

**BOND STRENGTH OF CONCRETE CONTAINING
RECYCLED CONCRETE AGGREGATES
AND
RECYCLED PLASTIC AGGREGATES**

**Thesis report submitted
in partial fulfilment of the requirements for
award the of degree of**

**MASTER OF ENGINEERING
in
CIVIL (STRUCTURES) ENGINEERING**

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DECLARATION

I, Vijay Kumar, hereby declare that this thesis report entitled “**BOND STRENGTH OF CONCRETE CONTAINING RECYCLED CONCRETE AGGREGATES AND RECYCLED PLASTIC 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 work done by me.

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.

Date: 29/12/2014



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CERTIFICATE

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


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ABSTRACT

The growing environmental concerns and proper disposal of construction and demolition waste is a challenge for construction industry. Now a days in our country Solid waste management is one of the major environmental concerns. A substantial growth in the consumption of plastic is observed all over the world in recent years . The use of demolition waste as a resource for recycling or recovery is gaining grounds in many countries. The proper selection and processing of demolition waste can be helpful in producing concrete. Production of concrete using recycled aggregate concrete has many benefits, such as, proper management of demolition waste, natural aggregates shortage is addressed, reduction in transport cost of raw materials.

Recycling of plastic waste to produce new materials like concrete or mortar appears as one of the best solution for disposing of plastic waste, due to its economic and ecological advantages. Several works have been performed or are under way to evaluate the properties of cement-composites containing various types of plastic waste as aggregate, filler or fibre.

This thesis aims to find the possibility of the structural usage of recycled concrete aggregates and plastic aggregates when added as an alternative or mixed in different proportion with natural aggregates. A comprehensive literature review is carried out for better understanding of mechanical properties of concrete containing recycled concrete aggregates and plastic aggregates.

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1.1 General

Research concerning the use of by-products to augment the properties of concrete has been going on for many years. In the recent decades, the efforts have been made to use industry by-products such as fly ash, silica fume, ground granulated blast furnace slag, glass cullet, etc., in concrete manufacturing and civil applications. The potential applications of industry by-products in concrete are as partial aggregate replacement or as partial cement replacement, depending on their chemical composition and grain size. The use of these materials in concrete comes from the environmental constraints in the safe disposal of these products. Big attention is being focused on the environment and safeguarding of natural resources and recycling of wastes materials. Many industries are producing a significant number of products which incorporate scrap (residues) such as- reclaimed aggregate, reclaimed asphalt pavement, foundry sand, glass cullet, polyethylene terephthalate, high density polyethylene (HDPE), un plasticized polyvinyl chloride (UPVC) plasticized polyvinyl chloride (PPVC), low density polyethylene (LDPE), polypropylene(PP), polystyrene (PS) expanded polystyrene (UPS).

Infrastructural development plays an important role in the growth and enhancement of any country or society. This facility is accompanied by construction, remoulding, maintenance and demolition of buildings, roads, subways and other structural establishments. The buildings which are over their serviceability state are demolished for safety reasons. The waste generated from demolition was earlier used for landfills of ditches and trenches. But with time the amount of construction and demolition waste generated increased exponentially. It consists mostly of inert and non-biodegradable materials such as wood, concrete, glass, plastic and steel. Many large project sites have heaps and piles of construction and demolition waste lying around on roads and highways causing inconvenience and accidents to traffic movement. It is estimated that in India construction industry generates nearly 10-12 million ton of waste annually (*Thomas and Wilson 2013*). Future predictions for use of aggregates in building and road construction indicate of shortage of 55,000 million cu.m and 750

million cu.m. 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.

In the last 20 years, a lot of work concerning the use of several kinds of urban wastes in building materials industrials process has been published. One of the new waste materials used in the concrete industry is recycled plastic. For solving the disposal of large amount of recycled plastic material, reuse of plastic in concrete industry is considered as the most feasible application. Recycled plastic can be used as coarse aggregate in concrete.

1.2 Classification :- of recycled aggregates are as follows:-

1.2.1 Recycled Concrete Aggregates :The quantity of demolish building waste all over the world has been growing day by day due to new technology & architect aspect in building construction . . The types of recycled aggregates are shown in Table 1.1.

Table 1.1 Types of recycled concrete aggregate

Sr. No.	Name of Recycled Concrete	Use of Recycled Concrete made from Recycled Waste Concrete
1	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.
2	Recycled Concrete and Masonry (RCM)	Graded aggregate produced from sorted and clean waste concrete and masonry
3	Reclaimed Aggregate (RA)	Coarse aggregates reclaimed from rejected concrete by separating the aggregates from the water-cement slurry.
4	Reclaimed Asphalt Pavement (RAP)	Old asphalt concrete
5	Reclaimed Asphalt	Reclaimed coarse aggregate and recycled asphalt

	Aggregate (RAA)	granules from waste asphalt concrete
6	foundry sand	Spent foundry sand
7	Glass cullet	Glass cullet pulverised into a sand-like product

1.2.2 Plastic Aggregates: The quantity of plastics consumed annually all over the world has been growing phenomenally. Its exceptionally user-friendly characteristics/features, unique flexibility, coupled with immense cost-effectiveness and longevity are the main reasons for such astronomical growth. Besides its wide use in packaging, automotive and industrial applications, plastics are also extensively used in medical delivery systems, artificial implants and other healthcare applications, water desalination and bacteria removal, preservation and distribution of food, housing appliances, communication and the electronics industry, etc. the uses of plastics and recycled plastics. The types of recycled plastics are shown in tabular form in Table 1.2.

Table 1.2 Types of recycled plastics (Nabajyoti and Brito 2012)

S. No	Name of Plastic	Description	Range of product	Use of plastic made from Recycled Waste Plastic
1	Polyethylene terephthalate	Clear tough plastic	Soft drink & mineral water bottles	Soft drink bottles; detergent bottles; clear packaging film; fleecy jackets; carpet fibers
2	High density polyethylene (HDPE)	Usually white or colored. Very common plastic.	Milk, cream, shampoo and cleaner bottles; milk crates; freezer bags.	Compost bins; Mobile garbage bins; agricultural pipes
3	Un plasticized	Hard rigid plastic may	Clear cordial & juice bottles:	Detergent bottles; hoses; tiles;

	polyvinyl chloride (UPVC) Plasticized polyvinyl chloride (PPVC)	be clear. Flexible clear elastic plastic.	plumbing fittings Garden hoses, shoe soles.	plumbing pipes & fittings.
4	Low density polyethylene (LDPE)	Soft, flexible plastic.	Garbage bags, black plastic sheet; icecream container lids.	Film & bags for building and packaging.
5	Polypropylene(PP)	Hard but flexible plastic	Ice-cream containers, drinking straws potato crisp bags.	Compost bins; Kerbside recycling crates.
6	Polystyrene (PS) Expanded polystyrene (UPS)	Rigid, brittle plastic. May be clear or glassy.	Yoghurt containers; plastic cutlery. Hot drink cups; meat trays; packaging.	Clothes pegs, coat hangers, video & CD boxes.

1.3 Current Position of RCA and RPA in India and World:- Realising the future & national importance of recycled aggregate concrete in construction, Science and Engineering Research Council (SERC) Ghaziabad had taken up a pilot R&D project on recycling and reuse of demolition and construction wastes in concrete for low rise and low cost buildings in mid-nineties with the aim of developing techniques/ methodologies for use recycled aggregate concrete in construction. The experimental investigations were carried out to evaluate the mechanical properties and durability parameters of recycled aggregate concrete made with recycled coarse aggregate collected from different sources. Also, the suitability in construction of buildings has been studied. The properties of RAC were established and demonstrated through several experimental and field projects successfully. It has been concluded that RCA can be readily used in construction of low rise buildings, concrete paving blocks & tiles, flooring, retaining walls, approach lanes, sewerage structures, sub base course of pavement, drainage layer in highways, dry lean concrete (DLC) etc. in Indian scenario. Use of RCA will further ensure the sustainable development of society with environment (*Shah and Pitroda, 2011*).

Germany is the largest producer of recycled aggregates (60 million tonne) followed by United Kingdom (49 million tonne). Even smaller countries like Netherlands produce about 20 tonnes of recycled aggregates. Australia recycles nearly 50% of its construction and demolition waste while rest is used for landfills. Japan has the highest rate (98%) in processing of concrete waste to recycled aggregates (*Ismail and Ramli, 2013*). The quantity of solid waste is expanding rapidly. It is estimated that the rate of expansion is doubled every 10 years. This is due to the rapid growth of the population as well as the industrial sector. Solid waste disposal is a major environmental issue to cities around the world. Recent studies have indicated that roughly 4.6 billion tons of nonhazardous solid waste materials are produced annually in the United States. Domestic and industrial wastes constitute almost 600 million tons of this total. The remaining 4.0 billion tons are divided about equally between agriculture and mineral waste resources, a large % of which are located in remote areas.

The solid-waste crisis is important from an environmental and economical point of view. As landfill areas are rapidly depleting, the cost of solid-waste disposal is rapidly increasing. Among the solid-waste materials, plastics have received a lot of attention because they are generally not biodegradable. On a weight basis, there are about 10 billion kg of plastic wastes in the U.S. per year, which represents about 7% by weight of the total solid wastes. However, plastic wastes are very visible, since they constitute about 30% by volume of the total solid wastes.

1.4 Example of Structural Application of RCA and RPA: The Vilbeler Weg office building in Darmstadt, Germany (1998) is one of the early applications of RCA in construction. It has a built in of 480 cubic metre of RAC.



Fig 1.1: Vilbeler Weg office building (www.b-i-m.de/projekte/projframe.htm)

Another early example of RAC is the BRE office building in Watford, UK(1996). Over 1500 M³ of RAC supplied for foundations, floor slabs, structural columns and waffle floors.



Fig 1.2: The BRE office building (www.projects.bre.co.uk)

In 2008, Re Crete Materials, Inc. of Arvada, Colo. provided approximately 7,900 cubic yards of ready mixed concrete containing recycled concrete aggregate for use in foundations and tilt-up panels at the Enterprise Park at Stapleton project in Denver, Colo.



Fig 1.3: Enterprise Park (www.concreterecycling.org)

1.5 Production of Recycled Aggregates

1.5.1 Production of RCA

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

1. Two stage RAC mixing approach
2. Heat treatment
3. Microwave decontamination
4. Pre-soaking treatment
5. Washing and chloride treatment

A number of methods are available for crushing and sieving of the construction and demolition waste for production of quality RCA meeting appropriate standards and specifications. Extensive research and process have been developed to demonstrate that both plain and reinforced concrete can be used to produce RCA with acceptable quality to conforming BS 882 standards. It is clear that such material often contains foreign matter in the form of metals, wood, hardboard, plastics, papers etc. Therefore,

a process scheme is adopted to remove large pieces of these materials, mechanically and/or manually, before crushing and thorough cleaning of the crushed product. In many European countries, as well in the USA, methods have been developed to improve quality of recycled aggregate to suit individual circumstances and applications. Dry processing of construction and demolition waste is a common practice that includes crushing, screening, magnetic separation and dry separation. During the past few years, wet processing has been adopted with local variations in some countries, e.g., Austria, Netherlands and USA. It could be marginally higher cost but it is claimed that the products from the wet process are cleaner and better in quality. 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 result.

1.5.1.1 Specifications to be considered while using RCA

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 RCA (*Tam et al 2007*).

Particles of RCA consist of natural aggregate partially coated with mortar or cement paste. The amount of surrounding mortar will vary depending on the method by which the RCA was produced; for example, an increasing number of cycles in a ball crusher can reduce the amount of mortar present. However there are other more efficient processing methods available, but the aim should still be to remove as much of the mortar as possible. The mortar, which is lighter and more porous than natural aggregate, affects the physical properties of the recycled material notably with respect to water absorption and density. Table 1.3 lists the specifications of RCA as per RILEM technical code.-

Table 1.3 Specifications for the properties of recycled aggregates for concrete (RILEM, 1994) (CHEMICAL)

Composition	Type 1	Type 2	Type 3
	Aggregates from masonry rubble	Aggregates from concrete rubble	Mixture of natural (80%) and RCA (20%)
Oven dry density (kg/m ³)	1500	2000	2400
Maximum content of foreign matter (glass, bitumen.) (%)	5	1	1
Maximum content of metal (%)	1	1	1
Maximum content of organic materials (%)	1	0.5	0.5
Maximum content of fines (<0.063 mm) (%)	3	2	2
Maximum content of sand (%)	5	5	5
Maximum content of sulfate (%)	1	1	1

1.5.2 Production of RPA

Methew, P. et al (2013) collected the superior plastic from the disposal area. These were crushed into small fraction and washed to remove the foreign particles. Then it was heated at a particular temperature so that the necessary brittleness was obtained. After extrusion the molten plastic was cooled down and collected in boulders of 100 mm size approximately. These plastic boulders were crushed down to the size of aggregates.

