mass and compressive strength of cubes were found to be negligible under Sulphate attack. It was observed that limestone and quarry dust powder resists Sulphate attack within tolerable limits

## METHODOLOGY

The methodology of the present study follows Indian Standard code IS: 516- 1959. Testing of strengths of concrete was carried out as per this code. Concrete mix design guidelines were as per IS: 10262-2009.

### SCOPE OF METHODOLOGY

This chapter covers the methods used for compressive strength, flexural strength and sulphate resistance tests of concrete with Recycled aggregates.

All the materials should be taken at room temperature before going for batching and mixing. Materials are taken separately to ensure the avoiding the mixing of foreign material in them. Materials should be taken in such a way as to produce a mix of desired grading. Sieves should be used to separate the fine aggregates and coarse aggregates.

### PROPORTIONING

Proportioning of the material should be done as per design mix. Proportions of the materials were decided as per weight used in test cubes and unit weight of materials.

### MIXING OF CONCRETE

Mixing of concrete should be done either by hand mixing or by machine mixing. In the present study, machine mixing was used for mixing of concrete. Power driven mixer was used for mixing the materials. All the mixing water was added to mixing drum before introducing the solid materials. Half of the coarse aggregate was added to drum, then fine aggregate was added following the addition of cement and at the last remaining coarse aggregate was added to drum. Mixing time was not taken more than 2 minutes after adding the materials to drum and mixing is continued till uniform concrete was appeared.

### CALCULATION

The flexural strength of the specimen should be expressed as the modulus of rupture σ Calculated as below

$$\sigma = \frac{FL}{bd^2}$$

Where

- *F* is the load (force) at the fracture point in MPa
- *L* is the length of the support (outer) span in mm
- b is width in mm
- d is thickness in mm

### SULPHATE RESISTANCE OF CONCRETE

Procedure of test should be same as of compressive strength except curing of samples. Curing of samples should be done in $MgSO_4$ solution for desired time period after keeping the cubes in water for 28 days.

Methodology of the present study includes the procedure of study. As discussed in chapter 1 , the main objectives of the study were to find out the compressive strength, flexural strength and sulfate resistance of the concrete made with demolished concrete. It was estimated that whether RCA concrete was usable in pavement construction. Methodology of this study has following parts:

1. Literature review of the available studies in various journals, conferences etc.
2. Collection of RCA and natural aggregate.
3. Investigation of physical and mechanical properties of concrete with of RCA and natural aggregate which includes sieve analysis, bulk density of aggregates (coarse+fine), water absorption of aggregates(coarse+fine) and specific gravity of aggregates(coarse+fine).
4. Mix design of concrete (M40).
5. Casting of test samples. (Cube for compressive strength and sulfate resistance, beams for flexural strength).
6. Curing of samples in water tank for specified time period. (curing in $MgSO_4$ solution for sulfate resistance).
7. Samples testing for compressive strength, flexural strength and sulfate resistance at specified time periods.
8. Analysis and discussions of test results.
9. Conclusions and recommendations.

## EXPERIMENTAL PROGRAMME

Mix design is done to select the mix material and their required proportions. There are a lot of methods to determine the mix design. The methods used in India are in compliance with Bureau of Indian Standards (BIS). The motive of mix design is to determine the proportion in which concrete ingredients like cement, water, fine aggregates and coarse aggregates should be mixed to provide specified strength, workability, durability and other specified requirements as listed in standards such as IS: 456-2000. The designed concrete mix must define the material and strength, workability and durability to be attained. Concrete mix design guidelines are given in IS: 10262-1982. In the study, 5 batches of mixes were prepared. These batches were designated as m0, m1, m2, m3 and m4. Batch m0 was taken as control mix. The natural coarse aggregate was replaced by recycled aggregate in proportion of 0%, 10%, 20 %, 30% and 40% in m0, m1, m2, m3, and m4 respectively as given in table 4.1. Content of sand, cement and water were kept constant in every batch. In the study properties of concrete such as compressive strength, flexural strength and sulphate resistance of concrete were determined.

