BOND STRENGTH OF STEEL BARS EMBEDDED IN CONCRETE CONTAINING RECYCLED FINE AND COARSE AGGREGATES

A Dissertation

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Submitted

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DECLARATION

I, Amandeep Mahay , hereby declare that this thesis report entitled " **BOND STRENGTH OF STEEL BARS EMBEDDED IN CONCRETE CONTAINING RECYCLED FINE AND COARSE AGGREGATES** "submitted in the partial fulfilment of the requirements for the award of degree of Master of Engineering in Structural Engineering, in the Civil Engineering Department, Thapar University, Patiala, is wholly my own work. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge & belief.

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ABSTRACT

In the growing environmental concerns, the proper disposal of construction and demolition waste is a challenge for construction industry. The experimental studies are done on the demolition waste to use it in some productive way .The proper selection and processing of demolition waste can be helpful in producing concrete. Hence the use of demolition waste as a resource for recycling or recovery is gaining grounds in many countries.

As In last two decades coarse recycled concrete aggregate (RCA), manufactured by processing of construction and demolition waste has received considerable attention as a potential substitute for natural coarse aggregate (NCA). However, structural application of RCA concrete has been slow primarily because of apprehensions that concrete containing RCA might be inferior to concrete made with NCA. The present work focuses on the effect of RCA on the compressive strength and bond strength between the concrete and the reinforcement.

Six MIX combinations are prepared by replacing natural fine aggregate and natural coarse aggregate by recycled fine and recycled coarse aggregate to study compressive strength and bond strength at 7 , 28 and 56 day testing. The mix combinations incorporating recycled aggregate were prepared by replacing 0%, 50% and 100% of natural coarse aggregate and 0%, 50% for natural fine aggregate by weight to form 6 mix combinations - MIX 1 (100% NCA + 100% NFA), MIX 2 (100% NCA + 50% RFA + 50% NFA) , MIX 3 (50% NCA + 50% RCA + 100% NFA), MIX 4 (50% NCA + 50% RCA +50% NFA+50% RFA) MIX 5 (100% RCA + 100% NFA), MIX 6 (100% RCA + 50 %RFA + 50% NFA).

The compressive strength and bond strength both were studied at 7days, 28days and 56 days .For studying bond strength , pull out tests were carried out as per IS:2770 (Part I), 1967 and IS:432 (Part I), 1966 using16 mm diameter of rebar. In all the MIXES there is a pattern observed, which can be arranged as MIX 2 > MIX 1 > MIX 4 >MIX 3 > MIX 6 > MIX 5 (descending order) at 7day, 28day And 56 Day testing.

MIX 2 (100% NCA + 50% RFA + 50% NFA) has shown the maximum bond strength whereas MIX 5 (100% RCA + 100% NFA) has shown minimum bond strength including control mix (MIX 1) i.e. 100% NCA and 100% NFA.

For studying the compressive strength the compressive strength testing machine of capacity 5000 KN is used for determining the maximum compressive loads carried by concrete cubes. In all the MIXES there is a pattern observed, which can be arranged as MIX 2 > MIX 1 > MIX 4 >MIX 3 > MIX 6 > MIX 5 (descending order) at 7day, 28day And 56 Day testing. MIX 2 (100% NCA + 50% RFA + 50% NFA) has shown the maximum compressive strength whereas MIX 5 (100% RCA + 100% NFA) has shown minimum compressive strength including control mix (MIX 1) i.e. 100% NCA and 100% NFA.

This thesis, aims to find the possibility of the structural usage of recycled aggregate concrete as alternative or mixed with natural aggregates, by conducting a comprehensive laboratory investigation for better understanding of compressive strength and bond strength properties of recycled aggregate concrete.

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CHAPTER 1

INTRODUCTION

1.1 General

Recycling make sense. Aggregates come from natural deposits on the Earth's surface that can take millions of years to form – that's why we call them non-renewable resources. Recycling aggregates can help preserve land, reduce energy consumption, reduce waste and conserve natural resources. We can reduce the demand for aggregates through reuse and recycling, we still need newly extracted aggregates for many uses and only a limited amount of used aggregate material is currently available for recycling. Recycling is only one part of conserving aggregate resources. Reducing the use of aggregates can also help us conserve.

In 2007 about 13 million tonnes of the aggregate used in Ontario was estimated to come from recycled sources – or about seven per cent of the total used. Since this information is not always tracked, additional aggregate recycling may be taking place that we don't know about.

More recycled aggregates are used in road construction than for any other use. The Ontario Ministry of Transportation has been using recycled aggregates from asphalt pavements since the mid-1970s to build Ontario's highways. Concrete from buildings, sidewalks and over passes is also recycled. By the end of the 20th century, sustainable development and environmental protection became key goals of modern society. Important role in the sustainable development of the built environment, reduction of pollution, conservation of natural resources and energy savings certainly has the entire civil engineering, especially construction materials industry.

Concrete is one of the most widely used construction materials in the world , mainly due to its favourable features such as durability , versatility, satisfactory compressive strength ,cost effectiveness and availability .However ,the use of conventional concrete has been claimed to be not environmentally friendly ,manifested by frequently voiced negative concerns such as the depletion of the reserve of natural resources , high energy consumption and disposal issues.

In the last two decades, a variety of recycling methods for construction and demolition wastes (CDW) have been explored and well developed .For instance, as one of the major components in CDW, concrete rubble has been used to replace natural aggregate (NA) after being treated .It is known as recycled concrete aggregate (RCA).

The recycled concrete aggregates are made available in the market from the demolition concrete waste. Regarding concrete, which is the construction material of our era, the protection of the environment concerns three basic axes:

- Use of high amounts of raw materials (aggregates for the production of cement and concrete) which result in the decrease of available natural resources which is continuously sub-graded.
- Consumption of high amounts of energy for the production, transport, use of raw materials and final ones, as cement and concrete.
- Creation of big volumes of old concrete from old construction works (demolition wastes).

The main reasons for the increase of this volume of demolition concrete waste are:

- Many old buildings and other structures have overcome their limit of use and need to be demolished.
- Structures, even adequate to use, are under demolition, because there are new requirements and necessities.
- Creation of building wastes which result from natural destructive phenomena (earthquakes, storms. . .).

Recycling of aggregates from construction and demolition waste may be helpful to bridge some of the gap. While wood, plastic, glass and glass is individually recycled. The concrete accounting for nearly 50% waste is not properly reused and recycled. Lately many countries like U.S, U.K, Germany and Japan have successfully utilised nearly 90% of their construction and demolition waste. However less insight and effort is reported regarding recycle of demolition waste in India.

1.2. Classification of Recycled Aggregates:

- Recycled Concrete Aggregate (RCA) -Crushed sound and clean waste concrete of at least 95% by weight of concrete with total contamination lower than 1% of the bulk mass
- Recycled Concrete and Masonry (RCM) - Graded aggregate produced from sorted and clean waste concrete and masonry
- Reclaimed Aggregate (RA) -Coarse aggregates reclaimed from rejected concrete by separating the aggregates from the water-cement slurry.
- Reclaimed Asphalt Pavement (RAP) - Old asphalt concrete.
- Reclaimed Asphalt Aggregate (RAA) - Reclaimed coarse aggregate and recycled asphalt granules from waste asphalt concrete.
- Glass Cullet - Glass cullet pulverised into a sand-like product.
- Scrap Tyres - Processed scrap tyres as tyre chips and crumb rubber aggregate.
- Used Foundry Sand - Spent foundry sand.

1.3 Example of Structural Application of RCA

Recycled concrete aggregate had been used in constructing a new high school, outside the city of Oslo, Norway in 2001 as shown in Fig. 1.1 (below). Thirty – five percent of coarse aggregate were replaced by recycled concrete aggregate in the foundations, half of the basement walls and columns. Several tests were conducted based on fresh and hardened concrete properties and the results shown that the concrete with thirty – five percent of recycled concrete aggregate have good freeze – thaw resistance. The use of recycled concrete aggregate did not shown any noticeable increase in cracking.

Fig. 1.1: Construction of the New High School in Sorumsand, Oslo, Norway

1.4 Production of RCA

1.4.1 Aggregate Production Plant

The present method does not remove attached mortar, but rather adjust the aggregate size. Therefore, the equipment simply consists of two types of crushers and a vibrating screen, as is shown in Fig 1.2. A production plant used to crush concrete block for recycling is shown in Fig 1.3, which is slightly adjusted and modified as changing the open set of the crusher and the size of the sieves appropriate for concrete aggregate.

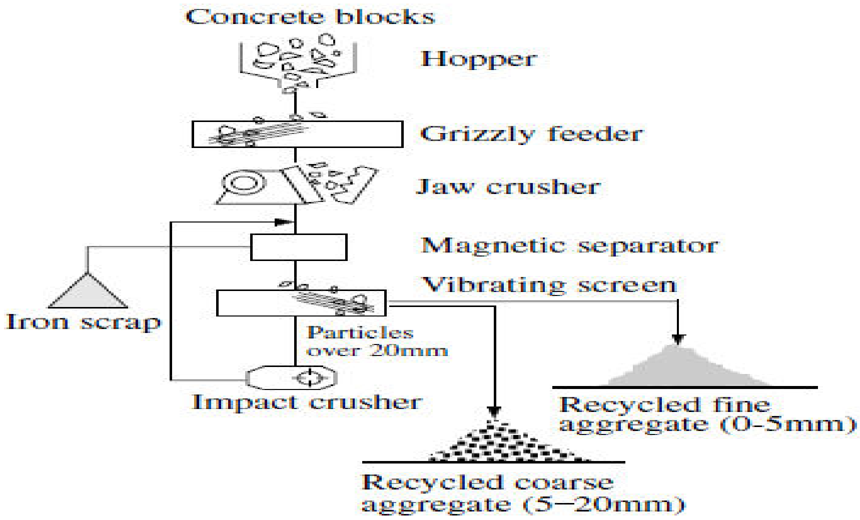


Fig. 1.2: Flow chart for recycled aggregate production

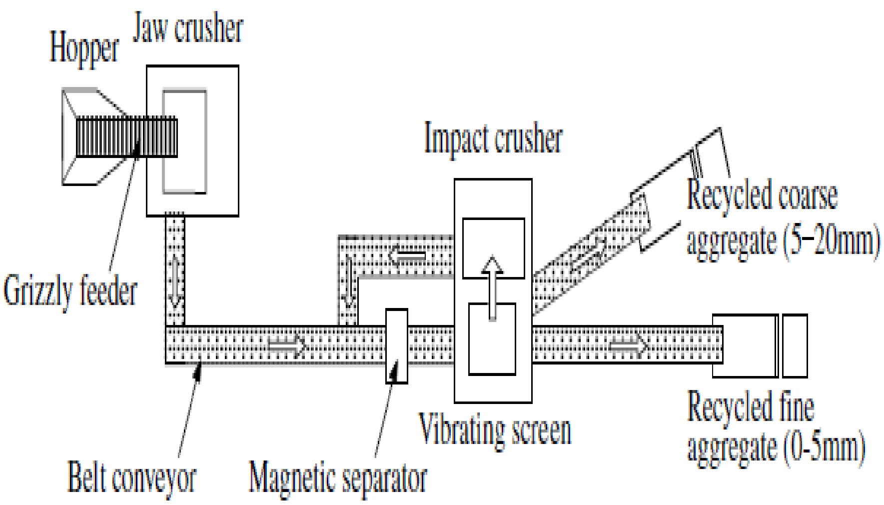


Fig. 1.3: Production plant for recycled aggregate (Masafumi 2007)

After successful batching of RCA, the next step is to carry out mix design process. Water absorption and adhered mortar content should be kept in mind in order to get appreciable results.

1.5 Properties of recycled coarse aggregate

Xuand Shi (2006) and Xiao (2008) observed that RCA often contains a large amount of attached mortar and cement paste. The volume percentage of old mortar may range from 20% to 30%, depending on the properties of parent concrete and the production process. The attached mortar and cement paste on recycled coarse aggregate are the principal cause of the difference between recycled coarse aggregate (RCA) and natural coarse aggregates. Test results indicated that recycled coarse aggregate has the following technical properties:

1) Low bulk and saturated-surface-dry (SSD) density: The bulk density of recycled coarse aggregate is about 1290–1470kg/m^3. The SSD density of recycled coarse aggregate is about 2310–2620 kg/m3

2) High water absorption. The absorptions of recycled coarse aggregate are approximately:

□8.34% (10 min)

□8.82 (30 min)

□9.25% (24 h)

These above values are larger than that of natural coarse aggregates and might be regarded as the most important characteristic

3) High porosity: The porosity of RCA is approximately 23.3%, due to high mortar cement paste content.

4) High crushing index: The crushing index of RCA is approximately 9.2% to 23.1%.

5) High clay content: The clay content of RCA is approximately 4.08%.

6) Particle Size Distribution The amount of fine particles (<4.75mm) after recycling of demolished were in the order of 5-20% depending upon the original grade of demolished concrete. The particle shape analysis of recycled aggregate indicates similar particle shape of natural aggregate obtained from crushed rock.