Saikia and Brito (2012) studied the plastic waste obtained from different sources. In general plastic bottles were grinded in the laboratory by using a grinding machine and then sieved to get the suitable size fraction. Different types of crusher like propeller crushers or blade mills are used to grind the plastic waste. However in some studies, plastic waste with suitable sizes was collected from plastic waste treatment plants or plastic manufacturing plants. In this case, sieving into suitable size range was done at the laboratory. In some studies a washing stage is adopted to remove impurities

present in the plastic wastes. Separate grinding steps are also adopted after normal shredding to increase the cement paste–plastic aggregate bonding. For example, Remadnia et al.(2004) shredded plastic pieces in one more stage using a propeller crusher in order to control size limit with crushing and to facilitate matrix-aggregate adhesion due to the irregular shape and rough surface texture.

In plastic waste treatment plants, several steps are adopted to recycle the waste plastic. . The two types of aggregates were obtained after mechanical grinding of plastic waste. The washing of waste plastic was done before and after grinding by using alkaline solutions. Stirring of ground plastic in a clean water bath and centrifugation of grinded plastic waste were also done to remove impurities. Several impurities such as paper, dust, PVC, ground glass and glues were removed during these treatment steps. The grinding of waste generated particles in the size range of 10–14 mm with small amount of fine particles. These fine particles were removed by using a de-dusting system. . The heating and melting of the heated material is performed in such a way that allows the extraction of volatile contaminants. The extrusion process is relatively short, which limits the occurrence of secondary reactions during the melting stage. After passing through a spinneret, the melt is collected in a cooling bath that solidifies the polymer before being granulated in a rotary cutter in water. The mixture of water and grains of polymer is subjected to a vibratory separator and then the grains of polymer (plastic pellets) are centrifuged to remove excess water. Modifications of plastic waste by heating, by mechanical means, by soaking in water, melting followed by mixing with other materials and other techniques were also done to improve the quality of plastic waste for using as aggregate in concrete. prepared two types of plastic aggregates by mixing granulated pet waste bottle with powdered river sand and blast furnace slag at 250°C

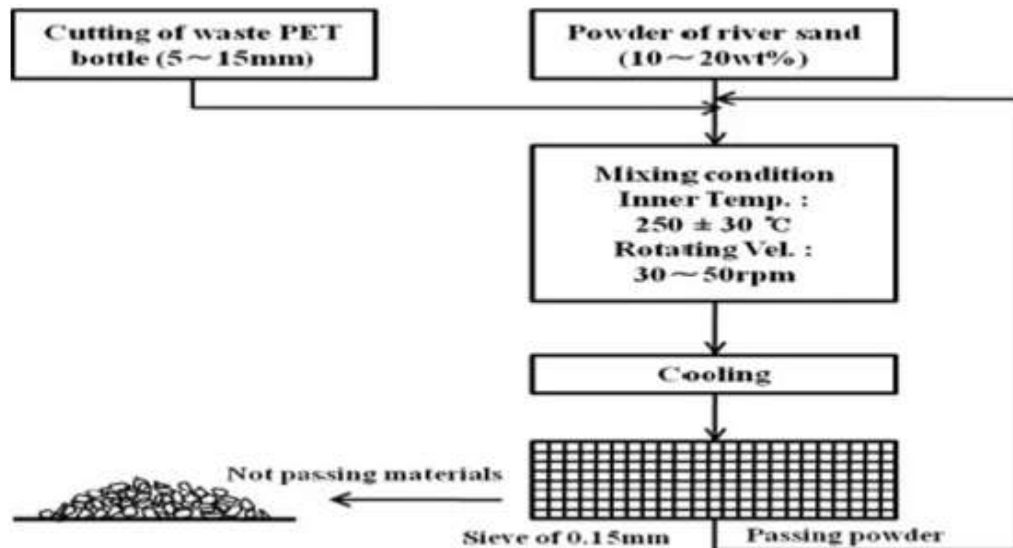


Fig 1.4. Manufacturing process of sand coated aggregate (Saikia and Brito 2012)
 After air-cooling the mixtures, the prepared aggregates and remaining powdered fractions were screened by using a 0.5 mm sieve. The schematic diagram to produce a plastic aggregate according to Saikia and Brito 2012 is presented in Fig. 1.4 .

1.5.2.1 Specifications to be considered while using RPA

The major effects on the quality of RPA is the weaker interfacial zone between cement mortar and plastic aggregates, which weakens the strength and mechanical performance of concrete made from Recycled plastic aggregates..

According to the Indian standard specifications the property of aggregates such as specific gravity, aggregate crushing value and density were determined. From Table 1.4 after comparing the properties of aggregate for both NCA and PCA it is observed that the specific gravity and density for PCA is much lower than NCA which offers a light weight concrete. A lower crushing value indicates the complexity with which a PCA concrete could be crushed under compressive stresses.

Table 1.4, Properties of aggregate (Methew, P. et al 2013)

Property	NCA	PCA
Specific gravity	2.74	0.9
Crushing value	28	2
Density	3.14	0.81

1.6 Use of Additional Materials

From the viewpoint of sustainability and durability, immense number of studies on the partial replacement of Portland cement with various mineral admixtures such as fly ash, blast furnace slag, silica fume, nano-silica and lime powder were used. Satisfactory properties compressive strength, bond strength, split tensile strength of RAC have been reported, depending on the replacement of cement and natural aggregates and type of mineral admixtures used.

1.6.1 Silica fume

Silica fume, also known as micro-silica, is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete. Physical and chemical properties of silica fume are shown in Table .1.5 & 1.6 respectively.

Table: 1.5. Physical properties of silica fume as per Indian standards IS 15388, 2003

Sr.no.	Physical properties of silica fume	As per Indian standards IS 15388, 2003
1	Specific Surface (m^2/g) [Minimum	15
2	Oversize percent retained on 45 micron IS sieve[Maximum]	10
3	Oversize percent retained on 45 micron IS sieve, variation from average percent [Maximum]	5
4	Compressive strength at 7 days as percent of control sample [Minimum]	85

Table .1.6 Chemical properties of silica fume as per Indian standards IS 15388, 2003

Sr.no.	Chemical properties of silica fume	As per Indian standards IS 15388, 2003
1	SiO ₂ , Percent by mass, [Minimum]	85
2	Moisture Content, Percent by mass, [Maximum]	3
3	Loss on Ignition, Percent by mass, [Maximum]	4
4	Alkalis as NaO ₂ , percent, [Maximum]	1.5

1.7 Challenges and Scope of RCA &RPA

The use of RCA & RPA in concrete is relatively rare. There are three main reasons for that:

1. Overall economics – direct costs can also be un favorable.
2. 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.
3. Other end users are far more tolerant than concrete of the inevitable contaminants in RCA.

1.7.1 Technical problems may include in RCA:

1. High content of cement paste/mortar.
2. Weak interfacial transition zones between cement paste and aggregate .
3. Porosity and traverse cracks within demolished concrete .
4. High level of sulphate.
5. High level of chlorides.
6. Impurity.
7. Poor grading.
8. High variations in quality.

1.7.2 Technical problems may include in RPA:

1. Plastics are having low bonding properties so that the strength of concrete gets reduced such as compressive, tensile and flexural strength.
2. Melting point of plastic is low so that it cannot be used in furnaces because it gets melt as its comes in contact with the heat at high temperature
3. Plastics production also involves the use of potentially harmful chemicals, which are added as stabilizers or colorants. Many of these have not undergone an environmental risk assessment and their impact on human health and the environment is currently uncertain. Such an example is phthalates, which are used in the manufacture of PVC. PVC has in the past been used in toys and there has been concern that phthalates may be released when these toys are sucked (come into contact with saliva)

1.7.3 Scope of RCA

1. Comparatively lesser production cost.
2. Reduction of municipal solid wastes being land filled .
3. Cutting of rocks can be reduce.

1.7.4 Scope of RPA

1. Lighter weight of RPA than competing materials reducing fuel consumption during transportation.
2. In Thailand, lightweight concrete is extensively used for the construction of interior and exterior walls of buildings for the case where the walls are not designed for lateral loads. This is due to the special characteristics of lightweight concrete.
3. Durability and longevity of RPA.
4. Resistance to chemicals, water and impact.
4. RPA Excellent thermal and electrical insulation properties.
5. Comparatively lesser production cost.
6. Unique ability to combine with other materials like aluminum foil etc .
7. Far superior aesthetic appeal.
8. Material of choice – human life style and plastic are inseparable.
9. Reduction of municipal solid wastes being land filled .

1.8 Objective of present study

The review of literature reported in Chapter 2 indicates that scanty work has been carried out to investigate the bond strength properties of recycled aggregates with varying replacement ratios. Therefore, the main objective of the present study is to investigate the bond strength characteristics of concrete containing different proportions of recycled concrete aggregates and plastic aggregates.

2.1 General

This chapter gives a comprehensive review of the work carried out by various researchers in the field of using recycled concrete & recycled plastics in concrete as full or partial replacement of aggregates.

2.2. Effect of RCA & RPA on fresh properties of concrete

Some of the required fresh properties of fresh concrete are workability characteristics of concrete, which include slump, loss of slump and bleeding. All these aspects are discussed in the following section.

2.2.1 Properties of fresh concrete with RCA

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

Butler et al. (2013) graded the aggregates from different sources like decommissioned sidewalks, terminal structure and rejected ready mix concrete. Negligible difference in slump values between NA and RCA has been observed with all slump values meeting the required specific range

Ismail and Ramli (2013) pre-soaked the RCA in acid of different morality 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.

2.2.2 Properties of fresh concrete with RPA

Khatib and Bayomy (1999) examined the fresh concrete properties, it is concluded that rubberized Portland cement concrete mixes are workable to a certain degree and they result in lighter-weight concrete mixes. Unit weight can be decreased to as low as 75% of the normal concrete weight.

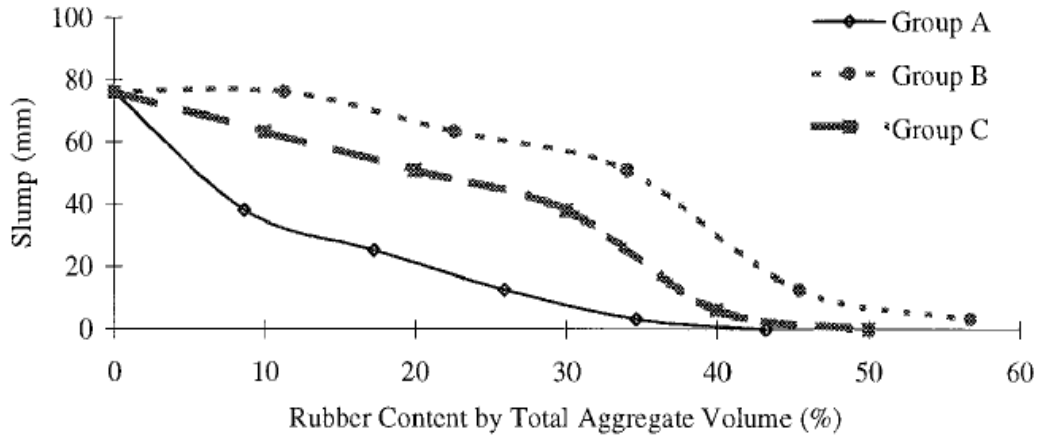


Fig .2.1,Effect of Rubber Content on slump of Fresh rubberized Portland cement concrete Mixtures (Khatib and Bayomy 1999)

Saikia and Brito (2012) investigated there are two parallel views on the workability behaviour of concrete containing plastic aggregate. In this studies that an increasing addition of plastic aggregate lowers the slump values. The reasons for the lower slump value of the concrete mix containing plastic aggregate are the sharp edges and angular particle size of plastic aggregate .

On the other hand, an increase in the slump value due to the incorporation of plastic aggregates since, unlike natural aggregate, plastic aggregates cannot absorb water during mixing, hence increase in the slump value of concrete with increasing content of treated plastic aggregate in concrete .The aggregates were spherical in shape & as well as slippery surface texture, which decreases the inner friction between the mortar and the plastic aggregate .