Table 4.1 Proportions of Natural and Recycled Aggregates in Batches

| Type of Mix Used | Recycled Aggregate (%) | Natural Aggregate (%) |
|---|---|---|
| m0 | 0 | 100 |
| m1 | 10 | 90 |
| m2 | 20 | 80 |
| m3 | 30 | 70 |
| m4 | 40 | 60 |

### 4.2.2 Natural Fine Aggregates

Natural coarse sand was used as fine aggregate. The sand conformed to zone II as per IS: 383-1970. The grading of fine aggregates and other properties are given in table 4.3

Table 4.3 Sieve Analysis of Fine Aggregates

Weight of sample =1000gm

| IS Sieve Size(mm) | Weight Retained(gm) | Cumulative Weight Retained(gm) | Cumulative %Age of Weight Retained(gm) | Percentage Passing |
|---|---|---|---|---|
| 4.75 | 156 | 156 | 15.6 | 84.4 |
| 2.36 | 57 | 213 | 21.3 | 78.7 |
| 1.18 | 113 | 326 | 32.6 | 67.4 |
| 0.6 | 111 | 437 | 43.7 | 56.3 |
| 0.3 | 376 | 813 | 81.3 | 18.7 |
| 0.15 | 145 | 958 | 95.8 | 4.2 |
| 0.075 | 30 | 988 | 98.8 | 1.2 |

∑F=389.3

Fineness Modulus(F.M)=3.89

Sand conforming grading zone II of I.S 383-1970.

**Testing Procedure**

After casting samples were kept in water for curing for specified period. In case of sulphate resistance testing, cubes were kept in sulphate solution after keeping them in water for 28 days. Sulphate solution curing was done for specified time period.

After specified time period of curing, samples were taken out of curing tank and wiped out their surface to clean. They were dried for 24 hours. Various tests were performed to determine the desired strengths. Following tests were performed.

1. Compressive strength of cubes at the age of 7, 28, 56 and 90 days.
2. Flexural strength of beams at the age of 7, 28 and 90 days.
3. Sulphate resistance of cubes at the age of 7, 28 and 56 days.

## COMPRESSIVE STRENGTH

The dried cubes were tested at the age of 7, 28, 56 and 90 days. The cubes were tested on compression testing machine (CTM) after drying at room temperature as per IS: 516-1959 as shown in Figure 4.3. The load was applied at rate of 350MPa/minute in a uniform and continuous manner. Impacts were prevented during the application of load. Application of load was kept continued until the sample failed and maximum load carried by the sample was recorded. Three samples for each test reading were tested. Final value of test is taken as an average of three samples.


Figure 4.3 Test for Compression Strength In CTM.

### Flexural Strength

The dried beams were tested on flexural testing machine using two points loading. The transverse bending test was employed. Flexural strength was calculated as per equation 4.1 for a rectangular sample under a load in a two-point bending setup (as shown in Figure 4.4) where the loading span was one-third of the support span:

$$\sigma = \frac{FL}{bd^2}$$

(4.1)

- *F* is the load (force) at the fracture point in MPa
- *L* is the length of the support (outer) span in mm
- *b* is width in mm
- *d* is thickness in mm

Figure 4.4 Test For Flexural Strength

The tests were conducted at the age of 7,28 and 90 days. Three test samples were tested for each final value. The average value of three samples was taken as the final flexural strength.

### Variation of Flexural Strength with Age

Table 5.3 gives the test results of flexural strength at 7, 28, and 90 days. The results of flexural strength are the average of 3 beams. Table 5.4 shows the percentage reduction in flexural strength for all mixes at different ages. Figure 5.8 shows the comparison of flexural strength at ages of 7,28 and 90 days.

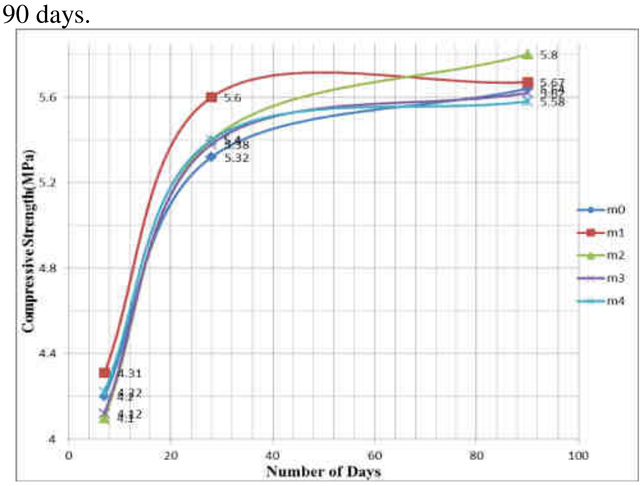


Figure 5.8 Comparison of Flexural Strength of all Mixes at 7, 28 and 90 days.