1.6 Specifications to be considered while using RCA

Tam et al. (2007) studied that the major effects on the quality of RCA is the large amount of adhered cement mortar that remains on the surface of the aggregate, resulting in higher porosity, water absorption rates and weaker interfacial zone between new cement mortar and aggregates, which weakens the strength and mechanical performance of concrete made from RA

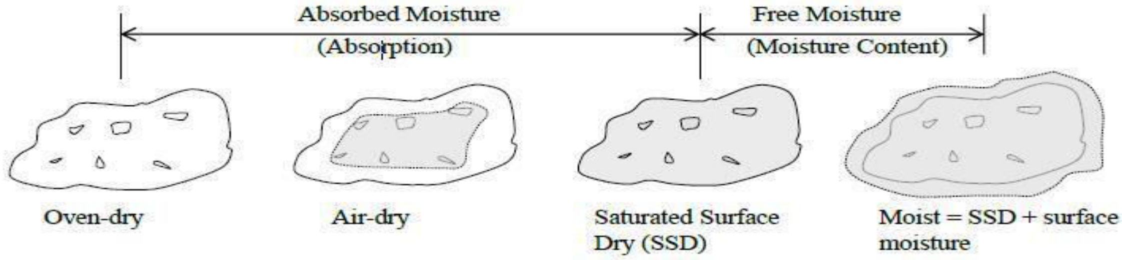


Fig.1.4: Several Moisture States of Aggregates (Neville, 1995)

The following methods can be used to enhance the quality of RCA

- Two stage RAC mixing approach
- Heat treatment
- Microwave decontamination
- Pre-soaking treatment
- Washing and chloride treatment

1.7 Challenges and Scope of RCA

The use of recycled aggregate in concrete is relatively rare. There are three main reasons for that:

- Overall economics – direct costs can also be unfavourable
- Situation of steady supply of suitable aggregates - aggregate producers do not want to build up large stock of recycled aggregate for concrete since there is no market.
- Other end users are far more tolerant than concrete of the inevitable contaminants in RA.

Technical problems may include:

- High content of cement paste/mortar

- Weak interfacial transition zones between cement paste and aggregate
- Porosity and traverse cracks within demolished concrete
- High level of sulphate
- High level of chlorides
- Impurity
- Poor grading
- High variations in quality

1.8 Research Objectives

The principle objective of this thesis is to study the possible techniques of improving the properties of recycled aggregate concrete that is made up with 50% or higher percentages of recycled aggregates both fine aggregate and coarse aggregate. This study is conducted to compare the fresh and hardened properties of RAC made with different recycled coarse aggregate (RCA) replacement levels with those of natural aggregate concrete (NAC). Evaluate the mechanical performance of RAC made with different RCA replacement levels.

1.9 Organisation of the Thesis

This thesis has been organized in five chapters as follows:

Chapter - 1. Introduction - It presents various aspects of RCA concrete.

Chapter - 2. Literature Review - Are view of recent literature on Bond Strength of RCA concrete and reinforcement using different parameters and their contributions to the composite materials in terms of compressive strength.

Chapter - 3 . Experimental Programme - It describes the material characteristics (physical / chemical) , mixture proportions, specimen size, test methods and associated instruments.

Chapter - 4. Results and Discussions - Deals with the presentation, analysis and discussion of different results.

Chapter-5.Conclusion- Summarises the main conclusions and recommendations for future scope of study is presented.

References are listed at the end for the convenience of the readers

CHAPTER 2

LITERATURE REVIEW

2.1 General

In this chapter a review of the literature related to compressive strength, bond strength of RCA concrete and reinforcement has been discussed. A brief review of the published work on material and structural characteristic of RCA. Structural characteristic of RCA concrete is presented and finally the need of the present investigation is identified.

2.2 Effect of RCA on fresh properties of concrete

2.2.1. Initial slump

Poon et al. (2004) studied the moisture condition of the aggregate on initial slump, showed that the initial slump of recycled aggregate concrete was significantly affected by the moisture condition of aggregates

Neville (1995) mentioned that various mixing conditions such as w/c, water-reducing admixture ratio, and grading and volume of recycled aggregates would control the initial slump of recycled aggregate concrete.

Ismail and Ramli (2013) pre-soaked the RCA in acid of different molarity and studied the slump values of both treated and untreated RCA, no significant difference in the slump values was observed. It has been reported that angular and rough surface of RCA decreases the slump values as compared to natural aggregates concrete.

2.3 Effect of RCA on Hardened Properties of Concrete

Some of the important hardened properties of concrete are compressive strength, splitting tensile strength and flexural strength. They are discussed in the following sections.

2.3.1. Compressive strength

Shin-chu et al. (2012) observed that the use of recycled aggregates resulted in a decrease in compressive strength of the concrete. At 28 days, the compressive strength of the concrete mixes prepared with 100% recycled aggregate in Series I, II and III were 35.7%, 25.6% and 12.2%, respectively lower than that of the natural aggregate concrete. The compressive strengths of the concrete mixes in Series III were higher than those of the concrete mixes in Series I and II. Moreover, Table 2.1, Fig 2.1 and Fig 2.2 below show that the relative compressive strength of the concrete made with the low-grade recycled aggregate (RAI and RAII) were lower than those of the natural and commercial recycled aggregate.

Series	Concrete mixes	Recycled agg. (%)	1-day	4-day	7-day	28-day	90-day
I	RA0-I	0	13.9	28	32.5	43.4	47.8
	RA20-I	20	12.1	24.6	29.3	39.4	44.2
	RA50-I	50	11.2	23.9	28.4	37.8	42.4
	RA100-I	100	8.4	16.5	20.4	27.9	33.8
II	RA0-II	0	13.9	28	32.5	43.4	47.8
	RA20-II	20	11.5	25.2	30.4	39.7	43.6
	RA50-II	50	10.8	21	26.2	33.9	39.6
	RA100-II	100	9.3	18.6	24.5	32.3	36.8
III	RA0-III	0	13.9	28	32.5	23.4	47.8
	RA20-III	20	11.9	22.4	29.1	45.3	49.1
	RA50-III	50	11.6	21.8	27.6	42.5	47.5
	RA100-III	100	10.2	18.6	24.4	38.1	45.5

Table 2.1: Relative compressive strength of series

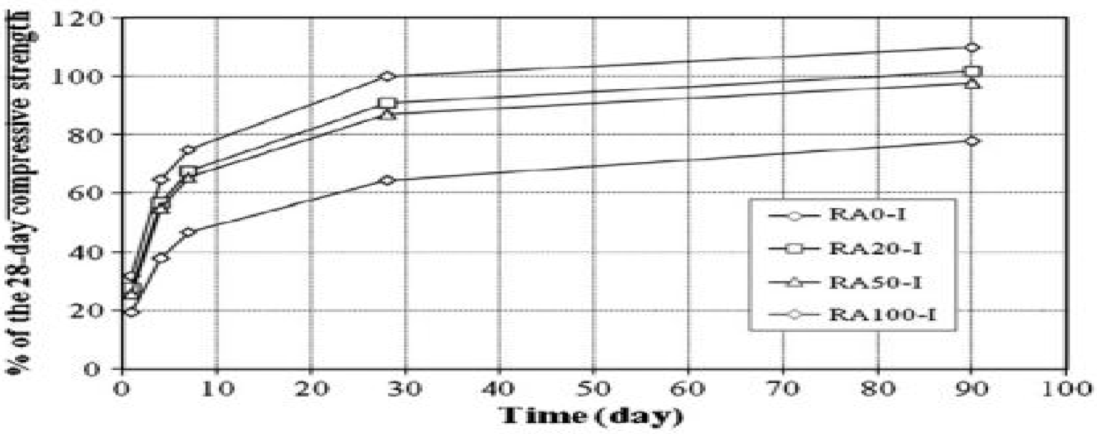


Fig. 2.1: Relative compressive strength of series 1

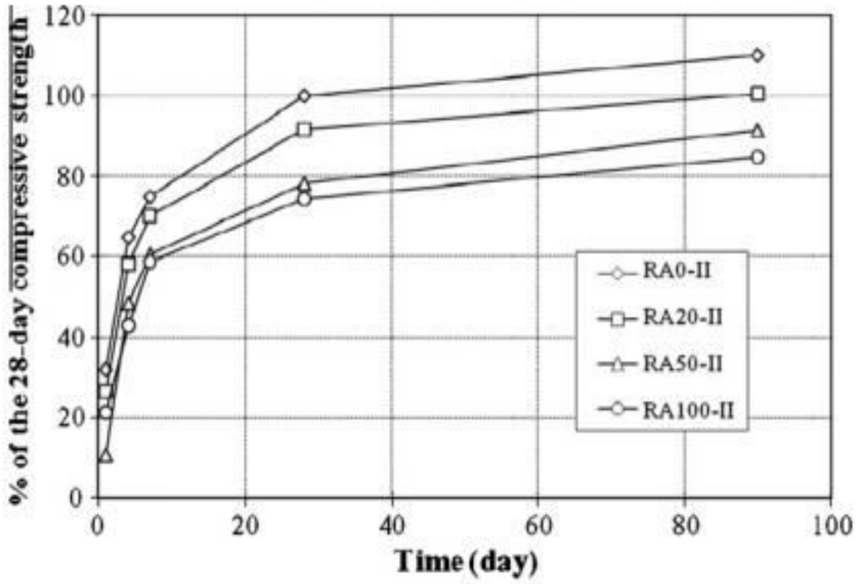


Fig. 2.2: Relative compressive strength of series 2

Rao et al. (2010) examined the compressive strength, indirect tensile strength, modulus of elasticity and density of recycled aggregate concrete prepared with 0%, 25%, 50% and 100% recycled coarse aggregate at 28 days curing period are presented in Table 2.2 and 2.3 below. It shows that the mechanical properties of recycled aggregate concrete decrease with the increase in recycled coarse aggregate content. It is observed that at high percentage of recycled coarse aggregates (50% and 100%), the gain in compressive strength of RAC is 17–23% while the normal concrete strength is increased by approximately 42% in the last 21 days of 28 days curing period. This indicates that the recycled aggregate concrete at higher percentages of recycled coarse aggregates attained more early strength than normal concrete. After 28 days, no significant improvement is observed in compressive strength of recycled aggregate concrete with curing age up to 90 days at 50% and 100% RCA compared to an increase of 5% and 12% in RAC at 25% RCA and normal concrete respectively. This may be due to the accumulation of cement paste on the surface of the aggregates which produces low w/c ratio and effective new interfacial transition zone (ITZ). Similar observation is reported for curing period between 28 days and 6 months

Table 2.2: Mechanical properties of RAC

		Compressive strength (MPa)				Split tensile strength (MPa)	Modulus of elasticity (MPa)	Density (kg/m3)
Mix designation	RCA (%)	7 days	28 days	56 days	90 days	28 days	28 days	28 days
M-RAC0	0	28.77	49.45	53.83	55.33	2.67	31.20*100	2415.64
M-RAC25	25	27.9	45.75	46	48.17	2.3	26.75*100	2349.45
M-RAC50	50	35.33	42.5	43.83	44.1	2.19	26.71*100	2257.96
M-RAC100	100	31.5	40.8	41.08	41.67	2.05	26.40*100	2148.1

Table 2.3: Details of mix proportions (in kg per cubic meter of concrete)

Mix designation	RCA (%)	Cement (kg)	Natural fine aggregate (kg)	Natural coarse aggregate (kg)	RCA (kg)	Super-plasticizers*	Slump
M-RAC0	0	401	574	1261	0	0.05	57.5
M-RAC25	25	401	574	93075	310.25	0.05	54
M-RAC50	50	401	574	602	602	0.175	52
M-RAC100	100	401	574	0	1128	0.225	49

* In % by weight of cement

Duan et al. (2014) investigated that the compressive strength of concrete made with RA was mostly lower than that made with NA, regardless of the w/c ratios used. This might be due to the porous nature of RA with a larger amount of cracks and attached mortar.

Xiao et al. (2012) concluded that compressive strengths of recycled coarse aggregate are generally lower than those of conventional concrete. Further compressive strength values decrease with the increase of RCA amounts. Several reasons could be responsible for the reduction of the compressive strength for RAC, including an increased concrete porosity and a weak aggregate-matrix inter face bond.

Tangchirapat et al. (2008) examined concrete containing 100% coarse recycled aggregate and recycled fine aggregate at 0%, 50% and 100% replacement along with rice husk-bark ash. The rice husk-bark ash was used to replace cement at rate of 20%, 35% and 50%. It has been concluded that higher amount of fine and coarse recycled aggregates resulted in lower compressive strength values. Though concrete having 100% coarse recycled aggregate and river sand showed higher strength than conventional concrete at 35% rice husk-bark ash.

Tuet al. (2006) concluded that an in consistent surface of recycled fine aggregate would produce numerous micro cracks between aggregates and cement paste, which would reduce compressive strength of concrete

Corinaldesi and Moricioni (2009) presented the study on influence of mineral additions on the performance of 100% recycled coarse aggregate and 26% recycled fine aggregate concrete. Silica fume and fly ash were mixed and recycled aggregates consist of 70% old concrete and 30% bricks. Mineral additions were replaced at 15% and 30% by weight of cement and added as fine aggregate replacement. The W/C ratio was kept at 0.40. The compressive strength of concrete with silica fume was appreciable as compared to fly ash concrete. The compressive strength of fly ash concrete was nearly equal to control mixture concrete.

Kim et al. (2012) studied that compressive strength decreased when the coarse aggregate was replaced with the recycled. Additional replacement of the fine aggregate reduced the strength as the recycled fines amount increased. When the fine aggregate replacement

Was greater than 60% the strength reduction became more significant. Reason for reduction in compressive strength is:

(i) Remained mortar on the surface of the recycled aggregate

(ii) Cracks in the aggregate itself (which could occur during the crushing)

(iii) The original aggregate's strength. From, the observations, it is recommended that the fine aggregate should better be replaced with the recycled less than 60% in the consideration of compressive strength.