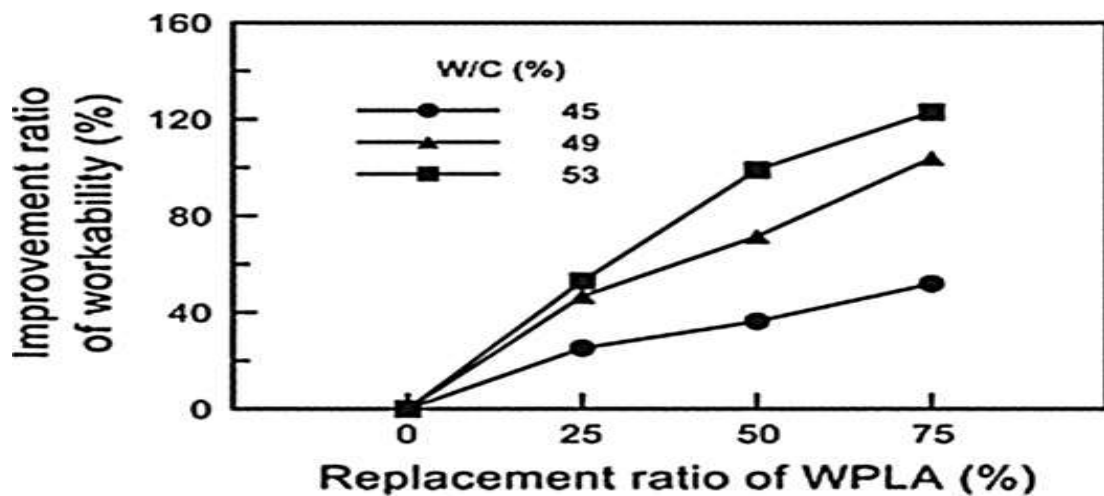


Fig. 2.2.Improvement of workability due to the addition of slag coated PET aggregate (Saikia and Brito 2012)

Methew, P. et al (2013) conduct tests to determine the fresh and hardened properties of both NCA and PCA concrete. Slump and compaction factor was determined as per the Indian standards and the values are tabulated in Table no .2.1 It shows that the workability of 20% PCA concrete is superior to NCA concrete which is due to the lower water absorption rate of plastic aggregates.

Table: 2.1 Properties of fresh concrete (Methew, P. et al 2013)

Particulars	Slump in mm	Compaction factor
NCA	33	0.93
20% replaced with PCA	36	0.95

Nibudey R. N. et al. (2013) observed that the workability (Slump and Compaction factor) of green concrete decreases as fibres content increases. The initial slump of control concrete was 67 mm (0.0 %) and it was reduced to 32 mm (3.0%) i.e 52.3% loss in slump was observed at 3.0 % of fibers. The compaction factor at 0.0 % fibres was 0.877 and finally it was reduced to 0.78 i.e. 11 % loss in compaction factor was found. Similarly dry density also reduced from 25.382 Kg/Cu,m (0.0 %) to 25.185 Kg/Cu,m (3.0%) & results are also presented in Table 2.2.

Table: 2.2 :Properties of fresh concrete (Nibudey R. N. at el.2013)

Tests	% Fibres						
	0.0	0.5	1.0	1.5	2.0	2.5	3.0
Slump (mm)	67	63	57	47	48	42	32
Dry Density kg/m ³	25.382	25.402	25.363	25.323	25.244	25.244	25.185

Shalaby A. et al (2013) observed that there was a significant reduction in the density of cement paste utilizing 30% and 50% of fine plastic aggregate as a replacement to sand in cement paste, respectively.

Table2.3: Properties of fresh concrete (Shalaby A. at al 2013)

Sr. No.	Replacement percentage.	Average density (g/cm ²)
1	0	2.265
2	10	2.166
3	20	2.100
4	30	1.757
5	50	1.370

This is because the density of plastic is much less than that of sand. It could also be seen that there was a reduction of about 20% and 40% in the density of the specimens utilizing 30% and 50% of fine plastic aggregate, respectively, compared to the control specimen. However, for the control and utilizing 10% of fine plastic aggregate the reduction was only 4%.

Ghernouti , y. et.al (2014) observed that more waste plastic content increases the fluidity of concrete improves, that is favourable for concretes, because the plastic cannot absorb water, therefore an excess of water which improves the workability & the results are shown in Fig. 2.3

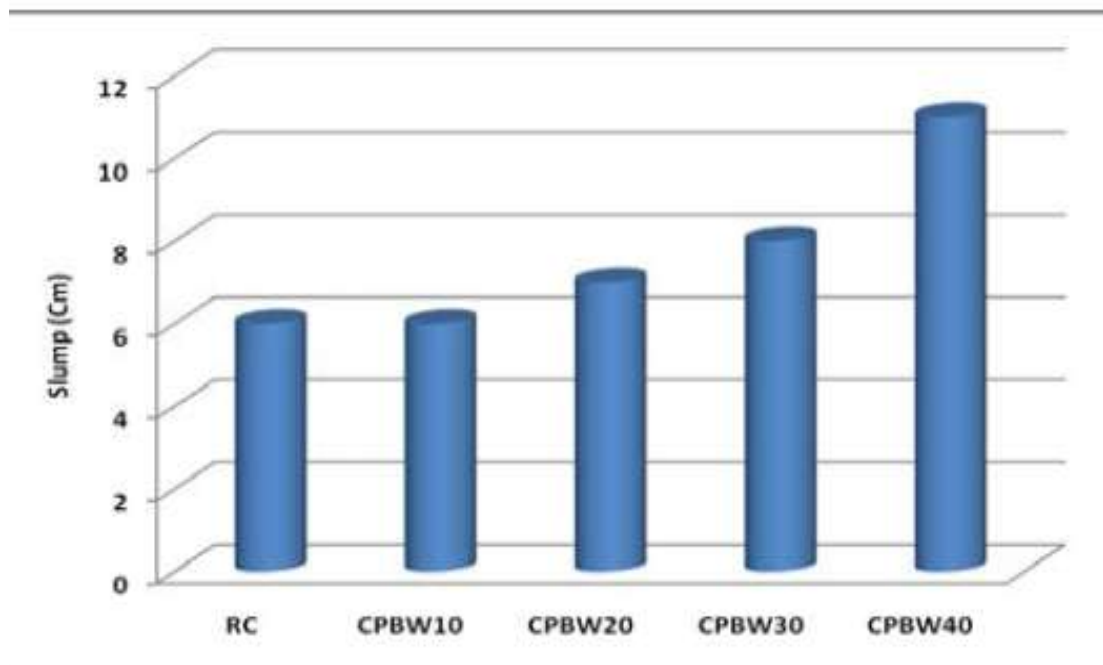


Fig 2.3: Evolution of slump test value of all mixtures as function of content plastic bag wastes, (Ghernouti , y. et.al 2014).

2.3 Effect of RCA and RPA 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 of RCA

Poon et al. (2004) studied influence of moisture states of natural and recycled aggregates on the compressive strength of concrete. Concrete mixtures prepared with the incorporation of recycled aggregates, the air dried (AD) aggregate concretes exhibited the highest compressive strength. The surface dried density (SSD) recycled aggregates seemed to impose the largest negative effect on the concrete strength, which might be attributed to ‘‘bleeding’’ of excess water in the pre-wetted aggregates in the fresh concrete. Air dried RCAs when used at 50% replacement level to NAs give optimum strength.

Kou et al. (2011) compared the compressive strength recycled aggregate concrete prepared with different mineral admixtures including silica fume (10%), metakaolin (15%), fly ash (35%), ground granulated blast slag (55%) used as cement replacement. The recycled aggregates were replaced at 50% and 100%. The recycled aggregate concrete with addition of silica fume and meta kaolin exhibited positive effects on compressive strength at both replacement levels when compared to control concrete. Fly ash and ground granulated blast slag had a detrimental effect on the compressive strength results are shown in figure no 2.4 and 2.5

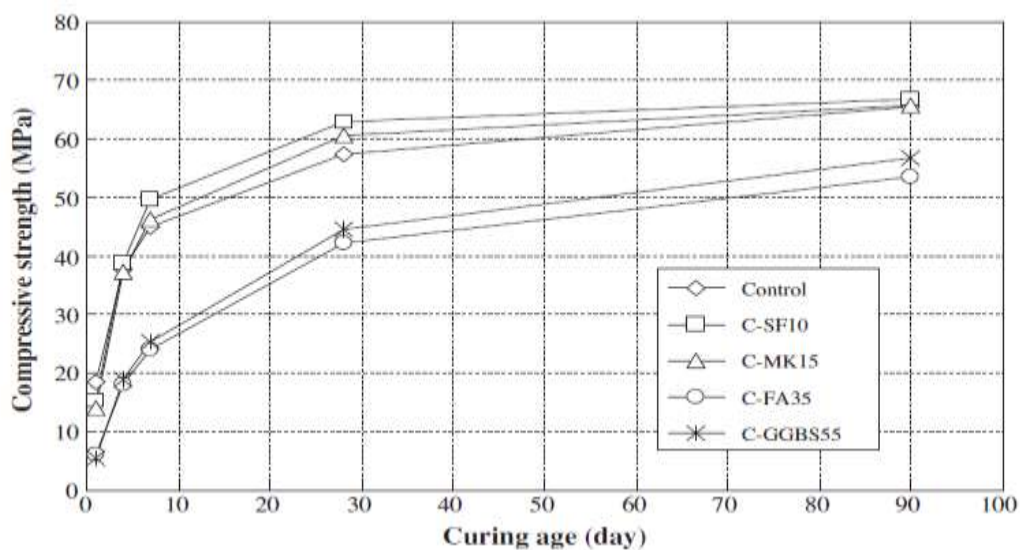


Fig 2.4: Development of compressive strength of concrete mixtures (Kou et al. 2011)

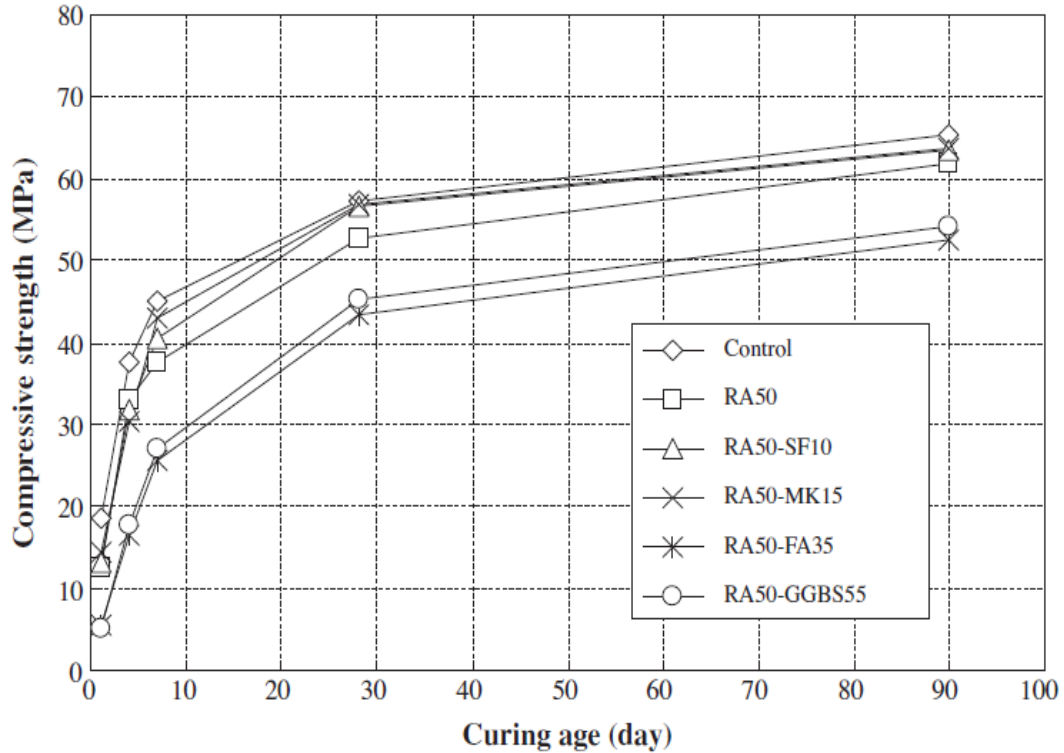


Fig 2.5: Development of compressive strength of concrete mixtures (Kou et al. 2011)

Kou et al. (2012) used the 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. Results are shown in Table no 2.4

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

Concrete mixes	Recycled aggregates (%)	Compressive Strength (MPa)	
		28-day	90-day
RCA 0	0	43.4	47.8
RCA 20	20	45.3	49.1
RCA 50	50	42.5	47.5
RCA 100	100	38.1	45.5

Butler et.al. (2013) concluded that the compressive strength of recycled aggregate concrete can be equivalent to that of conventional concrete if basic mixture proportions can be adjusted properly and the quality of recycled aggregates are of fine

quality. The source of the recycled aggregate played an important role in achieving the desired compressive strength. To achieve adequate batch to batch compatibility the aggregates were pre-soaked. The recycled aggregate was procured from three different sources such as decommissioned curbs and sidewalks, demolished terminals from airport and returned ready-mix concrete. The aggregates were replaced at 100% level.