Figure 5.9 to Figure 5.11 shows the variation of flexural strength at 7days, 28 days, and 90 days with different mixes used in tests keeping the water cement ratio 0.38. The results showed fluctuations from mix to mix.

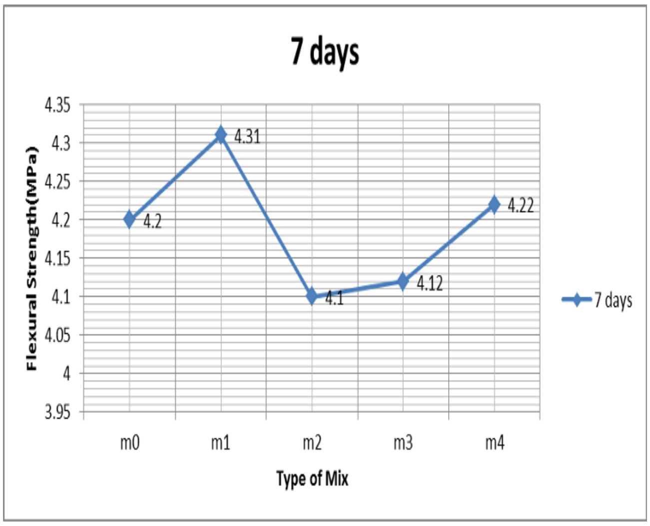


Figure 5.9 Variation of Flexural Strength at 7 Days with all Five Mixes.

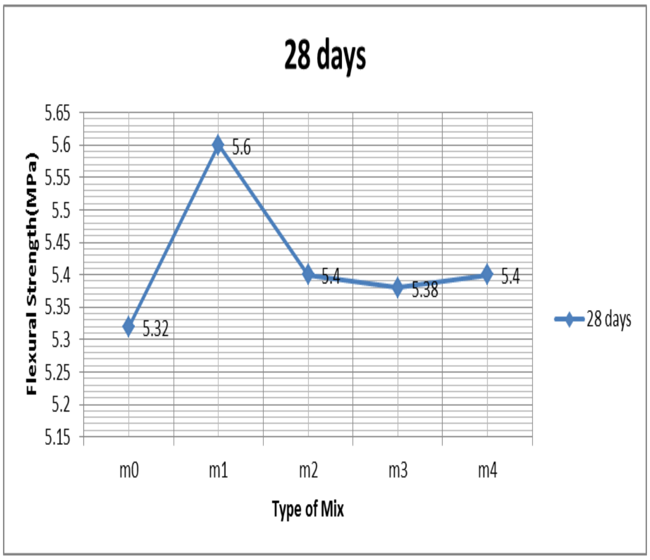


Figure 5.10 Variation of Flexural Strength at 28 Days with all Five Mixes.

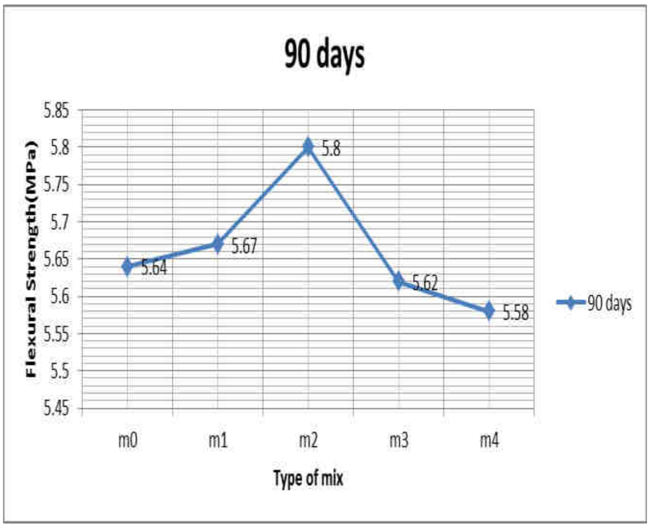


Figure 5.11 Variation of Flexural Strength at 90 Days with all Five Mixes.