Kou et al. (2012) studied the compressive strength of used commercial recycled aggregates at 0%, 25%, 50% and 100% replacement levels on natural aggregates. At 28 days the compressive strength of 100% recycled aggregate concrete was 12.2% lower than natural aggregate concrete. After 90 days the values of recycled aggregate concrete was better and even more at 20% replacement level of natural aggregate.

Table 2.4: Compressive strength of concrete (Kou et al. 2012)

Concrete mixes	Recycled aggregate (%)	28 day compressive strength	90 day compressive strength
RA0	0	43.4	41.8
RA20	20	45.3	49.1
RA50	50	42.5	47.5
RA100	100	38.1	45.5

Andreu and Miren (2014) analysed the properties of high performance recycled aggregate concrete. The recycled aggregates were sourced from high strength concrete and were replaced as 20%, 50% and 100%. The recycled were produced from 40, 60 and 100 MPa concrete. When 100 MPa recycled aggregates were used the compressive was higher than control mixture. High quality of cement paste was capable to develop a better bond with recycled aggregates. Only 40 MPa recycled aggregates at 100% replacement performed poorly. The negative influence was because of inferior adhered mortar content on the aggregates. The low water-cement ratio of 0.285 was used, to compensate for this in recycled aggregate concrete overly saturated fine aggregates were used.

Table 2.5: Compressive strength of concrete mixtures (Andreu and Miren 2014)

Concrete reference	Compressive strength (MPa)	Compressive strength (MPa)	Compressive strength (MPa)
	1 DAY	7 DAY	28 DAY
CC	57.36	91.19	102.09
RC-20-100	73.79	88.51	108.03
RC-50-100	79.24	94.76	104.8
RC-100-100	78.73	93.43	108.51
RC-20-60	73.55	102.1	102.18
RC-50-60	72.38	98.77	103.1
RC-100-60	79.42	100.1	100.78
RC-20-40	67.06	91.73	104.28
RC-50-40	60.69	84.39	96.84
RC-100-40	56.62	79.88	91.23

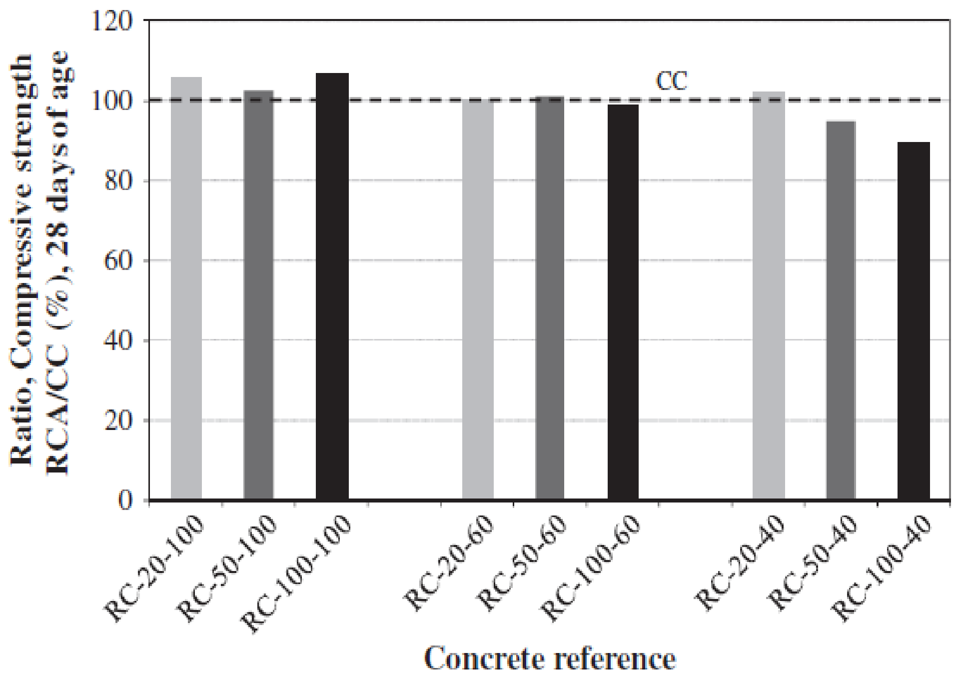


Fig. 2.3: Compressive strength of recycled aggregate concrete compared with conventional concrete (*Andreu and Miren 2014)*

2.3.2. Splitting tensile strength

Yangetal. (2008) observed that the normalized splitting tensile strength of recycled aggregate concrete decreased with the increase of relative water absorption and it was less than 0.53 for most specimens having relative water absorption larger than approximately 2.25%.

Tangchirapat et al. (2008) examined concrete containing 100% coarse recycled aggregate and recycled fine aggregate at 0%, 50% and 100% replacement along with rice husk-bark ash. The rice husk-bark ash was used to replace cement at rate of 20%, 35% and 50%. The splitting tensile strength of concrete is presented as a percentage of its compressive strength. The results indicated that splitting tensile strength of the recycled aggregate concrete was not much different from the concrete made from normal aggregates. The addition of rice husk-bark ash did not change the characteristic of splitting tensile strength of recycled aggregate concrete.

Kou et al. (2012) analyzed the splitting tensile strength by using commercial recycled aggregates at 0%, 25%, 50% and 100% replacement levels of natural aggregate in concrete mixtures. The values of splitting tensile strength were lower than that of control mixture at 28 days. At 90 days the gain percentage of recycled aggregate concrete was higher than conventional concrete. This can be attributed to microstructure of the (ITZ) and increased bond strength between new cement paste and aggregates.

Butler et al. (2013) analysed three types of recycled aggregates. Different water cement ratios were used to obtain 100% recycled aggregate concrete. The splitting tensile values were higher for low compressive strength specimen and lower for higher compressive strength. For higher concrete compressive strength, the strength of coarse recycled aggregate influenced the splitting tensile strength of concrete.

Table 2.6: Splitting tensile results (Butler et al. 2013)

Mix	Split tensile strength (MPa)
NAC-40	3.18
RAC1-40	3.51
RAC2-40	3.11
RAC3-40	3.3
NAC-60	4.38
RAC1-60	3.84
RAC2-60	3.7
RAC3-60	3.72

Lima et al. (2013) presented the splitting tensile strength property of concrete made with recycled aggregate and fly ash. The percentage of recycled aggregates was 30, 60 and 100. Both coarse and fine recycled aggregates were used in concrete mixtures. To keep the water available for chemical reaction constant, extra amount of water was added in various mixes calculated from water absorption capacity of aggregates. The content of fly ash was kept as “Low”, “Medium” and “High”. The specimens containing 60% and 100% recycled aggregates showed strong reduction in tensile strength. Addition of medium level of fly ash at 30% recycled aggregates gave the best values in recycled aggregate concrete mix.

Thomas et al. (2013) prepared and studied total of 24 mixtures with different water-cement ratios, substitution of coarse aggregate with recycled aggregate was 20%, 50% and 100%. Clear tendency of lower tensile splitting strength of recycled aggregate concrete than conventional concrete was found. In case of 100% recycle aggregates loss was around 20%.

2.4 Effect of RCA on bond between steel and concrete

The bond of reinforcement in concrete is responsible for three main features of structural performance, namely

(1) Bond is used to anchor the ends of reinforcing bars

(2) Bond transfers force from concrete in tension, thereby reducing the strain in the flexural reinforcement and enhancing member stiffness

(3) Bond helps to maintain the composite action between the reinforcing bar and surrounding concrete. Bond action is also required to ensure sufficient level of ductility in structural members. In design codes, bond is generally assumed as shear stress acting uniformly along the nominal surface area of a reinforcing bar.

Practically, the bond stress varies along the length of the rebar and higher at the end of the rebar. Also, in ribbed rebar, the transfer of load between the reinforcing bar and surrounding concrete is initially through bearing of the ribs.

2.4.1 Mechanisms of Bond Resistance

Followings are various mechanisms due to which the bond between the rebar and concrete exists. The major mechanisms are:-

- Chemical adhesion: Due to adhesive property in the products of hydration (formed after hardening of concrete).
- Frictional resistance: Due to the surface roughness of the reinforcement bar and the grip applied by the concrete shrinkage.
- Mechanical interlock: Due to the surface ribs provided in deformed bars.

The resistance due to "mechanical interlock" is not available in plain reinforcing bar. Friction starts to play a significant role when ribbed bars are used. Fig. 2.3 Shows the various bond transfer mechanisms on a reinforcing bar.

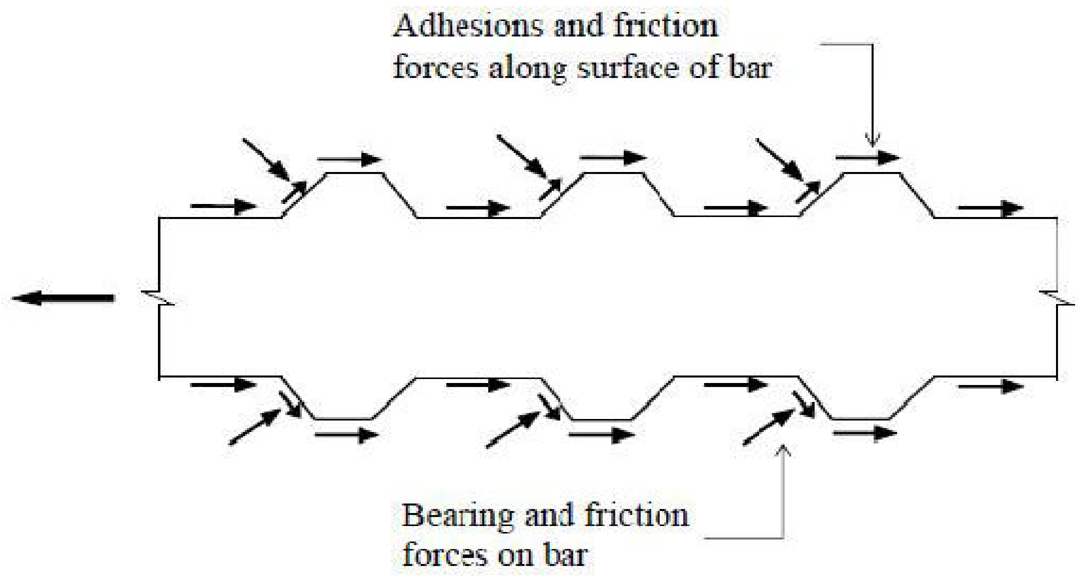


Fig.2.4: Mechanism of bond transfer (Wight et al. 2009)

Bearing and friction forces on ribbed portion of the bar and adhesions and friction forces acting along the surface of bar i.e. compressive bearing force perpendicular to the rib surface increases friction forces parallel to the surface. The forces acting in the rebar surface is balanced by the compressive and shear forces.

These compressive and shear forces are then resolute into tensile forces which caused cracks parallel and perpendicular to the reinforcing bar. Generally, splitting cracks may occur if insufficient spacing or cover is provided.

If cover, spacing, and transverse reinforcement are inadequate to stop splitting failure then shear failure initiating at the top of the ribs of the bar will occur and a pull-out failure will occur. In general, bond resistance is governed by the following factors:

- The mechanical properties of concrete and its components
- Concrete cover and bar spacing
- Transverse reinforcement
- Surface condition of the bar (ribbed, plain, etc.)
- Bar geometry (deformation height, spacing, width, etc.)

2.4.2 Bond between RCA Concrete and Steel Rebars

Bond strength can be measured by various test setups. The most common is Pullout test, in which the load (P) and the slip(s) at the free end of steel rebar anchored in the test specimen were measured in order to determine a load–slip relationship. The monotonically increased load was applied by the testing machine. Other methods used are be amend specimen and splice beam method. The results obtained by various researchers are discussed in the following sections.

(A)Pull-out Method

Prince et al. (2013) studied the bond performance between deformed steel bars in recycled aggregate concrete. The results of sixty pullout tests carried out using 12mm, 16mm, 20mm and 25mm diameter deformed steel bars concentrically embedded in recycled aggregate concrete designed using equivalent mix proportions with coarse recycled concrete aggregate (RCA) replacement levels of 0%,25%,50%,75%and100% are reported towards investigation of bond behaviour of RCA concrete.

The control concrete mixture consisting of only NCA was designed using the absolute volume method and the mixture design of RCA concrete was carried out using equivalent mix proportions where in the mixture proportions for the NCA and the RCA concretes were nominally kept the same, except for direct weight-to-weight replacement of NCA with RCA, depending upon the desired RCA replacement level.

The RCA replacement level is defined as the weight ratio of RCA to the total coarse aggregates in the concrete mixture and depending upon the desired replacement level, direct substitution of NCA with an equal weight of RCA particles was carried out. The following five weight combinations of NCA and RCA were adopted: 100%NCA (control mixture), 75%NCA + 25% RCA, 50%NCA + 50% RCA, 25%NCA + 75% RCA, 100%RCA, and the concrete mixture proportions are summarised in Table 3 where in it may be noted that the water-cement ratio, w/c, across all the mixtures was nominally kept equal to 0.54. Since the RCA used in this investigation had water absorption values which were about 6 times higher than that of the NCA, Table 1, the uniform w/c across all the concrete mixtures was achieved by ensuring that the NCA and the RCA particles were in the saturated surface-dry (SSD) moisture condition at the time of batching.