Ismail and Ramli (2013) observed the compressive strength of treated recycled aggregate. The recycled aggregates were pre-soaked in acids of different of molarity for 1, 3 and 7 days. The compressive strength values of treated recycled aggregate were higher than normal recycled aggregates. The acid removed the loose adhered mortar on the aggregate surface. The replacement levels of NA at 15%, 30%, 45% and 60%. At 60% replacement level the compressive strength showed improvement when compared to non-treated aggregate. Though on higher side 45% achieves the optimum strength.

Kou and Poon (2013) examined the long term compressive strength of recycled aggregate concrete prepared with incorporation of fly ash. The recycled aggregate concrete was prepared by using 25%, 35% and 55% fly ash whereas recycled aggregate used were substituted as 0%, 50% and 100%. Two types of curing conditions were imposed water and air curing. It was concluded that even after 10 years the compressive strength recycled aggregate concrete was lower than conventional concrete.

Surya et al. (2013) observed five different concrete mixes with and without class F Fly ash. Three mixes containing recycled aggregate at 50%, 75% and 100% replacement of natural aggregate were prepared containing fly ash, and two natural aggregate concrete mixes with and without fly ash. Recycled aggregates were generated by crushing waste dump of lab samples. Water-cement ratio was kept constant at 0.4. The compressive strength exhibited by recycled aggregate concrete was better than traditional concrete. The concrete containing 100% recycled aggregate exhibited maximum compressive strength. The transition zone of recycled aggregate concrete improved due to addition of fly ash making its strength parallel or greater than control mixture.

Table 2.5: Compressive strength of various mixes (Surya et al. 2013)

Mix Designation	Compressive strength (MPa)			
	3 days	7 days	28 days	56 days
NAC	33.85	43.85	45.63	53.19
NAF	33.33	41.03	47.25	57.77
R50	28.89	37.49	47.40	54.02
R75	30.67	34.96	46.61	54.22
R100	30.15	43.11	48.89	57.33

Thomas et al. (2013) used different water to cement ratios (0.45, 0.50, 0.55 and 0.65) to study samples containing 20%, 50% and 100% recycled aggregates. The compressive strength test were carried out at 28, 180 and 365 days. At 20% replacement level no significant decrease was noted. Whereas at higher replacement levels there is significant loss of compressive strength. Study concluded that to achieve higher strength W/C has to be reduced.

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 results are shown in Table 2.6.

Table 2.6: Compressive strength of concrete mixtures (Andreu and Miren 2014)

Concrete Reference	% RCA	Compressive Strength (MPa)		
		1-day	7-day	28-day
CC	0	57.36	91.19	102.09
100MPa	20	73.79	88.51	108.03
	50	79.24	94.76	104.80
	100	78.73	93.43	108.51
60MPa	20	73.55	102.1	102.48
	50	72.38	98.77	103.10
	100	79.42	100.1	100.78
40MPa	20	67.06	91.73	104.28
	50	60.69	84.39	96.84
	100	56.62	79.88	91.23

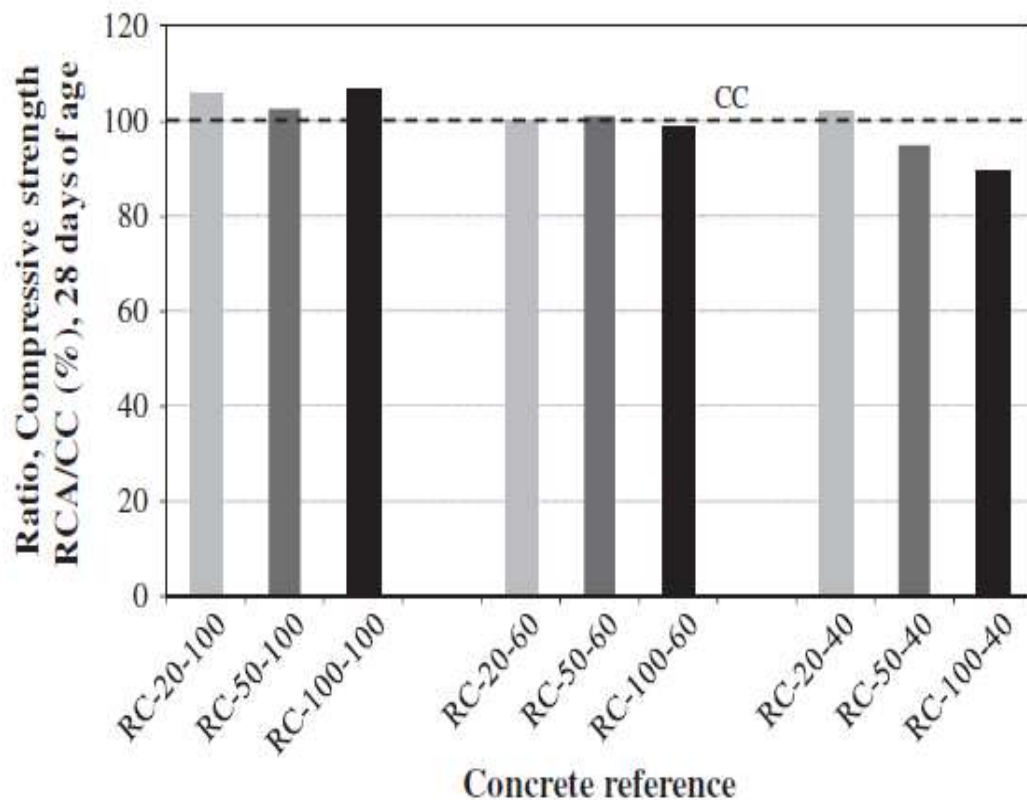


Fig2.6:Compressive strength of recycled aggregate concrete compared with conventional concrete (Andreu and Miren 2014)

Dibas et al. (2014) investigated recycled aggregate concrete with silica fume for compressive strength. Two types of recycled aggregates were used, composed of concrete, tiles and bricks. The replacement levels of aggregates was 30% and 40%, later both types were used simultaneously taking replacement of 70%. Silica fume replaced was 5% and 10% by weight of cement. The results showed that impurities in recycled aggregates can reduce the effect of silica fume. Despite that concrete containing separate recycled aggregates exhibited good results using 5% and 10% silica fume when compared with traditional concrete.

Table 2.7: Compressive Strength at 28 days (Dibas et al. 2014)

Notation	Silica fume (%)	Recycled Aggregates (%)	Compressive Strength (MPa)
1st Group			
NAC	0	0	35.8
RA1C	0	40	33.0
RA2C	0	30	34.1
RA12C	0	70	29.1
2nd Group			
NACSF5	5	0	39.9
RA1CSF5	5	40	34.8
RA2CSF5	5	30	35.2
RA12CSF5	5	70	33.2
3rd Group			
NACSF10	10	0	45.5
RA1CSF10	10	40	37.2
RA2CSF10	10	30	38.5
RA12CSF10	10	70	28.9

2.3.2. Compressive Strength of RPA

Naik T R et al. (1994) observed the concrete mix prepared with addition of plastics to the control mixture (35 MPa) in various amounts ranging between 0.5 and 5% of total weight of the mixture. The plastic samples were treated by soaking them in water, bleach, and bleach plus NaOH (alkaline bleach) per Table 2.8.

Table 2.8: Compressive strength MPa (Naik T R et al(1994).

Mix No.	P0	P1	P2	P3	P4	P5	P6	P7
Treatment	None	Water	Bleach	Bleach + NaOH	None	Water	Water	Water
%age Plastic Agg.	0.00	4.50	4.50	4.50	0.00	0.50	1.50	2.00
Test Age Days	Compressive strength MPa							
3	20.23	7.07	6.09	9.8		18.2	14.49	10.92
7	28.98	8.89	6.72	13.16	21.84	22.47	18.34	13.09
28	34.58		7.49	13.09	28.56	29.05	22.19	15.4

As could be anticipated the effect of soft plastic as "aggregates" on all concrete mixtures containing 4.5% post consumer plastic showed lower compressive strength than the reference mixture without plastic This was attributed to lower compressive strength of the plastic particles compared to cementitious matrix as well as natural fine and coarse aggregates. Among the various treated samples (P1, P2, and P3) the sample treated with bleach oxidant plus NaOH gave the best results The sample soaked in water showed better results than the sample treated with bleach alone

Naik T R et al. (1996) studied the plastics were added to the control mixture in various amounts ranging between 0.5 and 5% of total weight of the mixture. The plastic samples were treated by soaking them in water, bleach (5% HOCl), and bleach plus NaOH (5% HOCl and 4% NaOH). .

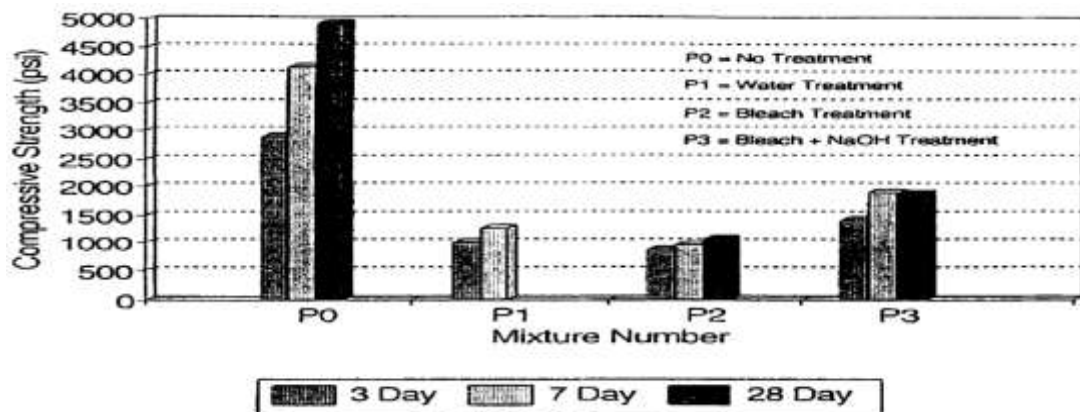


Fig.2.7.Effect of treatment on compressive strength of concrete,(Naik T R et al,1996)

Lakshmi and Nagan,(2010) compressive strength test was conducted to evaluate the strength development of concrete containing various E waste contents at the age of 7, 14, 28 days respectively on A & B series containing 10% fly ash+ E waste contents of mix specification following the standard test procedures. From Table 2.9 & 2.10 find that compressive strength increase with addition of 10% fly ash in control mix.

Table 2.9: Compressive strength without fly ash N/mm² (Lakshmi and Nagan 2010)

Mix Specification	Control mix	A 1	A2	A3	A4	A5	A6
Proportion of E waste	0%	4%	8%	12%	16%	20%	25%
7 Days	10.74	10.19	9.54	8.65	8.60	6.40	6.06
14 Days	13.70	13.52	12.42	10.74	10.74	8.26	6.40
28 Days	19.83	19.89	18.80	16.40	16.23	8.25	6.15

Table 2.10: Comp. strength with fly ash in N/mm²(Lakshmi and Nagan 2010)

Mix Specification	Control mix B	A1	A2	A3	A4	A5	A6
Proportion of E waste+10% Fly ash	0%	4%	8%	12%	16%	20%	25%
7 Days	10.75	18.62	18.51	18.36	17.60	15.56	12.08
14 Days	27.23	26.82	26.55	24.82	24.13	22.51	21.04
28 Days	29.79	27.83	27.27	27.45	26.98	25.45	22.42

Lakshmi and Nagan,(2011) examined in Table 2.11 presents the 28 days compressive strength results of concrete with and without E-plastic waste replacement to coarse aggregate in concrete. The maximum strength observed was 19.89MPa with 4% replacement and 18.80MPa with 8% replacement. It was also revealed that maximum strength reduction was observed for more than 20% replacement of E-plastic waste to coarse aggregate in concrete.