The research on usage of RCA in construction of pavement is very important because material waste is gradually increasing with the increase in urban development and increase in population. Recycled aggregates are easily available while natural aggregates need mining and their cost is much higher than the cost of natural aggregates. Recycled aggregates are cheaper than the virgin aggregates, so builders can easily afford these for construction purpose if their strength is equal or comparable to natural aggregates.

The study examines the properties of RCA when used with natural coarse aggregates. A lot of studies have been carried out on use of RCA concrete in construction. But in case of highway construction some more investigation is required. The main objective of the study was to investigate whether RCA can be used as material aggregates for concrete pavement construction. Compressive strength, flexural strength and sulfate resistance of RCA concrete is examined, where it was observed that mixing of RCA cause increased water absorption. To avoid this, super plasticizer is used to reduce the cement consumption. Concrete mix of M40 was designed as per properties of aggregates. The results of this study showed that RCA concrete gave comparable strength to conventional concrete. This indicated that RCA concrete can be viable source for construction of pavements. From the results, it is also found that workability of concrete is decreased due to higher water absorption. Whenever recycled aggregate is applied, water content is monitored carefully in concrete mix as water absorption is increased due to presence of porous mortar. In this study, super plasticizer (0.6% of cement) is used to overcome this problem.

## CONCLUSIONS

1. The compressive strength of all mixes exceeded at the age of 28 days. Compressive strength of control mix i.e. of m0 is 50.05 MPa which is greater than the target strength of 48.25 for M40 concrete. Compressive strength of m1 is slightly increased to 50.36. So the compressive strength increases by 0.5%. For m2, compressive strength is increased to 50.20 MPa, it also showed an increase in compressive strength by 0.3%. Compressive strength of m3 is decreased to 49.11 MPa that showed a decrease in compressive strength by 1.9%. But in case of m4, there is sudden increase in compressive strength that raises the compressive strength to 52.36 MPa. Compressive strength is increased by 4.5%. So the results of test show that compressive strength does not follow a regular trend from m0 to m4. But from the results it is also concluded that compressive strength never went below the target strength for 28 days. This indicates that RCA can be used as replacement aggregates for compressive strength.
2. Flexural strength also followed the same pattern as of compressive strength. Flexural strength of control mix is 5.32MPa at age of 28 days. Flexural strength of mix m1 increased to 5.60 MPa. It shows that the increase in flexural strength is 5% for m1. For m2 flexural strength at age of 28 days is 5.40MPa, which shows an increase in flexural strength by 1.5%. Flexural strength of mix m3 is 5.38 and the flexural strength increased by 1 %. For the mix m4, flexural strength is 5.40 MPa. It shows that the flexural strength increased by 1.5 % at the age of 28 days. From the results and discussion of the results it is found that the flexural strength of RCA concrete is comparable to the natural aggregate concrete which is a positive point. So the RCA concrete can be used for flexural strength by adjusting W/C ratio.
3. Use of 5% of $MgSO_4$ solution caused the reduction in compressive strength. The compressive strength of RCA mixed concrete reduced upto 7%. Effect of sulphate solution increased when quantity of demolished concrete aggregate increased. This study showed that the strength of m4 at 56 days was most affected. So with increase in sulphate caused reduction in compressive strength of concrete.
4. It was found that the RCA concrete have relatively lower bulk density, specific gravity and high water absorption as compared to natural concrete. This was due to the presence of mortar in present on recycled coarse aggregates.
5. In this study, trial castings were done to arrive at water content and desired workability. So it was advisable to carry out trial castings with demolished concrete aggregate proposed to be used in order to arrive at the water content and its proportion to match the workability levels and strengths requirements respectively.
6. From this study it was observed that the demolished concrete was viable source for construction of concrete pavements. Economical and environmental pressures justify suitability of RCA concrete as alternative to the natural concrete. Where there is non-availability of natural aggregate from new rocks RCA can be a good or viable replacement option for natural coarse aggregate in pavement construction.

From above conclusions it can be said that it is eco-friendly and creative to use demolished concrete in construction of concrete pavements.

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