Table 2.7: Concrete mixture proportions (kg/m^3) (Prince et al. 2013)

Mix ID	RCA replacement	Cement	Sand	NCA	RCA	Mixing Water
ARO	0	369	854	912	0	199
AR25	25	369	854	684	228	199
AR50	50	369	854	456	456	199
AR75	75	369	854	228	684	199
AR100	100	369	854	0	912	199

The pullout tests were carried out using cylindrical specimens 100 mm in diameter and 200 mm long with concentric rebar placement. Pull out specimens are widely used for investigation of bond behaviour because of their ease of fabrication. Pull out tests provide a simple means of comparing relative bond behaviour across different types of concretes and rebars as mentioned in table 2.7.

The water absorption of the RCA particles used in this investigation was about six times higher than that of the NCA and when used in the SSD moisture state the RCA particles through the phenomenon of internal curing readily release water as needed for hydration or to replace moisture lost through evaporation or self desiccation. Internal curing is expected to result in better cement hydration, improved integrity of the contact zone between the RCA particles and the concrete matrix and a significant reduction of permeability due to extension of the curing time.

The improved integrity and mechanical properties of the concrete conglomerate are expected to enhance the bond strength as well. It is postulated that due to internal curing action of the RCA particles, the relative bond strengths, obtained by normalising the measured bond stress with the respective compressive strength of concrete, across all the RCA replacement levels were higher for the RCA concrete compared to the NCA concrete. Further, the relative bond strengths increased with RCA replacement levels and the highest values were obtained for 100% replacement of natural coarse aggregate with RCA.

Table 2.8: Experimental Results of Pullout Specimens (Prince et al. 2013)

Specimen	Comp. Strength (MPa)	Load (P) max (kN)	t max(MPa)
A12R0	36.9	42.2	18.7
A12R25	28.9	44.2	19.5
A12R50	24	42.7	18.9
A12R75	26.2	43	19
A12R100	24.7	43.2	19.1
A16R0	36.9	59.9	14.9
A16R25	28.9	58.5	14.5
A16R50	24	50.4	12.5
A16R75	26.2	54.1	3.5
A16R100	24.7	55	13.7
A29R0	36.9	84.6	13.5
A20R25	28.9	77.1	12.3
A20R50	24	75.7	12
A20R75	26.2	82.6	13.1
A20R100	24.7	83.1	13.2
A25R0	36.9	95.6	9.7
A25R25	28.9	89.9	9.2
A25R50	24	79.4	8.1
A25R75	26.2	80.5	8.2
A25R100	24.7	82.1	8.4

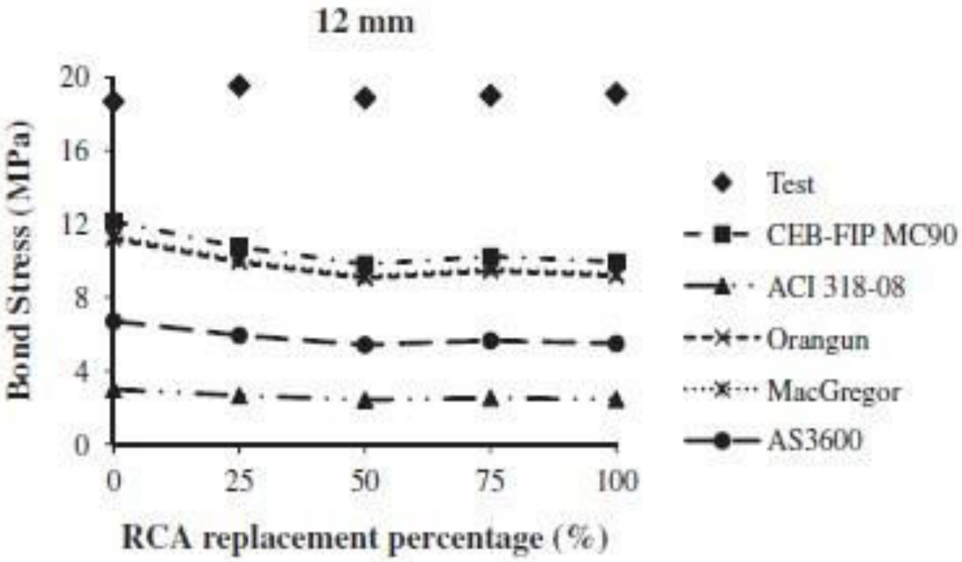


Fig. 2.5(a): Comparison of measured and predicted Bond Stress values for 12mm diameter rebar (Prince et al.2013)

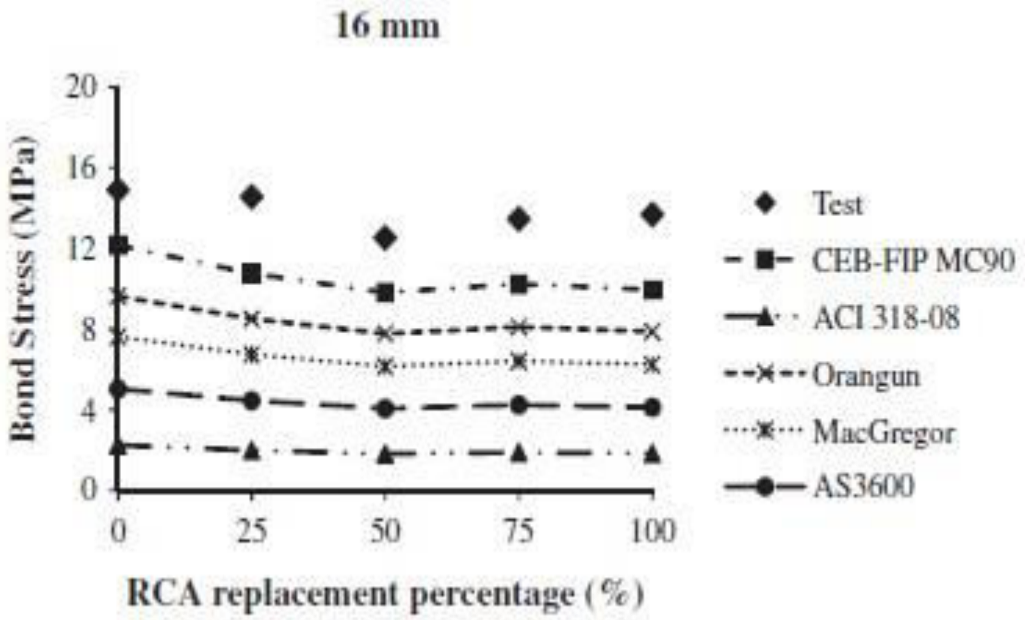


Fig. 2.5(b): Comparison of measured and predicted Bond Stress values for 16mm diameter rebar (Prince et al.2013)

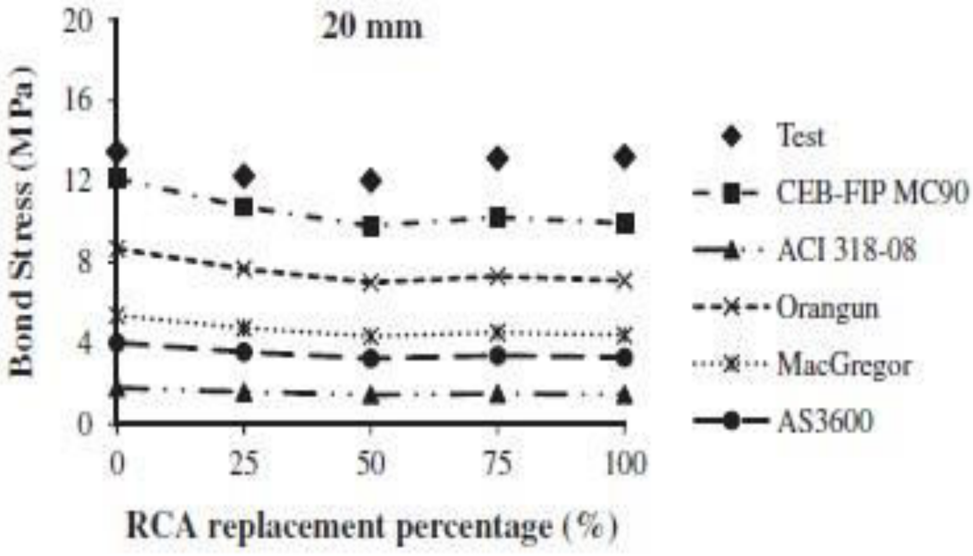


Fig. 2.5(c): Comparison of measured and predicted Bond Stress values for 20 mm diameter rebar (Prince et al.2013)

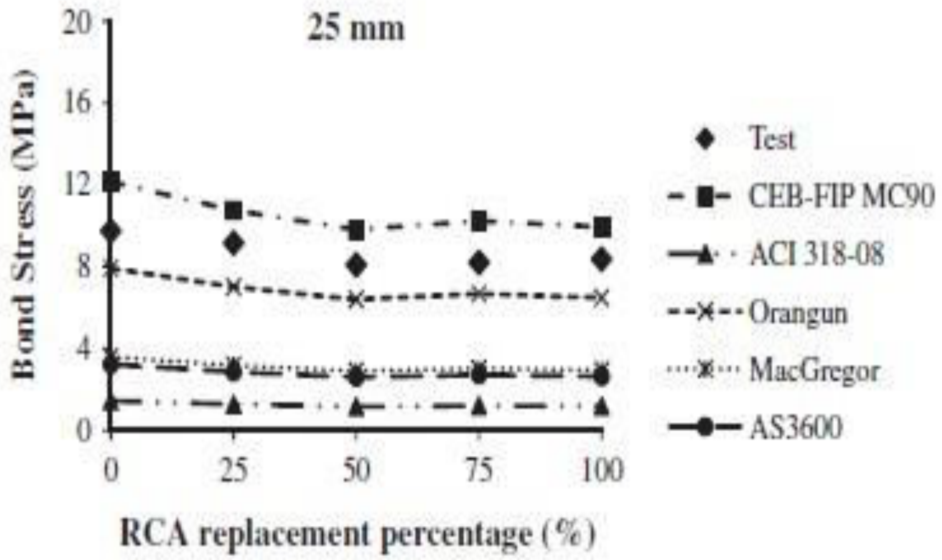


Fig. 2.5(d): Comparison of measured and predicted Bond Stress values for 25 mm diameter rebar (Prince et al.2013)

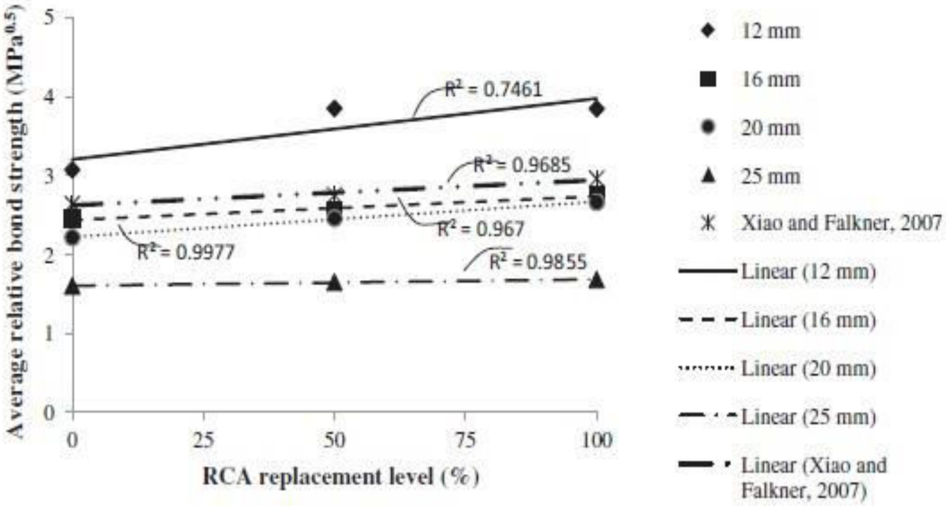


Fig. 2.6: Average Relative Bond Strengths for various RCA replacement levels

(Prince et al .(2013)

Xiao et al. (2007) studied the recycled coarse aggregate replacement ratio and the steel rebar style as the main experimental parameters. The main aim of this work is to investigate the bond behaviour between recycled aggregate concrete and steel rebars and to find a bond stress versus slip relationship between recycled aggregate concrete and steel rebar. Thirty six pull-out test specimens were tested in order to investigate the bond behaviour. Steel rebar (i.e. plain and deformed) and recycled coarse aggregate (RCA) replacement percentages (i.e., 0%, 50% and100%) were the main parameter considered in this paper. The mean values of the bond strengths are compared in Fig. 2.5. From Fig. 2.5, it can be concluded that under the equivalent mix proportion (i.e., the mix proportions are the same, except for different recycled coarse aggregate replacement percentages), the bond strength between the recycled aggregate concrete and the plain rebar decreases by 12% and 6% for an recycled coarse aggregate replacement percentage of 50% and 100%, respectively; while the bond strength between the recycled aggregate concrete and the deformed rebar is similar, regardless of the recycled coarse aggregate replacement percentage. Therefore, it is concluded that for the plain rebar, with increase in recycled coarse aggregate replacement ratio, bond strength decreases, where as for the deformed bar the bond strength between the recycled coarse aggregate and the deformed rebar remains same.

(Xiao et al 2005) Analysed the thirty six pullout tests were carried out in order to investigate the bond behaviour between recycled aggregate concrete (RAC) and steel rebars. Three recycled coarse aggregate (RCA) replacement percentages (i.e., 0%, 50% and 100%) two types of steel rebar (i.e., plain and deformed) were considered in this paper.