Table 2.11: Compressive Strength with-plastic waste (Lakshmi and Nagan 2011)

Sr. No	Age in Days	% of replacement		Compressive strength in Mpa
		E –waste	Fly ash	
1	28	0%	0%	28.79
2	28	4%	0%	19.89
3	28	8%	0%	18.80
4	28	12%	0%	16.40
5	28	16%	0%	16.23
6	28	20%	0%	08.25
7	28	24%	0%	08.10

Tables 2.12 showed that the compressive strength increases with increase in replacement of coarse aggregate with plastic aggregate. The maximum compressive strength for the mix with 12% of plastic aggregate was 29.79MPa which is higher than that of compressive strength of conventional concrete. It was observed that 10% fly ash addition to cement in concrete which in turn results in a denser concrete and thereby the enhancement in strength was achieved in early age also. However there was reduction in strength was observed for more than 20% replacement of coarse aggregate with E-plastic aggregate .

Table 2.12: Compressive Strength with-plastic waste & fly ash (Lakshmi and Nagan 2011)

Sr. No.	Age in Days	% of replacement		Compressive strength in MPa
		E –waste	Fly ash	
1	28	0%	0%	28.79
2	28	4%	10%	27.03
3	28	8%	10%	27.38
4	28	12%	10%	29.79
5	28	16%	10%	26.98
6	28	20%	10%	21.97
7	28	24%	10%	20.10

Saikia and Brito (2012) the incorporation of plastic as aggregate decreased the compressive strength of the resulting concrete/mortar .Fig. 2.8 shows some of the reported results of 28-day of fine and coarse natural aggregates. The factors that may be responsible for low compressive strength of concrete containing plastic aggregate are: (1) the very low bond strength between the surface of the plastic waste and the cement paste; the hydrophobic nature of plastic waste, which can inhibit cement hydration reaction by restricting water movement compressive strength performance of concrete containing plastic waste as partial substitution.

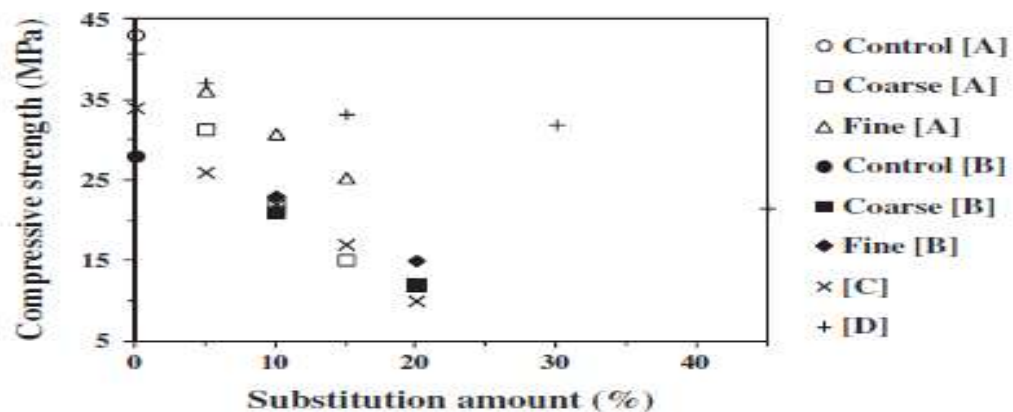


Fig. 2.8. Compressive strength of concrete containing plastic aggregate (Saikia and Brito 2012)

Raghatate Atul M.(2012) Compressive strength test were carried out on 150 mm X 150 mm X 150 mm specimen for that three cube were prepared for each mix. Strength of each cube was evaluated after 3, 7 and 28 days respectively. Test was carried out as per IS 14858 2000. Result of compressive strength test was presented in Table.2.13 The compressive strength of concrete goes on reducing with increase in percentage of plastic pieces but the rate of reducing compressive strength is very low. This reduction in strength is may be due reduction in bonding due introduction of plastic pieces

Table 2.13: Compressive strength N/mm² (Raghatate Atul M.2012)

Mix Specification						
% of plastic	0%	0.20%	0.408%	0.60%	0.80%	1.00%
7 Days	1.54	1.85	2.35	2.83	3.12	3.85
14 Days	1.82	1.96	2.63	2.98	1.80	3.12
28 Days	4.12	4.38	4.92	5.16	5.57	5.12

Methew P. et al. (2013) In this method the volume occupied by NCA was substituted with RPA for various percentage substitutions, knowing their densities .The cube compressive strength (size: 15 x 15 x 15 cm) obtained for various percentages are shown in Fig.2.9. It can be seen that 20% substitution has shown a better strength even more than NCA concrete at the end of 28 day curing period for M20 mix . From the graph shown in Fig.2.9 the optimum percentage substitution was taken at 22% for maximum compressive strength.

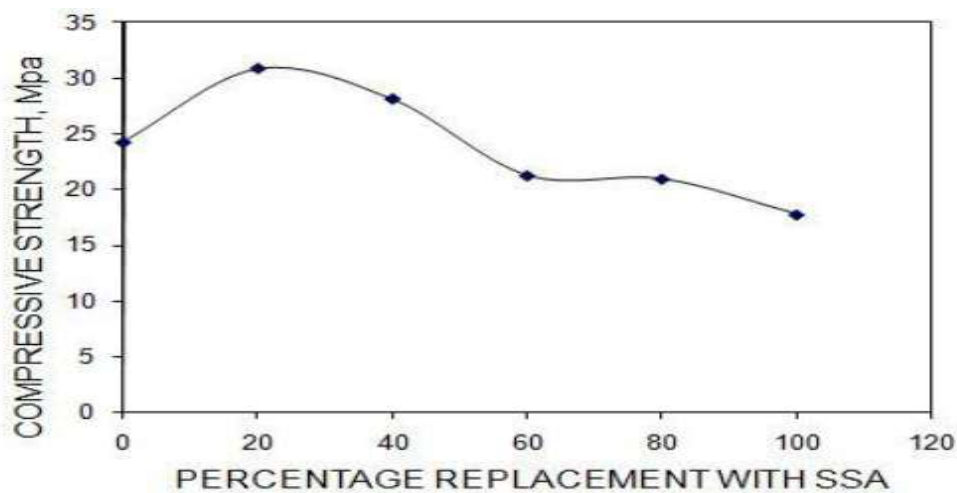


Fig.2.9 Compressive Strength Curve (Methew, P. et al 2013)

Volumetric substitution and grade substitution was also employed with a view to decide the best method for substituting plastic aggregates. In grade substitution method a particular grade of NCA was entirely replaced with RPA of same size which was 20 mm. From the results of compressive strength tabulated in Table 2.14, it can be seen that, the grade substitution is only inferior to both NCA concrete and 20% replaced PCA concrete. Hence volumetric substitution was selected as the best among the two substitution methods

Table 2.14: Compressive Strength for Grade Substitution,(Methew, P. et al. 2013)

Particulars	Compressive strength in MPa	Cylinder compressive strength in MPa
NCA	24.2	11.8
20% RPA	30.83	16.27
20mm size NCA replaced with RPA	18.74	

Nibudey et al.(2013) observed that by adding plastic fibers from 0.5 % to 3.0 % by weight of cement in the ingredients for M30 conc. conclude that compressive strength increase 4.30% with addition of plastic fibre then decrease rapidly with more addition of plastic fibre result are as shown in Table 2.15-

Tables 2.15: Compressive strength of concrete (Nibudey et al. 2013)

Sr. No.	Addition of fibre	Failure Load (KN)	Compressive Strength in (MPA)	Average Compressive strength (Mpa)	% change in Compressive strength
1	0.0	980	43.56	41.19	0.00
		860	38.22		
		940	41.78		
		940	41.78		
		960	42.67		
		880	39.11		
2	0.5	920	40.89	41.78	1.43
		960	42.67		
		940	41.78		
3	1.0	940	41.78	42.96	4.30
		1000	44.44		
		960	42.67		
4	1.5	960	42.67	42.67	3.59
		960	42.67		
		960	42.67		
5	2.0	900	40.00	40.30	-2.16
		960	42.56		
		860	38.22		
6	2.5	780	34.67	34.67	-15.83
		760	33.78		
		800	35.56		
7	3.0	700	31.11	31.70	-23.04
		720	32.00		
		720	32.00		

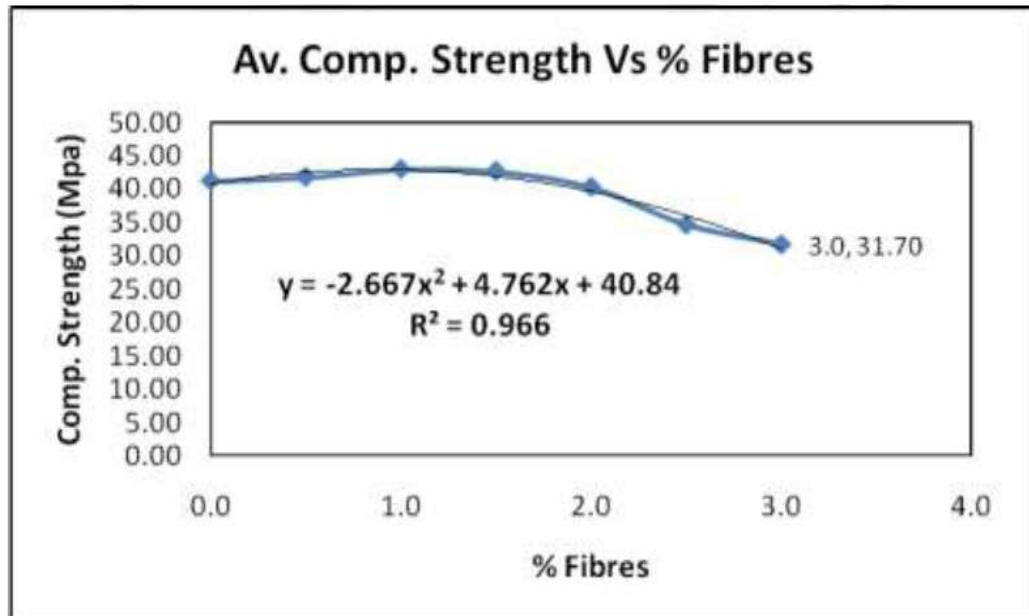


Fig 2.10: Average compressive strength verses % Fibres (Nibudey at el. 2013)

Shalaby A. et al.(2013) The specimens tested were cubes of dimensions 50 mm different percentages of PET as a replacement to sand in the cement paste.

It could be seen from the Table 2.16 that there was a significant reduction in the compressive strength of cement paste for the group utilizing 30% and 50% of PET, respectively and the conclusion of the impracticability of utilizing 30% and more of fine plastic aggregate by weight in cement paste is confirmed

Table 2.16: Average compressive strength (N/mm²) (Shalaby A. et al.,2013)

Group no.	% of pet	Average compressive strength (N/mm ²)		
		@ 3 days	@ 7 days	@ 28 days
G1	0	17.6	22.27	31.20
G2	10	17.40	18.67	30.40
G3	20	15.47	17.07	18.27
G4	30	Not tested	Not tested	9.93
G5	50	Not tested	Not tested	2.67

Suganthy p. et al (2013) observed that compressive strength of cubes having different proportions of plastic(0%, 25%, 50%, 75%, 100%) as a replacement for sand were tested and conclude that ultimate strength decrease with increase of plastic sand. Comparison of the average values of strength are given in fig no.2.11

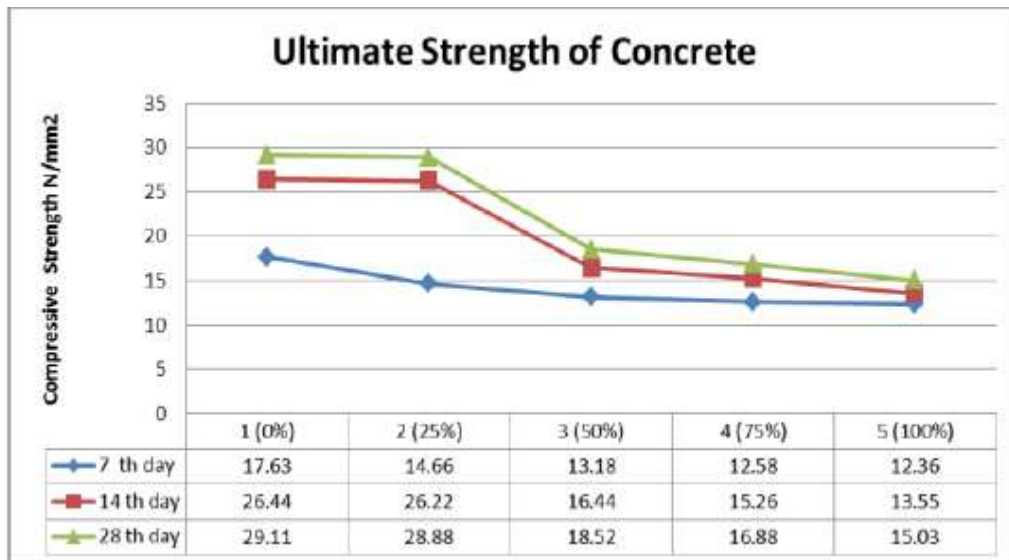


Fig -2.11: Comparison of Ultimate Strength of cubes having different proportions of Plastics at 7,14,28 days (Suganthy p. et al 2013)