Table 2.9: Mix proportions of concrete (kg/m3)

No.	RCA replacement percentage (r)	C	S	NCA	RCA	Mixing water
RAC-0	0	430	473	1058	0	185
RAC-50	50	430	473	529	529	185
RAC-100	100	430	473	0	1058	185

Based on the test results, the influences of both RCA replacement percentages and the rebar surface on the bond strength between the RAC and steel rebars were investigated. It was found that under the equivalent mix proportion (i.e., the mix proportions are the same, except for different RCA replacement percentages), the bond strength between the RAC and the plain rebar decreases with an increase of the RCA replacement percentage, whereas the bond strength between the RAC and the deformed rebar has no obvious relation with the RCA replacement percentage. The empirical bond stress versus slip relationship between RAC and steel rebars was established through regression analysis using the experimental data.

Table 2.10: Bond strength results

No.	Mean peak load Po (N)	Mean bond strength to (MPa)	Standard deviation (MPa)	Coefficient of variation (%)
RAC-I-0	14030	8.93	1.29	14.47
RAC-I-50	12310	7.84	1.46	18.58
RAC-I-100	13130	8.36	1.29	15.46
RAC-II-0	27300	17.39	1.5	8.62
RAC-II-50	27060	17.24	0.78	4.53
RAC-II-100	27300	17.39	0.34	1.95

Butler et al. (2011) observed that the purpose of this study was to investigate the influence that replacing natural coarse aggregate with recycled concrete aggregate (RCA) has on concrete bond strength with reinforcing steel. Two sources of RCA were used along with one natural aggregate source. Numerous aggregate properties were measured for all aggregate sources. Two types of concrete mixture proportions were developed replacing 100% of the natural aggregate with RCA. The first type maintained the same water–cement ratios while the second type was designed to achieve the same compressive strengths. Beam-end specimens were tested to determine the relative bond strength of RCA and natural aggregate concrete. On average, natural aggregate concrete specimens had bond strengths that were 9 to 19% higher than the equivalent RCA specimens. Bond strength and the aggregate crushing value seemed to correlate well for all concrete types.

Table 2.11: Direct replacement concrete mixture proportions and test results

S.No	Material	RAC1-30	RAC1-50	RAC2-30	RAC2-50
1	Water (kg/m3)	160	180	160	180
2	Cement (kg/m3)	267	474	267	474
3	Coarse aggregate (kg/m3)	975	975	949	949
4	Fine aggregate	863	635	863	635
5	water-cement ratio	0.6	0.38	0.6	0.38
6	Slump (mm)	25	35	45	75
7	Compressive strength (MPa)	44.1	59	36.9	54

2.5 Need of the Present Investigation

A review of literature presented shows that recycled aggregates are being investigated for proper use in concrete. The total use of recycled aggregates in concrete with positive results has been done in very few studies.

2.6 Closing Remarks

A review of recent literature on behaviour of natural coarse aggregate and recycled coarse aggregate and recycled fine aggregate concrete has been presented on the basis of which the need of the present investigation has been identified.

CHAPTER 3

EXPERIMENTAL WORK

3.1 General

The details of experiment programme in terms of material properties, test set-up for measuring different parameters and the testing procedure discussed in this chapter.

3.2 Material Properties

Cement, fine aggregates, coarse aggregates, recycled coarse aggregate, recycled fine aggregate and water is used for present investigation. The properties of these materials are discussed in the following sections.

3.2.1 Cement

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel and crushed stone to make concrete. The ordinary cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous materials, clay predominates and in calcareous materials calcium carbonate predominates. Ordinary Portland cement of grade – 43 (J.K cement) conforming to Indian standard IS: 8112-1989 has been used in the present study. The results of the various tests on cement properties are given in Table 3.1.

Table 3.1: Physical properties of ordinary Portland cement

S.NO	Properties	Values	Values as per IS code 8112:1989
1	Consistency	29%	_
2	Initial setting time	127 minutes	not less then 30 mints
3	Final setting time	183 minutes	not greater then 600 minutes
4	Fineness	97.34%	_
5	Specific gravity	3	_
6	Compressive strength (Mpa)		
	3 days	32.6	23
	7 days	43.2	33
	28 days	48.01	43

3.2.2 Fine aggregates

The material which passes through 4.75 mm sieve is termed as fine aggregate. Usually natural sand is used as a fine aggregate at places where natural sand is not available crushed stone is used as a fine aggregate. The sand used for the experimental works is locally procured and conformed to grading zone III. The sieve analysis of fine aggregates is shown in Table 3.2. The physical properties are provided in Table 3.3

Table 3.2: Sieve analysis of fine aggregates

S.NO	sieve size (mm)	Weight retained (grams)	Retained (%)	Passing (%)	cumulative (%) retained
1	4.75	6	1.2	98.8	1.2
2	2.36	32	6.4	92.4	7.6
3	1.18	186	37.2	55.2	44.8
4	600micrn	122	24.4	30.8	69.2
5	300micrn	85	17	13.8	86.2
6	150micron	51	10.2	3.6	99.4
7	pan	18	3.6	0	
					sum = 308.4

Table 3.3: Physical properties of fine aggregates

S.No.	Characteristics	Value
1	type	Natural
2	specific gravity	2.67
3	Fineness modulus	3.08
4	grading zone	type 1

3.2.3 Natural coarse aggregate

The broken stone is generally used as a coarse aggregate. The nature of work decides the maximum size of the coarse aggregate. Locally available coarse aggregate having the maximum size of 20 mm was used in the present work. The properties of natural aggregate are presented in Table 3.4.

Table 3.4: Sieve analysis of natural coarse aggregates

S.NO	Sieve size (mm)	Weight retained (kg)	Retained (%)	Passing (%)	cumulative (%)weight retained
1	20	0	0	100	0
2	12.5	2.18	72.88	27.12	72.84
3	10	0.67	22.48	4.66	95.37
4	4.75	0.14	4.63	0.01	99.99

Table 3.5: Physical properties of coarse aggregate

S.No.	Properties	Natural aggregates value
1	Specific gravity	2.31
2	Water absorption (%)	1.8
3	Fineness modulus	7.6

3.2.4 Recycled coarse aggregate

Tested concrete specimens e.g. cubes, cylinders and beams lying in the dump yard of concrete laboratory at Thapar University has been used as a source of RCA. To make RCA, the specimens without reinforcement were manually broken down into small pieces and then crushed using jaw crusher as shown in Fig. 3.1 and 3.2. The larger fraction, passing through 20 mm sieve but retained on 12.5 mm sieve was designated RCA20 – 12.5 mm. The fraction passing through 12.75 mm sieve was discarded.

Fig. 3.1: Waste concrete rubble for obtaining RCA

Fig. 3.2: Jaw crusher to obtain RCA

Fig. 3.3: Concrete breaker

Table 3.6: Sieve analysis of recycled coarse aggregates

S.No.	sieve size (mm)	weight retained in (kg)	Retained (%)	Passing (%)	Cumulative (%) weight retained
1	20mm	0 kg	0	100	0
2	12.5mm	0.458kg	45.8	54.2	45.8
3	10mm	0.158kg	15.8	38.4	61.6
4	4.75mm	0.376kg	37.6	0.08	99.2

Table 3.7: Physical properties of the recycled coarse aggregate

S.No.	Properties	Value
1	Specific gravity	2.48
2	Water absorption (%)	3.4
3	Fineness modulus	7.8

Table 3.8: Sieve analysis of recycled fine aggregates

S. No.	Sieve size (mm)	Weight retained in (kg)	Retained (%)	Passing (%)	Cumulative (%) weight retained
1	4.75mm	3	0.3	99.7	0.3
2	2.36mm	122	12.2	87.5	12.5
3	1.18 micron	357	35.7	51.8	48.7
4	600 micron	169	16.9	34.9	65.1
5	300 micron	135	13.5	21.4	78.6
6	150 micron	132	13.2	8.2	91.8
7	residue	82	8.2	0	
					sum = 297

Table 3.9: Physical properties of the recycled fine aggregate

S.No.	Characteristics	Value
1	Type	Recycled aggregate
2	Specific gravity	2.2
3	Fineness modulus	2.97

Fig. 3.4: (A pouring waste, B crushing and sieving)

3.2.5 Reinforced steel

High strength deformed steel bars (Fe500) with a nominal diameter of 16 mm tensile strength 533.412MPa was used as main longitudinal reinforcements in all pull out test specimens .

Fig. 3.5: Steel cutter

3.2.6 Comparison between coarse recycled and coarse natural aggregate:

Fig. 3.6 presents the texture comparison between coarse natural aggregate and coarse recycled aggregates. Following observations were drawn:

1. Recycled aggregate has rough – textured, angular and elongated particles where natural aggregate is smooth and rounded compact aggregate.
2. Recycled aggregate is well graded as natural aggregate.
3. The water absorption capacity of coarse recycled aggregate is 5.0% which is about two times more than natural coarse aggregates.

4. The dry density of coarse recycled aggregate is lower than dry density of natural aggregate.

The difference is due to cement paste adhered to aggregate and some kinds of impurities in recycled aggregate .The rough – texture, angular and elongated particles require more water than the smooth surface which increase the capacity of water absorption .The void content will increase with the angular aggregate which decrease the dry density of coarse recycled aggregate.

(a) (b)

Fig. 3.6: Texture comparison between coarse natural aggregate and coarse recycled a) Natural coarse aggregate b) Recycled coarse aggregate

3.2.7 Water

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. Potable water is generally considered satisfactory. In the present investigation, tap water is used for both mixing and curing purposes.

3.3 Mix Combinations

Concrete mix has been designed using the provisions under the IS code specification of IS 10262: 2009. All the concrete mixes were designed for water-cement ratio (0.39). The mix proportion of corresponding mixes for water-cement ratio was prepared by replacing natural aggregate by recycled coarse aggregate both in coarse and fine aggregate part. To maintain slump, super plasticizer at 0.1% - 0.2% weight of cement has been used in recycled aggregate concrete.

The RCA replacement percentage is defined as the weight ratio of recycled coarse aggregate to the total coarse aggregates in the concrete mixture and depending upon the selected replacement percentage, direct substitution of NCA with an equal weight of recycled coarse aggregate particles is carried out. The following six weight combinations of NCA and recycled coarse aggregate are adopted:

Table 3.10 Mix prepared by different level of replacements of fine and coarse aggregates

S.No.	Type of Mix	COARSE AGGREGATE (10/20MM)	FINE AGGREGATE (<4.75MM)
1	Control mix	100% NATURAL	100%NATURAL
		0%RECYCLED	0% RECYCLED
2	Mix 2	100% NAYURAL	50% NATURAL
		0% RECYCLED	50% RECYCLED
3	Mix 3	50% NATURAL	100%NATURAL
		50%RECYCLED	0% RECYCLED
4	Mix 4	50% NATURAL	50% NATURAL
		50% RECYCLED	50% RECYCLED
5	Mix 5	0%NATURAL	100% NATURAL
		100% RECYCLED	0% RECYCLED
6	Mix 6	0%NATURAL	50% NATURAL
		100% RECYCLED	50% RECYCLED

Table 3.11 Mix proportions for the mixes at different replacement of NCA, NFA with RCA and RFA (in kg/m^3)

Mix	W/C Ratio	Replacement (coarse aggregate) (%)	Replacement (Fine aggregate) (%)	Cement	NCA	NFA	RCA	RFA	Water
Mix 1	0.39	0	0	476.92	445.81	956.12	0	0	185.99
Mix 2	0.39	0	50	476.92	445.81	478.06	0	478.06	185.99
Mix 3	0.39	50	0	476.92	222.91	956.12	222.91	0	185.99
Mix 4	0.39	50	50	476.92	222.91	478.06	222.91	478.06	185.99
Mix 5	0.39	100	0	476.92	0	956.12	445.81	0	185.99
Mix 6	0.39	100	50	476.92	0	478.06	445.81	478.06	185.99

The concrete mixture proportions and the corresponding mix designations are presented in Table 3.11.

3.4. Casting of Specimens

In this section casting procedure for compressive strength test and bond strength test are discussed. In concrete batching, first the natural coarse aggregates and RCA are added in the mixer, subsequently, fine aggregates and cement are added to the mixer the ingredients are dry mixed in the mixer for 2 minutes. Then half of water is added and again mixed for 1minute. After this, the rest of the water mixed for another 2 minutes. The mixture is now ready to be poured in the moulds.

3.4.1 Casting for compressive strength test

Three cube specimens of size 150×150×150mm were casted for static compressive strength. The quantities of cement, coarse aggregate natural and recycled, fine aggregate natural and recycled , water for each batch replacement was weighed separately. Fine aggregate was mixed to this mixture in dry form.

The coarse aggregates were mixed to get uniform distribution throughout the batch. Water added to the mix. Firstly, 50 to 70% of water was added to the mix and then mixed thoroughly for 3 to 4 minutes in mixer.

Fig. 3.7: (A oiling ,B mixing ,C casting ,D curing)

The cubes are filled with fresh concrete using vibrating table. Immediately after casting cubes, the specimens are covered with gunny bags to prevent water evaporation. Three cubes are casted for each parameter. The compressive strength test is carried out for 7 days and 28 days..

3.4.2 Casting for Pullout Strength Test

Pull out specimens are widely used for investigation of bond behaviour between rebar and concrete because of their ease of fabrication and the simplicity of the test. Pullout tests provide a simple means of comparing normalized bond behaviour. In the present investigation, cube of size 150mm is used for carrying out the pull out strength test.