Ghernouti , y. et.al (2014). Observed that increase in percentage of plastic bag waste in the concrete, a fall of compressive strength at 28 days of about 10 and 24 % respectively. Indeed, in this paper, compared to control mixes, up to 72% reductions in compressive strength were observed for concrete prepared by replacing natural aggregate at the replacement level of 20% . This fall of strength must mainly with:

- The substitution of the sand by waste which is less resistant.
- Low roughness of waste which returns adherence between the grains and cement paste and the circular shape of waste which increases the void volume in the mortar which reduces the compactness

The reduction in the compressive strength of concrete might be due to either a poor bond between the cement paste and the plastic bag wastes or to the low strength of this plastic wastes. However, the fracture surface of concrete prismatic showed that most of plastic waste are not pulled out and remain stuck in the specimens

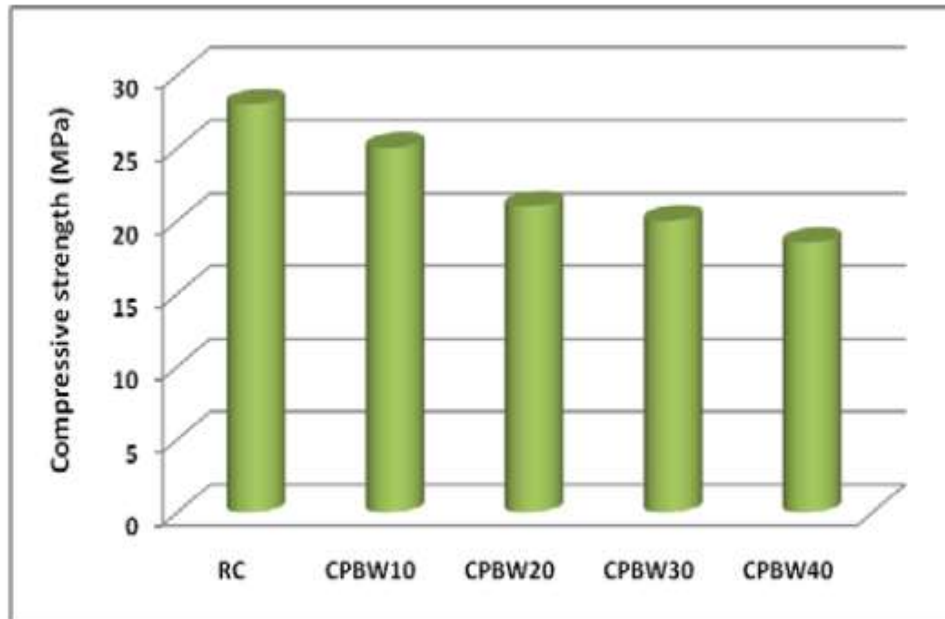


Fig2.12. Evolution of compressive strength of all mixtures as function of content plastic bag wastes(Ghernouti , y. et.al. 2014).

2.4 Split tensile strength

2.4.1. Splitting tensile strength RCA

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.

Corinaldesi and Moricioni (2009) presented the study on influence of mineral additions on the performance of 100% recycled aggregate and 26% fine recycled aggregate concrete. Fly Ash was mixed and recycled aggregates consists of 70% old concrete and 30% bricks. Mineral additions were replaced at 38% by weight of cement and added as fine aggregate replacement. The water cement ratio used were 0.56 for control mix, 0.35 for plain recycled aggregate concrete and 0.40 for concrete containing both recycled aggregate and mineral admixtures. The differences were

very small in the tensile strength values. The failure pattern suggested that recycled aggregates were the weakest component of the concrete system.

Kou et al. (2011) compared the splitting tensile strength of recycled aggregate concrete prepared with different mineral admixtures including silica fume (10%), metakaolin (15%), fly ash (35%), ground granulated blast slag (55%) used as cement replacement. The recycled aggregates were replaced at 50% and 100%. The splitting tensile strength of natural and recycled aggregate concrete containing silica fume and metakaolin were better than traditional concrete. The use of fly ash and GGBS decreased the splitting tensile values, especially at the early ages due to their delayed binding action. The strength gains of the concrete mixtures with fly ash and GGBS were higher than that of mixtures containing silica fume and metakaolin.

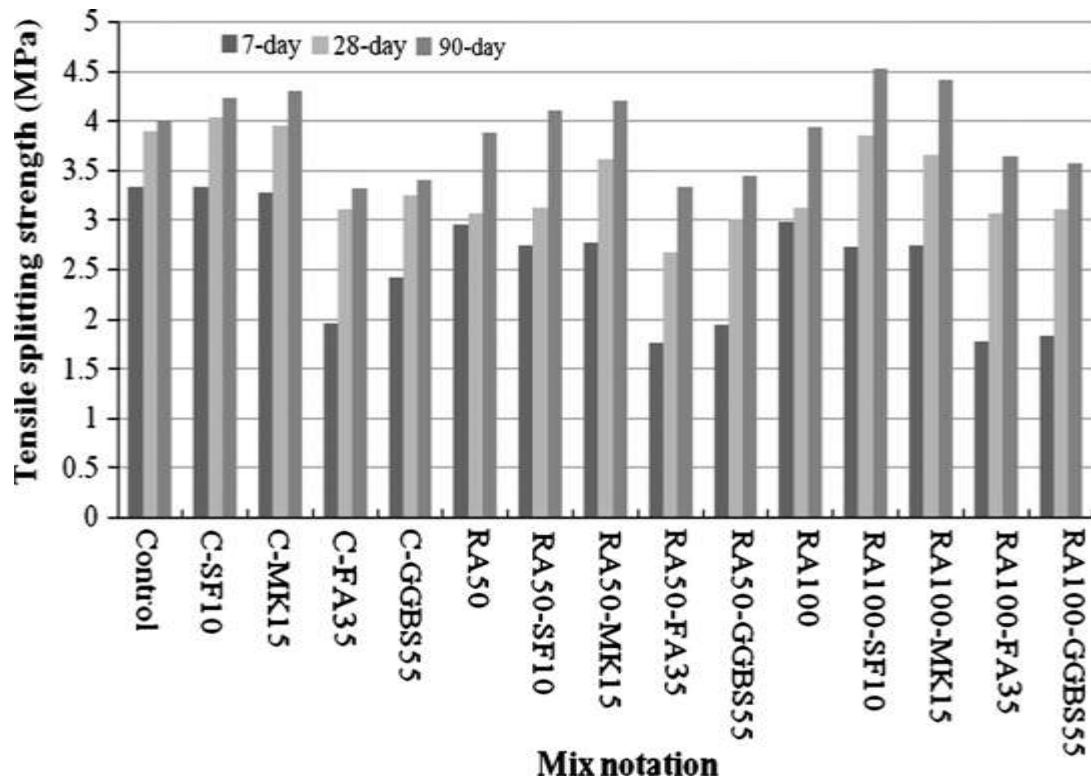


Fig 2.13: Tensile splitting strength of concrete mixtures (Kou et al. 2011)

Kou et al. (2012) used 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 interfacial transition zone 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 2.17: Splitting tensile results (Butler et al. 2013)

Mix	Splitting Tensile Strength (MPa)
NAC-40	3.18
RAC1-40	3.51
RAC2-40	3.11
RAC3-40	3.30
NAC-60	4.38
RAC1-60	3.84
RAC2-60	3.70
RAC3-60	3.72

Kou and Poon (2013) presented long term splitting tensile strength of recycled aggregate concrete prepared with incorporation of fly ash. The recycled aggregate concrete was prepared by using 25%, 35% and 55% fly ash whereas recycled aggregate used were substituted as 0%, 50% and 100%. Two types of curing conditions were imposed water and air curing. At 28 days the splitting tensile strength of control mixture was higher than the concrete incorporating recycled aggregates. However, comparison of the longer duration test results shows continuous and significant improvement in the splitting tensile strength of recycled aggregate concrete. The values of concrete mixtures prepared with 100% recycled aggregates were higher than traditional concrete. Moreover, the splitting tensile strength of concrete mixtures exposed to air curing was lower than the corresponding concrete mixtures with standard water curing.

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.

Radonjanin et al. (2013) replaced 50% cement with different mineral admixtures such as milled limestone, fly ash whereas fixed amount of 10% silica fume and metakaolin was used. The concrete mixtures consisted of 50% recycled aggregates. Seven concrete mixes were prepared. Chemical admixtures were added in some mixtures to achieve desired consistency. Different unconventional combinations such as 40% fly ash or milled limestone + 10% silica fume or metakaolin were also prepared. Concrete mixtures containing 10% silica fume and metakaolin exhibited higher values of split tensile when compared to conventional concrete. Use of fly ash and milled limestone even with silica fume and metakaolin exhibited low values of split tensile strength.

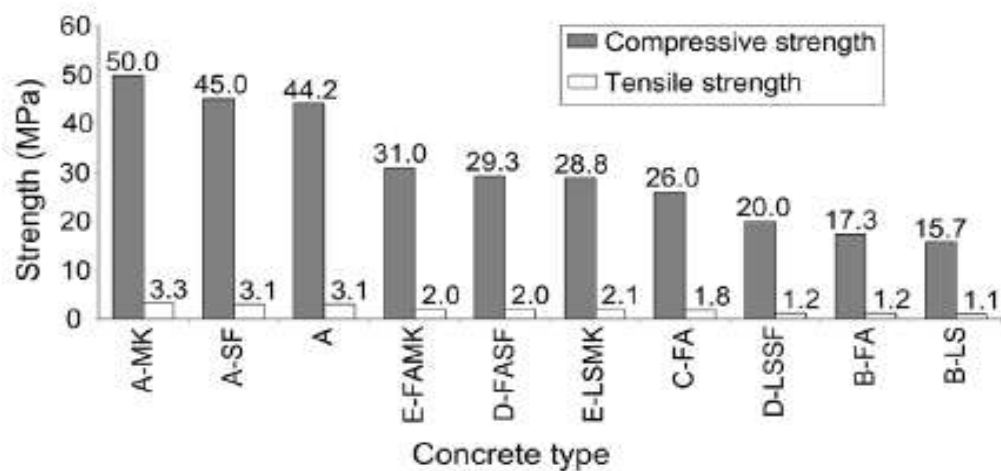


Fig 2.14: Splitting Tensile and compressive strength of different mixes (Radonjanin et al. 2013)

Surya et al. (2013) produced five different concrete mixes with and without class F Fly ash. Three mixes containing recycled aggregate at 50%, 75% and 100% replacement of natural aggregate were prepared containing fly ash, and two natural aggregate concrete mixes with and without fly ash. Recycled aggregates were generated by crushing waste dump of lab samples. Water-cement ratio was kept constant at 0.4. The splitting tensile strength exhibited by recycled aggregate concrete was better than traditional concrete. In case of recycled aggregate concrete the failure

pattern was through transition zone and aggregates. The concrete containing 100% recycled aggregate exhibited maximum splitting tensile strength. The transition zone of recycled aggregate concrete improved due to addition of fly ash making its strength parallel or greater than control mixture.

Table 2.18: Splitting tensile strength of various mixes (Surya et al. 2013)

Mix Designation	Splitting tensile strength (MPa)	
	28 days	56 days
NAC	3.49	3.96
NAF	3.74	4.15
R50	3.49	3.53
R75	3.11	3.63
R100	3.68	4.15

Thomas et al. (2013) prepared 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%.

Andreu and Miren (2014) procured recycled aggregates from high strength concrete. Substitution of recycled aggregates was 20%, 50% and 100%. All concrete mixtures showed good performance except aggregates with 100% replacement of lower strength concrete. All other series achieved more than 4.5 MPa of tensile strength. The splitting tensile strength did not seem to be very influenced by recycled aggregates.

Dilbas et al. (2014) investigated recycled aggregate concrete with silica fume for Splitting tensile strength. Two types of recycled aggregates were used, composed of concrete, tiles and bricks. The replacement levels of aggregates was 30% and 40%, later both types were used simultaneously taking replacement of 70%. Silica fume replaced was 5% and 10% by weight of cement. The tensile strength of low grade recycled aggregates was slightly lower than control mixture. Besides, the mixture containing better coarse recycled aggregates with and without silica fume was were higher than traditional concrete. This shows that usage of silica fume has very

marginal increasing effect on the splitting tensile strength. A severe decrease was noted when both quality of recycled aggregates were used simultaneously.