The specimen is prepared as per the IS code guide lines from IS: 2770 (Part I)–1967 (Methods of testing bond in reinforced concrete). In this, three rebar of 16mm diameter is used as concentric reinforcement that will be pulled for finding pull out strength. The pulls out specimens are casting vertical position in the laboratory using steel moulds. The embedded length is kept 5 d_b (rebar diameter) and was so selected to avoid yielding of the steel bar under pull out load. Contact between the concrete and there bar along the de bonded length was broken using a coaxially placed soft rubber tube. Then the rebar is placed exactly in the centre. Then in the mould, the concrete mixed is poured and compacted using vibrating table. To prevent excessive evaporation from the fresh concrete, the pull out specimens are covered with a plastic sheet after casting and de moulded after 24h following which they are moist cured in the laboratory for a nominal period of 28days from the day of casting by keeping them wet by gunny bags. The water is sprinkle on gunny bags, twice a day. To ensure repeatability of results, two nominally identical companion specimens are cast for each mix under investigation. The typical sample specimens are shown in Fig. 3.8 as below.

Fig. 3.8: casted moulds

3.5 Testing of Specimens

In this section test setup for the tests (compressive strength test, bond strength test) are discussed.

3.5.1 Setup for static compressive strength test

Three specimens are crushed at 7, 28 days and 56 days. The compressive strength is calculated by dividing the failure load by average cross sectional area .The compressive strength testing machine of capacity 5000 kN is used for determining the maximum compressive loads carried by concrete cubes. The compressive strength test machine which used in all tests is shown in Fig. below. At the test age the specimens are taken out of the curing tank and kept outside for 10 minutes. Then one specimen is placed on the steel plate of the machine such that the specimen is tested perpendicular to the casting position. Then the test is carried out at the loading rate of 5 kN/s specified IS: 516 - 1959. Maximum load on the specimen was recorded as load at which specimen failed to take any further increase in load

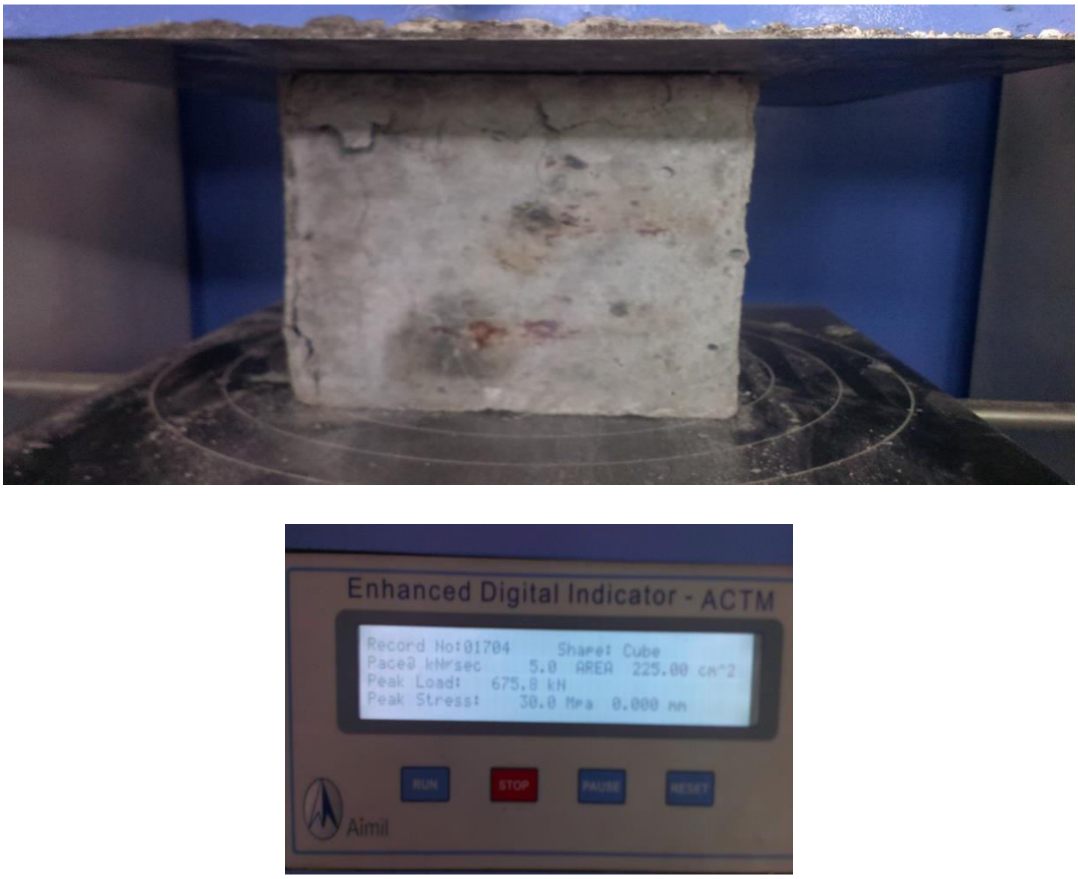


Fig. 3.9: Testing for compressive strength

3.5.2 Test Setup for Pull out Strength

Pull out strength test are carried out on universal testing machine of capacity 1000 KN

Shown in Fig. 3.10.

Fig 3.10: Pullout testing machine

The test setup for pull out test is shown in Fig.3.10. A special arrangement of 40mm thick steel plate is made to carry out the test shown in Fig. 3.11. The plates are connected by four nut-bolts of 25mm diameter. Lower plate is welded with rod having diameter 25mm. And opening at the top plate just allow the deformed steel bar to pass.

Fig. 3.11: Test Setup for Pull out Strength Test

To carry out test, the rod of 25mm is welded to lower plate of the set up is fixed in the lower jaw of the machine. The specimen is kept in between the two plates and is fixed by tightening the nut -bolts. The rebar (16mm) embedded in the specimen is passed through the hole in the upper plate and is fixed to the upper jaw of the universal testing machine. There bar is pulled out at the rate of 2.25kg/m in for all test specimens.

Fig.3.12 shows the dimensions of pull out test specimens, the location and the length of embedded deformed steel bar in concrete specimens. The bond strength is calculated by dividing the pull out force by the surface area of the embedded length of steel bars as follows

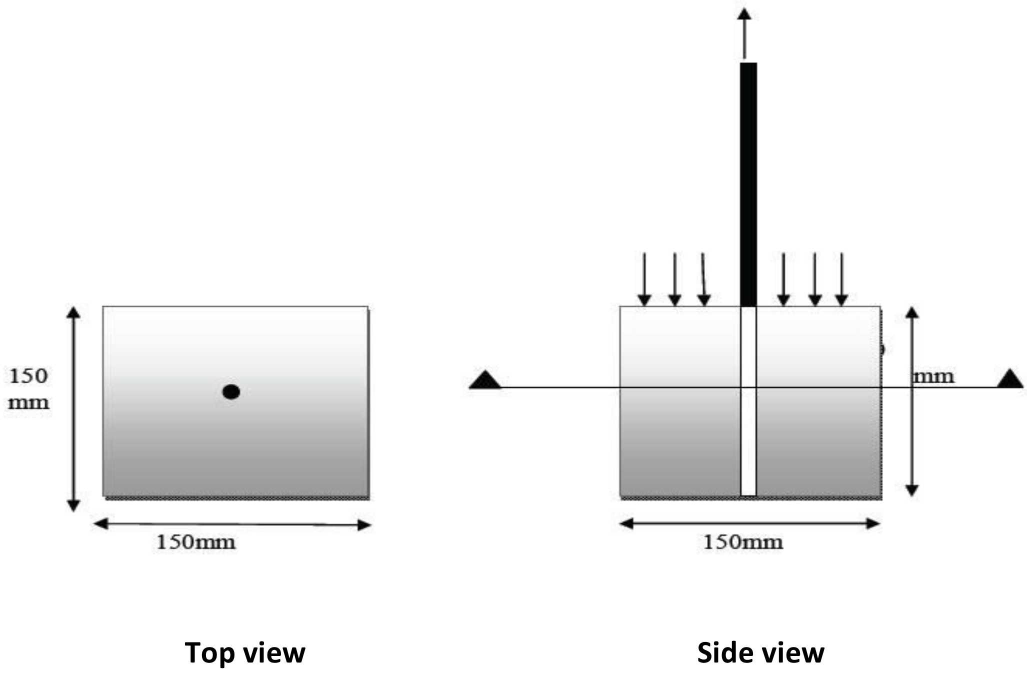


Fig. 3.12: The dimensions of pull out test specimens, the location and the length of embedded deformed steel bar in concrete specimens

$$\text{Bond strength} = P/(\pi * D * L)$$

where,

P= Pullout load, (KN)

D = Diameter of rebar, it is kept as 16mm for experimental programme.

L = embedment length, the value is taken as 80mm for 16mm for experimental programme.

The pull out strength test is carried out at the age of 7, 28 and 56 days.

The different samples are tested for each mix at the specified age. After completion of test, sample was removed from the test setup, physical verification of crack and type of slip is observe as shown in Fig.3.13. It is observed that specimen failed by both pull out and by splitting of concrete.

Fig.3.13 (a,b,c): Crushing due To Pull out Bar Lugs after Pull out Test

3.6 Closing Remarks

The experimental programme described in this chapter includes the significant material properties and specifications of the ingredients of concrete and the testing procedure. The specimen details and the test set-up have been discussed.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

In this chapter, results of compressive strength, bond strength of various concrete mixes incorporating 0%, 50% and 100% recycled aggregates, 0 % and 50% of fine recycled aggregate are discussed. All the tests conducted were in accordance with the methods described in Chapter 3.

4.2. Compressive Strength Test

Three cubes (150mm) from each batch of concrete mix are casted and cured for 7 and 28days in order to determine compressive strength of RCA concrete. Table 4.1 shows the average compressive strength of different mix combinations tested at 7 and 28 days. The data is further represented in the form of bar graphs

Table 4.1: Compressive strength of specimen at 7 and 28 and 56 days in MPa

	Compressive Strength (MPa)					
Duration	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6
7 days	34.71	35.55	34.07	34.28	32.98	33.6
28 days	39.07	40.67	37.77	38.26	36.89	37.64
56 days	43.11	46.98	40.53	42.09	38.20	39.69

1. In MIX 2 (100% NCA + 50% RFA + 50% NFA) the compressive strength approaches the satisfactory level , as after replacing 50% of fine natural aggregates by weight with the recycled fine aggregates there is increase in compressive strength by 2.4 % at 7 day, 4.09% at 28 day and 8.96% at 56 day testing respectively.
2. In MIX 3 (50% NCA + 50% RCA + 100% NFA) there is decrease in the compressive strength, the percentage decrease in compressive strength is 1.84% at 7 day, 3.29% at 28 day and 5.97% at 56 day testing.
3. In MIX 4 (50% NCA + 50% RCA +50% NFA+50% RFA) the replacement 50% of natural fine aggregates by weight with the recycled fine aggregate and 50% of replacement of natural coarse aggregate by weight with the recycled coarse aggregates there is decrease in compressive strength denoted in terms of percentage decrease as 1.23% decrease at 7 day, 2.045% decrease at 28 day and 2.37% decrease at 56 day testing respectively.
4. In MIX 5 (100% RCA + 100% NNFA), the percentage decrease in compressive strength is 4.99% decrease at 7 day, 5.57% decrease at 28 day and 11.38% decrease at 56 day testing respectively.
5. While in MIX 6 (100% RCA + 50 %RFA + 50% NFA) decrease of compressive strength denoted in terms of percentage is 3.20% decrease at 7 day , 3.6 % decrease at 28 days and 7.9 % decrease 56 day testing respectively.

Table 4.2: compressive strength (7 days)

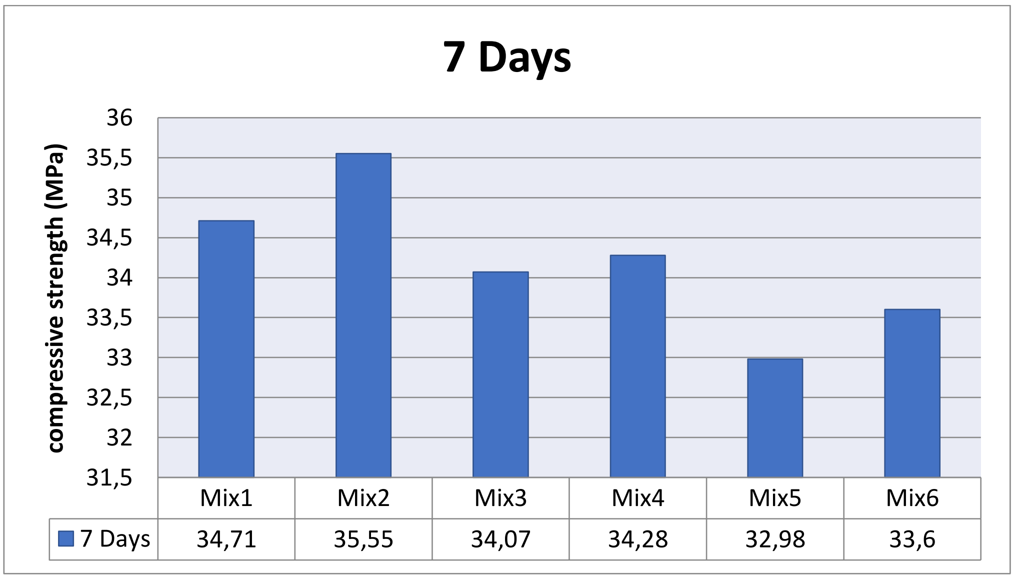


Table 4.3: compressive strength (28 days)