Table 2.19: Splitting tensile strength at 28 days (Dilbas et al. 2014)

Notation	Silica fume (%)	Recycled Aggregates (%)	Splitting tensile strength (MPa)
1st Group			
NAC	0	0	2.25
RA1C	0	40	2.24
RA2C	0	30	2.41
RA12C	0	70	1.58
2nd Group			
NACSF5	5	0	2.62
RA1CSF5	5	40	2.52
RA2CSF5	5	30	2.97
RA12CSF5	5	70	1.92
3rd Group			
NACSF10	10	0	3.40
RA1CSF10	10	40	2.46
RA2CSF10	10	30	2.63
RA12CSF10	10	70	1.62

2.4.1. Splitting tensile strength RPA

Naik T R et al,(1994) A reference concrete without plastic was proportioned to obtain 28 day compressive strength of 35 MPa. The plastics were added to the reference mixture in various amounts ranging between 0.5 and 5% of total weight of the mixture. . The plastic samples were treated by soaking them in water, bleach, and bleach plus NaOH (alkaline bleach)

As could be anticipated the effect of soft plastic as "aggregates" on all concrete mixtures containing 4.5% post consumer plastic showed lower Splitting tensile strength than the reference mixture without plastic . This was attributed to lower

Splitting tensile strength of the plastic particles compared to cementitious matrix as well as natural fine and coarse aggregates. The plastic treated with bleach plus NaOH showed the highest tensile strength, and the plastic treated with bleach alone exhibited the lowest tensile strength. The observed tensile strength as a function of plastic addition is shown in Table.2.20. The splitting strength increased with age, and with plastic addition up to 0.5%. Beyond the 0.5 plastic addition tensile strength decreased

Table 2.20 : Strength Properties Data.(Naik T R et al.1994)

Mix No.	P0	P1	P2	P3	P4	P5	P6	P7
Treatment	None	Water	Bleach	Bleach + NaOH	None	Water	Water	Water
%age Plastic Agg.	0.00	4.50	4.50	4.50	0.00	0.50	1.50	2.00
Test Age Days	Splitting Tensile strength MPa							
3	4.11	1.83	1.65	2.07	3.37	3.52	3.06	2.36
7	5.55	2.32	1.65	3.52	4.71	3.97	3.66	2.81
28	6.75		1.93	3.87	5.59	4.99	4.08	3.44

Lakshmi and Nagan,(2010) Split tensile strength test was conducted to evaluate the strength development of concrete containing various E waste contents at the age of 7, 14, 28 days respectively on A & B series of mix specification following the standard test procedures.

Results – A Series(only various % of plastic waste)

Table 2.21: Tensile strength test results in N/mm²(Lakshmi and Nagan. 2010)

	Control mix	A1	A2	A3	A4	A5	A6
% Waste plastic	0%	4%	8%	12%	16%	20%	25%
7Days	4.44	4.36	4,05	2.85	2.63	1,64	1.51
14Days	4.68	4.52	4.10	3.05	3.16	1.80	1.74
28Days	4.95	4.80	4.55	4.40	3.50	1.96	1.77

Results – B Series(with various % of plastic waste+ 10% fly ash)

Table 2.22: Tensile strength test results in N/mm² (Lakshmi and Nagan. 2010)

Mix specification	Control mix	B1	B2	B3	B4	B5	B6
% E Waste plastic+ 10% fly ash	0%	4%	8%	12%	16%	20%	25
7Days	3.85	3.56	3,55	3.46	3.15	2.80	2.42
14Days	4.58	4.37	4.01	4.00	5.05	3.61	3.10
28Days	5.53	5.35	5.20	4.89	5.40	4.78	3,90

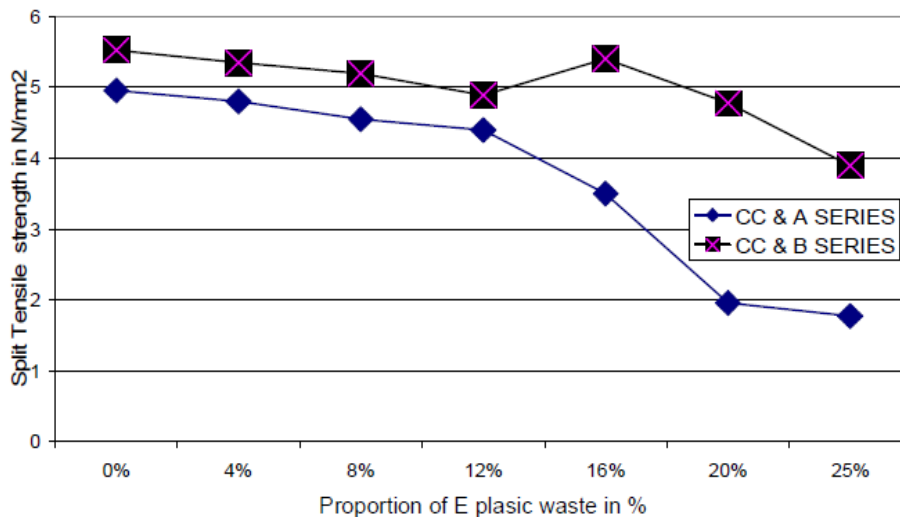


Fig. 2.15: Split Tensile Strength Results – Comparison of A & B Series (Lakshmi and Nagan. 2010)

Saikia and Brito,(2012) observed the incorporation of any type of plastic aggregate lowers the splitting tensile strength of concrete. The causes for the reductions observed in splitting tensile strength reported in various references were similar to those used to explain the decrease in compressive strength due to the incorporation of plastic aggregate. Some results on the tensile strength behaviour of concrete and mortar containing various percentages of different types of plastic aggregates are presented in Fig. 2.16.

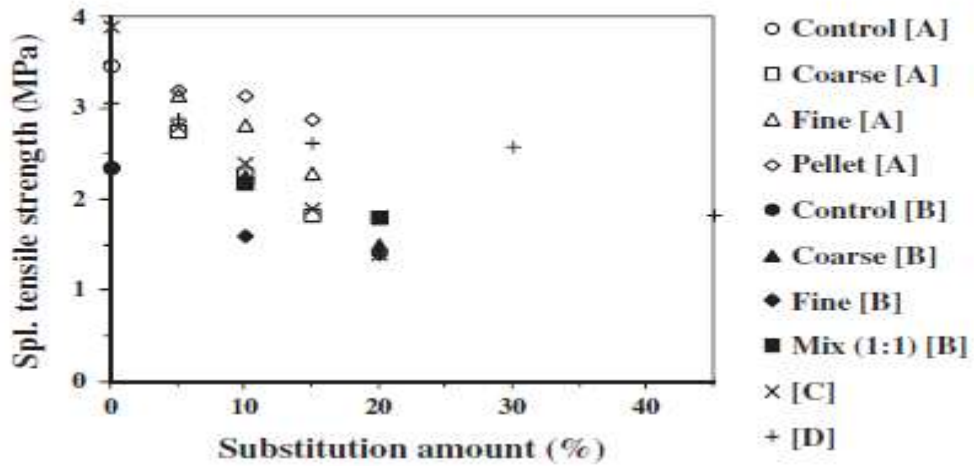


Fig. 2.16. Splitting tensile strength of concrete containing plastic waste aggregate containing plastic aggregate (Saikia and Brito 2012)

Raghatate Atul M.(2012)

Split tensile strength test were carried out on a cylindrical specimen 150 mm in diameter and 300 mm long. Specimen shall be tested after 3, 7, and 28 days respectively. Result of split tensile test was presented in Table.2.23

Table 2.23 split tensile strength N/mm² (Raghatate Atul M.2012)

% of plastic	0.00%	0.20%	0.40%	0.60%	0.80%	1.00%
	SPLIT TENSILE STRENGTH in MPa					
7 Days	1.54	1.85	2.35	2.83	3.12	3.85
14 Days	1.82	1.96	2.63	2.98	1.80	3.12
28 Days	4.12	4.38	4.92	5.16	5.57	5.12

.Improvement in splitting tensile strength after addition of plastic pieces in concrete was observed which show in Fig 2.20 & 2.21

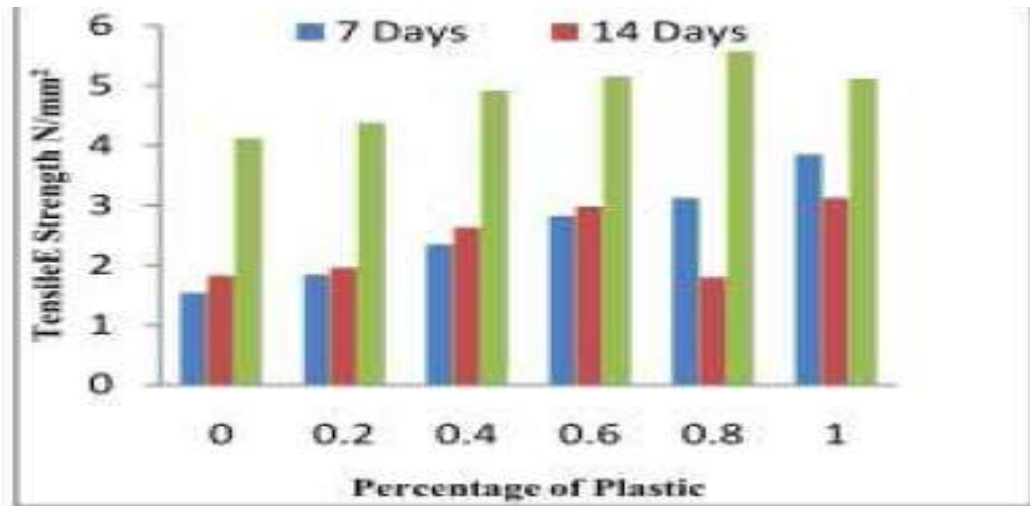


Fig.2.17: Variation of tensile strength (Raghatate Atul M. 2012)

Methew, P. et al (2013) Tests were conducted to determine the split tensile strength of size 150 mm x 300mm, and are shown in Table 2.24. Even though the PCA concrete has shown a better compressive strength as compared to conventional with an increment of 28%, it's lower in split tensile strength . It can be assessed that deficient bonding between PCA and the matrix must be a reason to have the lower values

Table 2.24: Structural Properties of Concrete(Methew, P. et al 2013)

Particulars	Cylinder Splitting tensile strength in MPa
NCA	2.45
22% PCA	1.91

Nibudey R. N. at el.(2013) The concrete mixture was prepared by adding plastic fibers from 0.5 % to 3.0 % by weight of cement in M30 concrete. The cylindrical specimens (diameter- 150 mm and length- 300 mm) were casted to determine split tensile strength of concrete. All the specimens were cured for a period of 28 days before test & result are shown in Table 2.25 :-.

Table 2.25 Tensile strength of concrete (Nibudey R. N. at el.2013)

Sr, no.	Addition of fibre	Failure Load (KN)	Tensile Strength (MPA)	Average Tensile strength (Mpa)	% change in Tensile strength
1	0.0	252	3.47	3.48	0.00
		244	3.45		
		252	3.57		
		240	3.40		
		240	3.40		
		248	3.51		
2	0.5	258	3.65	3.67	5.46
		258	3.65		
		262	3.71		
3	1.0	272	3.85	3.87	11.21
		274	3.88		
		274	3.88		
4	1.5	258	3.65	3.72	6.09
		266	3.77		
		264	3.74		
5	2.0	236	3.34	3.36	-3.45
		236	3.34		
		240	3.40		
6	2.5	214	3.03	2.95	-15.23
		212	3.00		
		200	2.83		
7	3.0	186	2.63	2.58	-25.86
		182	2.58		
		178	2.52		

2.5 Bond strength

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 ends 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.).