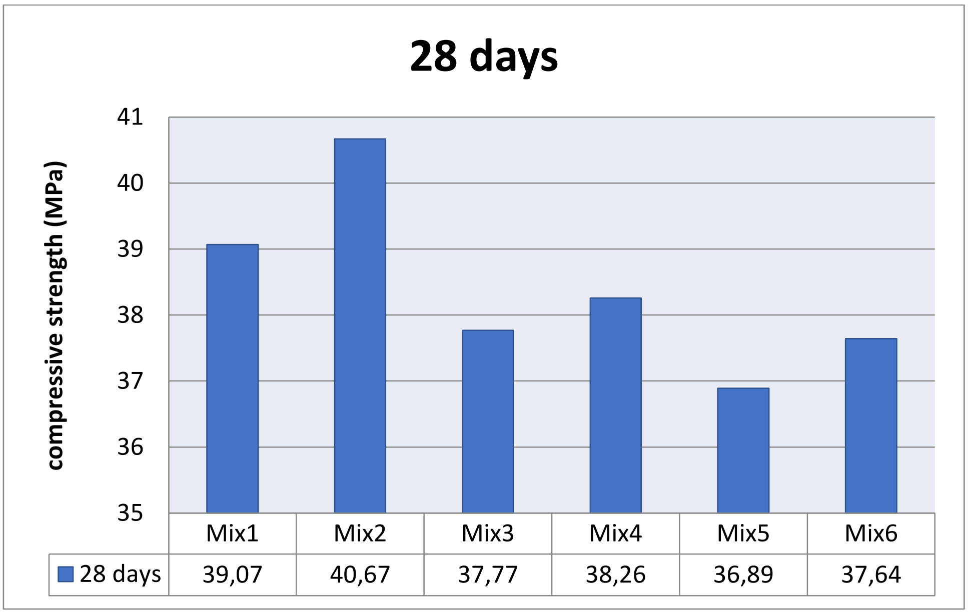


Table 4.4: compressive strength (56 days)

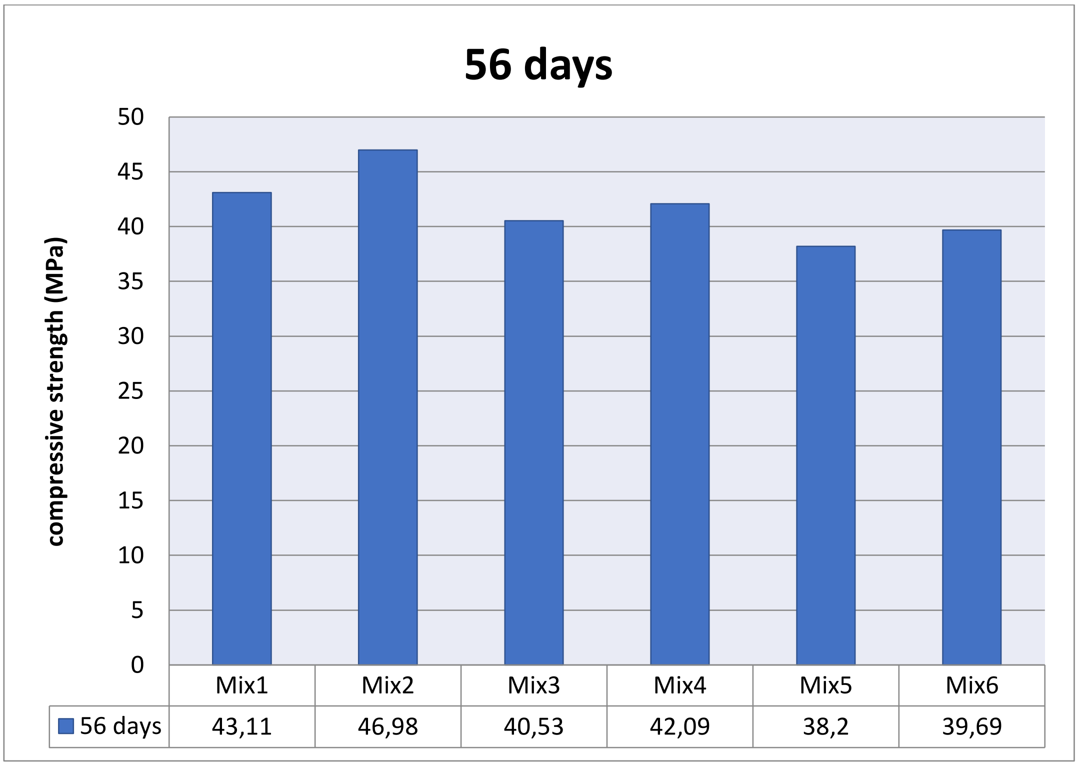
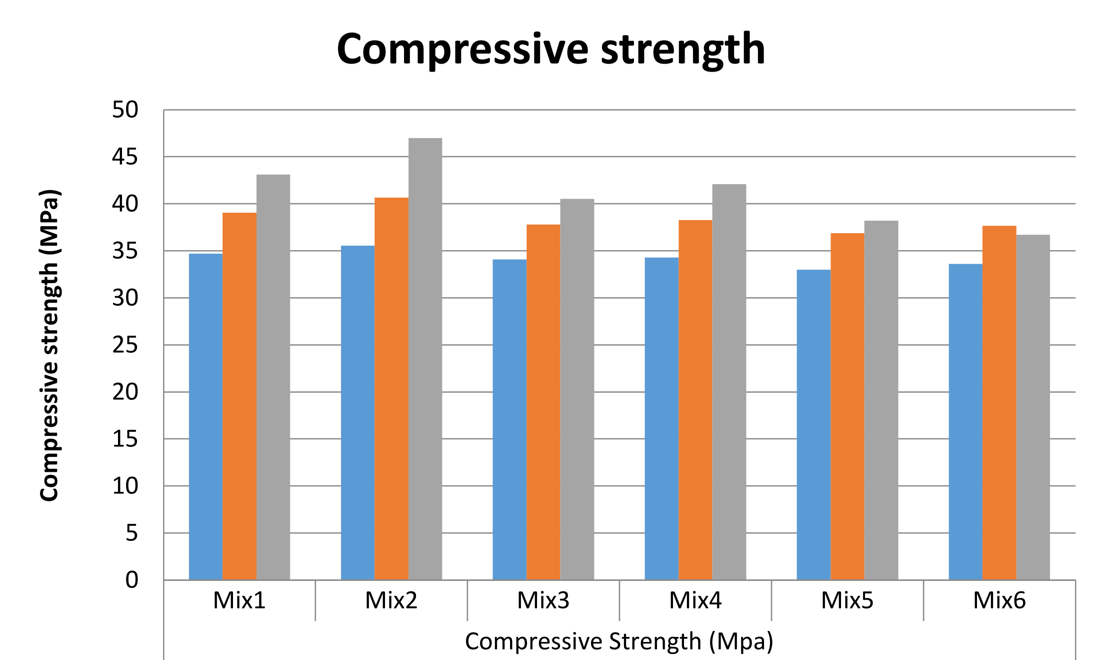


Table 4.5: Compressive strength value of control mixture and recycled aggregate concrete



	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6
7 days	34,71	35,55	34,07	34,28	32,98	33,6
28 days	39,06	40,67	37,8	38,27	36,89	37,65
56 days	43,11	46,98	40,53	42,09	38,2	36,69

The decrease of compressive strength due to increase of recycled aggregate percentage can be explained as follows:

1. The recycled aggregate is covered with hardened cement paste, which is very weak layer, so the compressive strength of recycled aggregate itself is weak.
2. The hardened cement paste on recycled aggregate is high in water absorption, consequently no enough residual water is present to complete all the quantity cement reaction.
3. The shape of recycled aggregate concrete prevents sliding due to compaction, this leads to poor quality of compaction, consequently not well compacted concrete.
4. The existence of cement paste layer on recycled aggregate prevent integration of all aggregate ,and prevent enough bond between recycled aggregate and new cement paste .

5. There was some impurities in the recycled aggregate like wood, glass, brick etc. which affect the bond in general adversely.

The increase of compressive strength due to increase of recycled aggregate percentage can be explained as follows:

1. The increase of the compressive strength for low replacement percentage may be due to the containing a higher percentage of fine soil, which was capable of filling up the voids more effectively.
2. The angular surfaces of the recycled aggregates provide more resistance between the particles and hence which leads to reduction the slip between the particles under the action of load.
3. The higher compressive strength is likely due to strong mortar-aggregate bond between the RCA and new mortar.

4.3 Bond strength

Three cubes for each batch of concrete mix are casted and cured for 7days, 28days and 56 days in order to determine bond strength of all the mix concrete. The mixes are casted at water- cement ratio 0.39. Bond strength between concrete and deformed steel bars increases as percent of recycled aggregate increases. The results obtained are discussed in the following sections:

4.3.1 Effect of RCA on Bond Strength

The specimen for testing is prepared as per the IS code guide lines from IS: 2770 (Part I)– 1967 (Methods of testing bond in reinforced concrete). In this, three rebar of 16mm diameter is used as concentric reinforcement that will be pulled for finding pull out strength. After the testing the peak load, elongation values are obtained correspondingly to each other as shown in Table 4.8 and bond strength in Table 4.9.

Table 4.6: load (kN) and elongation (mm) at 7, 28 and 56 day testing

MIX	7 DAYS		28 DAYS		56 DAYS	
	Load (KN)	Elongation (mm)	Load (KN)	Elongation (mm)	Load (KN)	Elongation (mm)
1	43.97	10.63	47.9	13.69	61	13.93
2	44.45	11.37	49.2	13.67	64.9	13.13
3	39.25	12.94	45.7	15.13	52.2	12.53
4	40.2	12.47	46.2	12.33	56.9	11.97
5	37	13.29	39.2	10.99	49.9	12.99
6	39.13	12.99	44.4	12.38	50.7	14.4

Table 4.7: Average Bond strength results obtained on the 16 mm dia steel bar used (MPa)

MIX	BOND STRENGTH (MPa)		
	7 days	28 days	56days
1	10.94	11.92	15.18
2	11.06	12.24	16.18
3	9.76	11.37	12.99
4	10.01	11.49	14.16
5	9.20	9.75	12.42
6	9.73	11.05	12.65

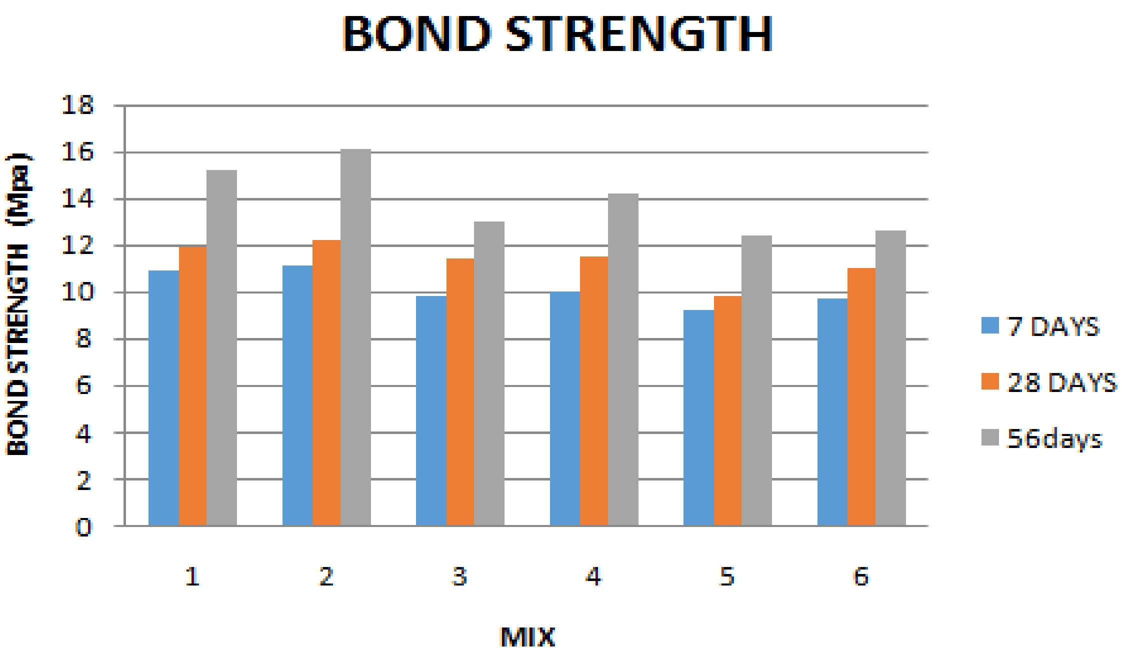


Table 4.8: Bond strength values of 7, 28 and 56 days

1. The bond strength approaches the satisfactory level when fine recycled aggregate are used by 50% replacement of natural fine aggregate by weight i.e. MIX 2 (100% NCA + 50% RFA + 50% NFA). After replacing 50% of fine aggregates there is increase in bond strength in terms of percentage as 1.09% increase at 7 day, 2.71% increase at 28 day and 6.39% increase at 56 day testing respectively as shown in Table 4.10.
2. In MIX 3 (50% NCA + 50% RCA + 100% NFA) , 0% replacement of fine natural aggregate and 50% replacement of coarse natural aggregate by weight with the recycled coarse aggregate. The amount of percentage decrease in bond strength is 10.73% at 7 day, 4.59% at 28 day and 14.26% at 56 day testing respectively.
3. In MIX 4 (50% NCA + 50% RCA +50% NFA+50% RFA), there is 50% replacement of fine natural aggregate by weight with the fine recycled aggregate and 50 % replacement of coarse natural aggregates by weight with coarse recycled aggregates . The Bond strength decrease that is shown in terms of percentage decrease as 8.57% decrease at 7 day, 3.54% decrease at 28 day and 6.72 % decrease at 56 day testing respectively.

4. In MIX 5 (100% RCA + 100% NFA) there is 100% replacement of coarse recycled aggregates by weight with the natural coarse aggregate and 0% replacement of fine recycled aggregate by weight with the natural fine aggregates shows an decrease in terms of percentage decrease as 15.85% at 7 day, 18.16% at 28 day and 18.19% at 56 day testing respectively .
5. At 100% replacement of coarse recycled aggregate by weight with the natural coarse aggregate and 50% fine natural aggregate by weight with the recycled fine aggregate i.e. MIX 6 (100% RCA + 50 %RFA + 50% NFA) show decrease in the Bond strength. The decreases in bond strength is shows in terms of percentage decrease as 11% decrease at 7 day, 15.65% decrease at 28 day and 16.8% decrease at 56 day testing respectively
6. The 7 day, 28day and 56 day load values with respect to elongation are displayed in form of curve in Fig.4.1, Fig.4.2 and Fig. 4.3 respectively.

Fig. 4.1: Load and Elongation curve of all the mixes of concrete at 7 days

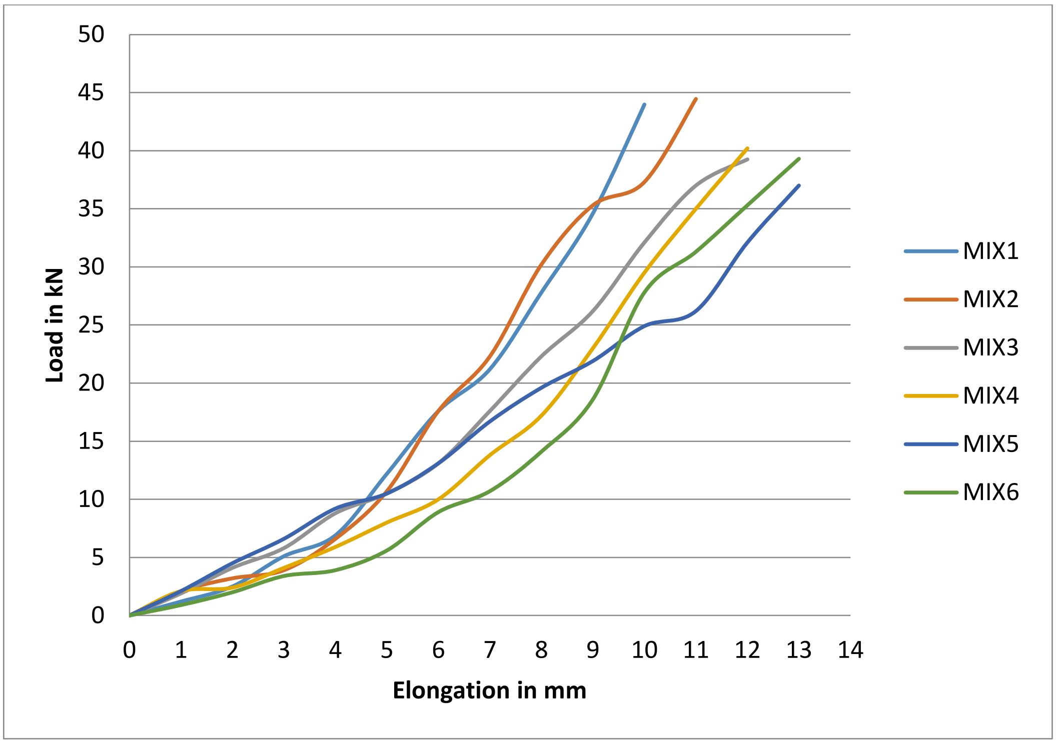


Fig. 4.2: Load and Elongation curve of all the mixes of concrete at 28 days

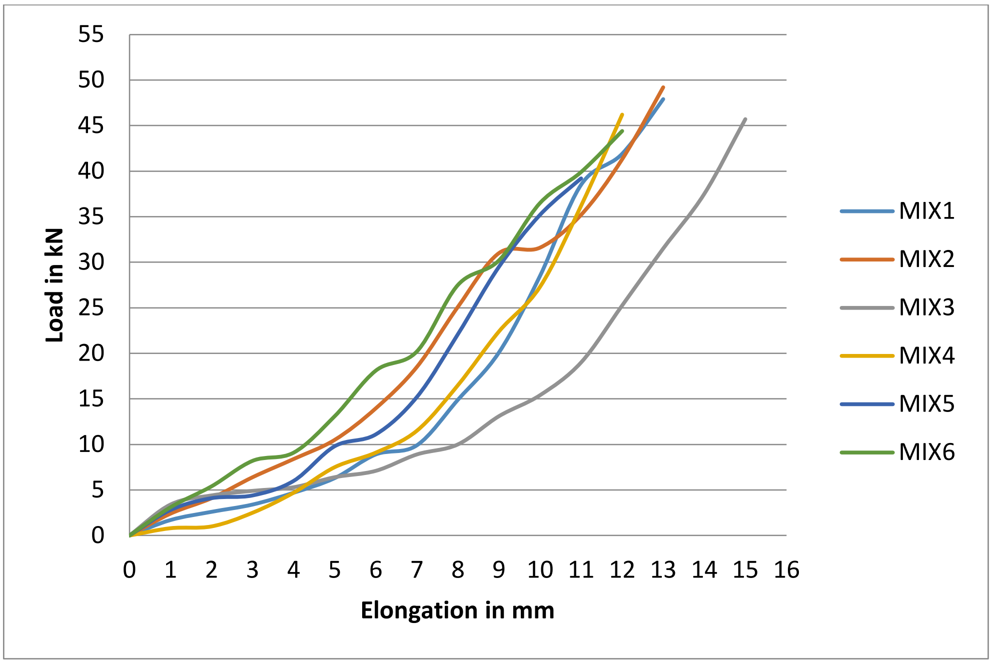
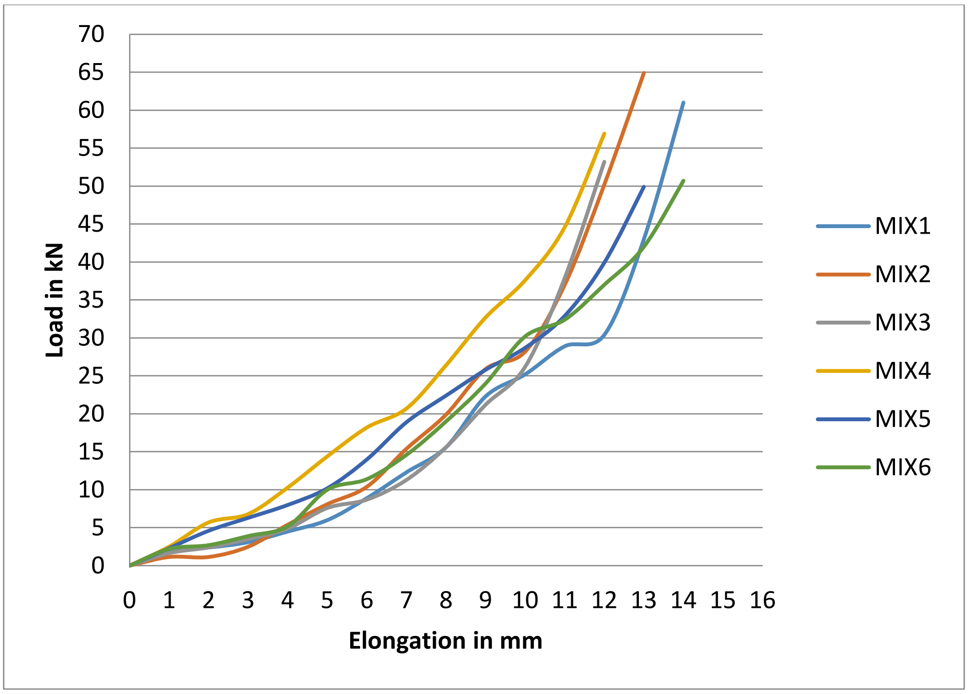


Fig. 4.3: Load and Elongation curve of all the mixes of concrete at 56 days



CHAPTER 5

CONCLUSIONS

5.1 General

From the results obtained in the tests on concrete mixes where fine and coarse natural aggregates were replaced by fine and coarse recycled concrete aggregates in different proportions, the following conclusions can be drawn in relation to compressive strength and bond strength:

1. In MIX 2 (100% NCA + 50% RFA + 50% NFA) the compressive strength approaches the satisfactory level , as after replacing 50% of fine natural aggregates by weight with the recycled fine aggregates there is increase in compressive strength by 2.4 % at 7 day, 4.09% at 28 day and 8.96% at 56 day testing respectively.
2. In MIX 3 (50% NCA + 50% RCA + 100% NFA) there is decrease in the compressive strength, the percentage decrease in compressive strength is 1.84% at 7 day, 3.29% at 28 day and 5.97% at 56 day testing.
3. In MIX 4 (50% NCA + 50% RCA +50% NFA+50% RFA) the replacement 50% of natural fine aggregates by weight with the recycled fine aggregate and 50% of replacement of natural coarse aggregate by weight with the recycled coarse aggregates there is decrease in compressive strength denoted in terms of percentage decrease as 1.23% decrease at 7 day, 2.045% decrease at 28 day and 2.37% decrease at 56 day testing respectively.
4. In MIX 5 (100% RCA + 100% NNFA), the percentage decrease in compressive strength is 4.99% decrease at 7 day, 5.57% decrease at 28 day and 11.38% decrease at 56 day testing respectively.
5. While in MIX 6 (100% RCA + 50 %RFA + 50% NFA) decrease of compressive strength denoted in terms of percentage is 3.20% decrease at 7 day , 3.6 % decrease at 28 days and 7.9 % decrease 56 day testing respectively.

6. The bond strength approaches the satisfactory level when fine recycled aggregate are used by 50% replacement of natural fine aggregate by weight i.e. MIX 2 (100% NCA + 50% RFA + 50% NFA). After replacing 50% of fine aggregates there is increase in bond strength in terms of percentage as 1.09% increase at 7 day, 2.71% increase at 28 day and 6.39% increase at 56 day testing respectively.
7. In MIX 3 (50% NCA + 50% RCA + 100% NFA) , 0% replacement of fine natural aggregate and 50% replacement of coarse natural aggregate by weight with the recycled coarse aggregate. The amount of percentage decrease in bond strength is 10.73% at 7 day, 4.59% at 28 day and 14.26% at 56 day testing respectively.
8. In MIX 4 (50% NCA + 50% RCA +50% NFA+50% RFA), there is 50% replacement of fine natural aggregate by weight with the fine recycled aggregate and 50 % replacement of coarse natural aggregates by weight with coarse recycled aggregates. The Bond strength decrease that is shown in terms of percentage decrease as 8.57% decrease at 7 day, 3.54% decrease at 28 day and 6.72 % decrease at 56 day testing respectively.
9. In MIX 5 (100% RCA + 100% NFA) there is 100% replacement of coarse recycled aggregates by weight with the natural coarse aggregate and 0% replacement of fine recycled aggregate by weight with the natural fine aggregates shows an decrease in terms of percentage decrease as 15.85% at 7 day, 18.16% at 28 day and 18.19% at 56 day testing respectively .
10. At 100% replacement of coarse recycled aggregate by weight with the natural coarse aggregate and 50% fine natural aggregate by weight with the recycled fine aggregate i.e. MIX 6 (100% RCA + 50 %RFA + 50% NFA) show decrease in the Bond strength. The decreases in bond strength is shows in terms of percentage decrease as 11% decrease at 7 day, 15.65% decrease at 28 day and 16.8% decrease at 56 day testing respectively.

The increase in compressive strength shows in terms of percentage increase is varied between 2% to 9 % with respect to control concrete i.e. MIX 1 (100% NCA + 100% NFA), where as the decrease shown in compressive strength is between 2% to 12% in terms of percentage with respect to control concrete i.e. MIX 1 (100% NCA + 100% NFA). The increase in the bond strength shows in terms of percentage increase is varied between 1 % to 7 % with respect to control concrete i.e. MIX 1 (100% NCA + 100% NFA), where as the decrease shown in the bond strength is between 3% to 19% in terms of percentage with respect to control concrete i.e. MIX 1 (100% NCA + 100% NFA).

In all the MIXES there is a pattern observed, which can be arranged as MIX 2 > MIX 1 > MIX 4 >MIX 3 > MIX 6 > MIX 5 (descending order) at 7day, 28day And 56 Day testing.

The superior bond strength of MIX 2 is due to the internal curing action of the RCA particles. The water absorption of the RCA particles used in this investigation was higher than that of the NCA and when used in the saturated surface dry moisture state the RCA particles through the phenomenon of internal curing readily release water as needed for hydration or to replace moisture lost through evaporation. Internal curing is expected to result in better cement hydration, improved integrity of the contact zone between the RCA particles and the concrete matrix and a significant reduction of permeability due to extension of the curing time. The improved integrity and mechanical properties of the concrete conglomerate are expected to enhance the bond strength as well.

Bond strength reductions have not been noted with only recycled fine aggregate is used; however, when recycled fine and coarse aggregates are used together in different combinations reductions has been reported.

Through this investigation, the use of recycled fine and coarse aggregates as partial replacement to natural aggregates in civil engineering applications, is established. Replacing 50% fine and coarse natural aggregate content with equal amount of recycled fine and coarse aggregates in concrete and yet achieving higher or comparable bond strength performance favours the use of recycled aggregates in concrete while contributing towards the sustainable construction and economical challenges at different levels.

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