2.5.1 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 2.18 shows the various bond transfer mechanisms on a reinforcing bar

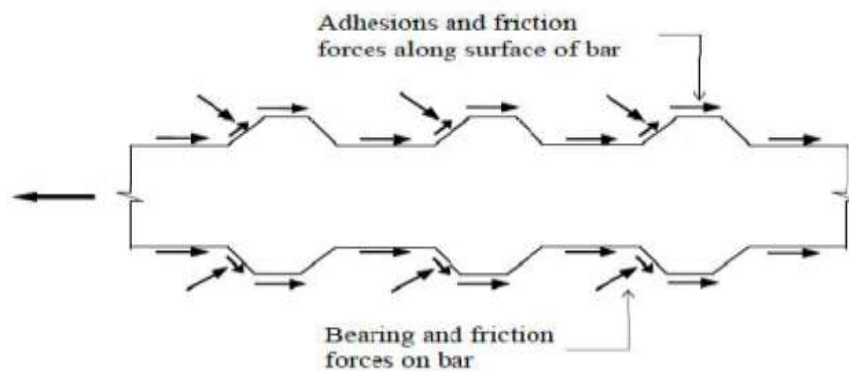


Fig 2.18: Mechanism of bond transfer (Wight et al. 2009)

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.)

2.5.2 Bond between RCA Concrete and Steel Rebars: Bond strength can be measured by various test setups. The most common is Pull out 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 beam end 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 12 mm, 16 mm, 20 mm and 25 mm 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% and 100% 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 wherein 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 2.26, 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 2.26: Concrete mixture proportions (kg/m³) (Prince et al. 2013)

Mix ID	RCA Replacement (%)	Cement	Sand	NCA	RCA	Mixing Water
AR0	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. Pullout specimens are widely used for investigation of bond behaviour because of their ease of fabrication. Pullout tests provide a simple means of comparing relative bond behaviour across different types of concretes and rebars as mentioned in Table 2.27. 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 2.27: Experimental results of pullout specimens (Prince et al. 2013)

Specimen)	CS (MPa)	P _{max} (kN)	τ _{max} (MPa)
A12R0	36.9	42.2	18.7
A12R25	28.9	44.2	19.5
A12R50	24.0	42.7	18.9
A12R75	26.2	43.0	19.0
A12R100	24.7	43.2	19.1
A16R0	36.9	59.9	14.9
A16R25	28.9	58.5	14.5
A16R50	24.0	50.4	12.5
A16R75	26.2	54.1	13.5
A16R100	24.7	55.0	13.7
A20R0	36.9	84.6	13.5
A20R25	28.9	77.1	12.3
A20R50	24.0	75.7	12.0
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	24.0	79.4	8.1
A25R75	26.2	80.5	8.2
A25R100	24.7	82.1	8.4

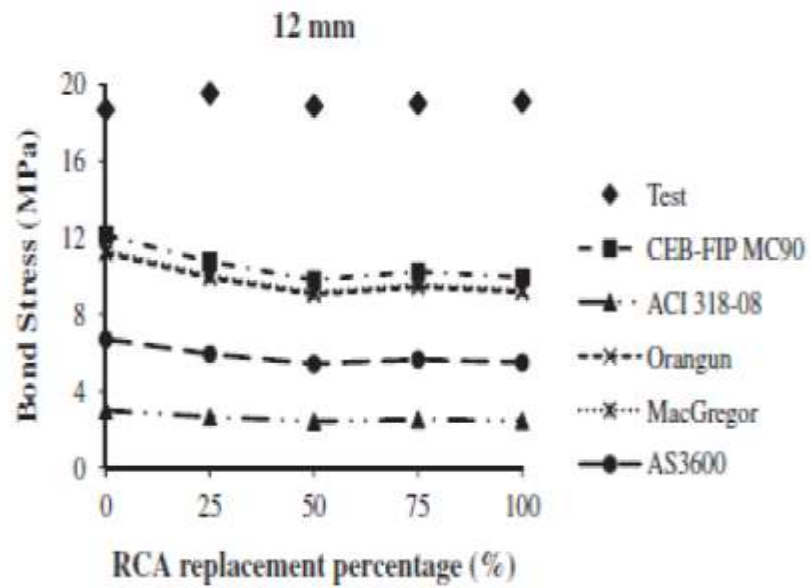


Fig 2.19 (a): Comparison of measured and predicted Bond Stress values for 12mm diameter rebar (Prince et al. 2013)

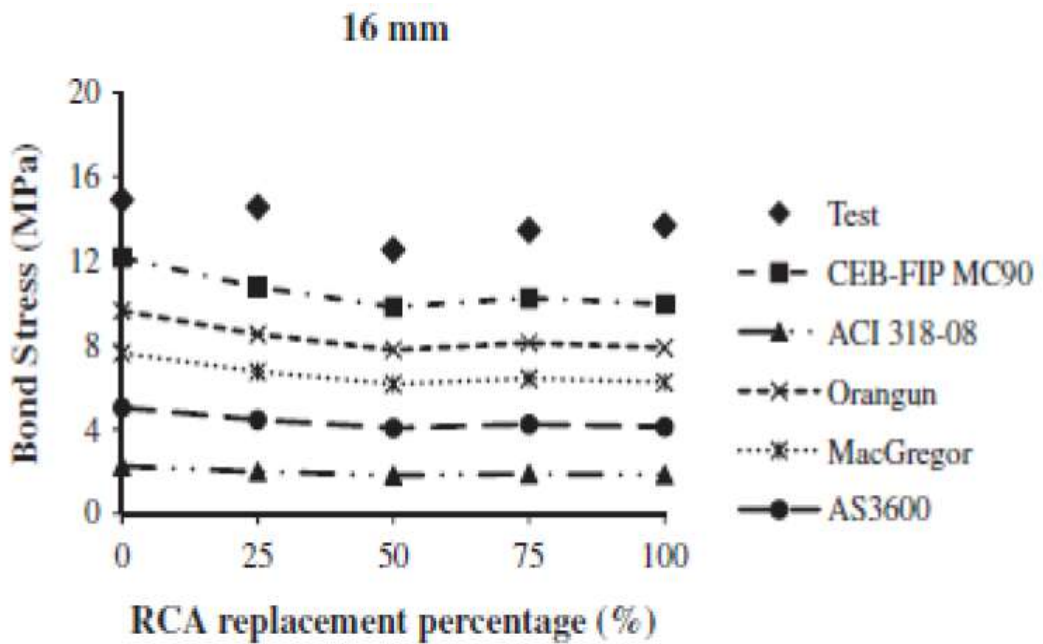


Fig2.19(b): Comparison of measured and predicted Bond Stress values for 16mm diameter rebar (Prince et al. 2013)

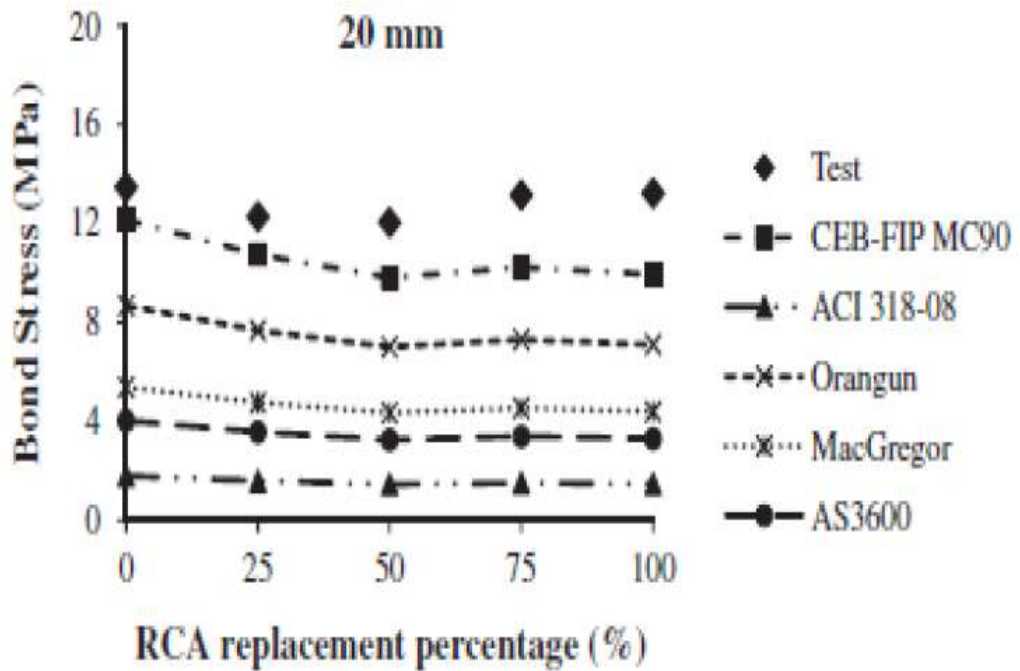


Fig 2.19(c): Comparison of measured and predicted Bond Stress values for 20mm diameter rebar (Prince et al. 2013)

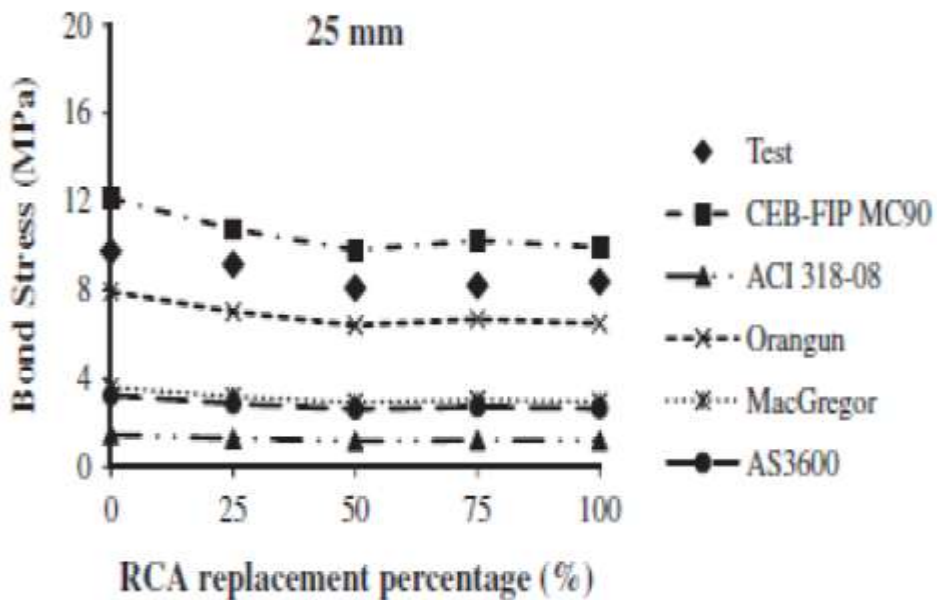


Fig 2.19 (d): Comparison of measured and predicted Bond Stress values for 25mm diameter rebar (Prince et al. 2013)

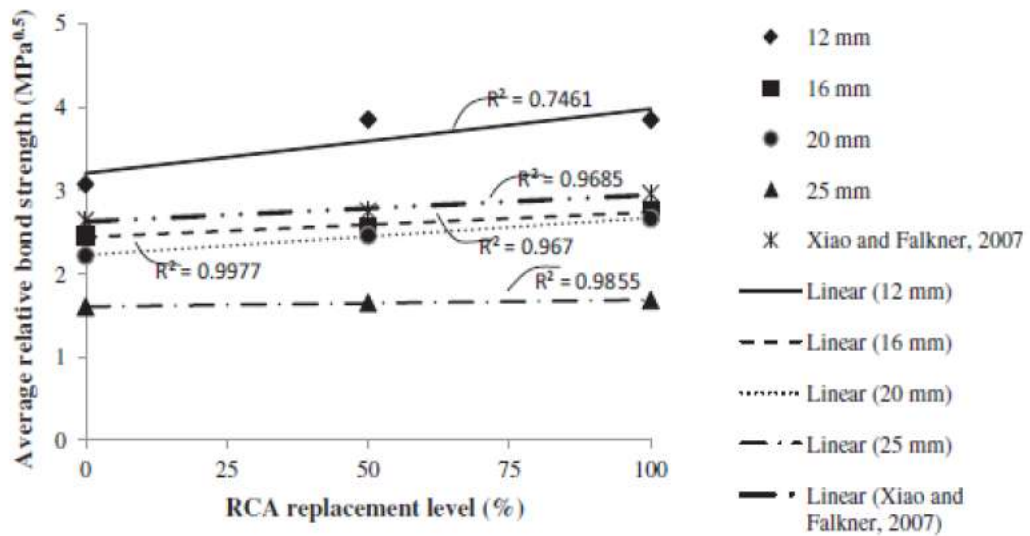


Fig 2.19(e): Average Relative Bond Strengths for various RCA replacement levels(Prince et al. 2013)

Xiao et al. (2007) 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% and 100%) were the main parameter considered in this paper. The mean values of the bond strengths are compared in Fig 2.20. From Fig 2.20, 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, whereas for the deformed bar the bond strength between the recycled coarse aggregate and the deformed rebar remains same.

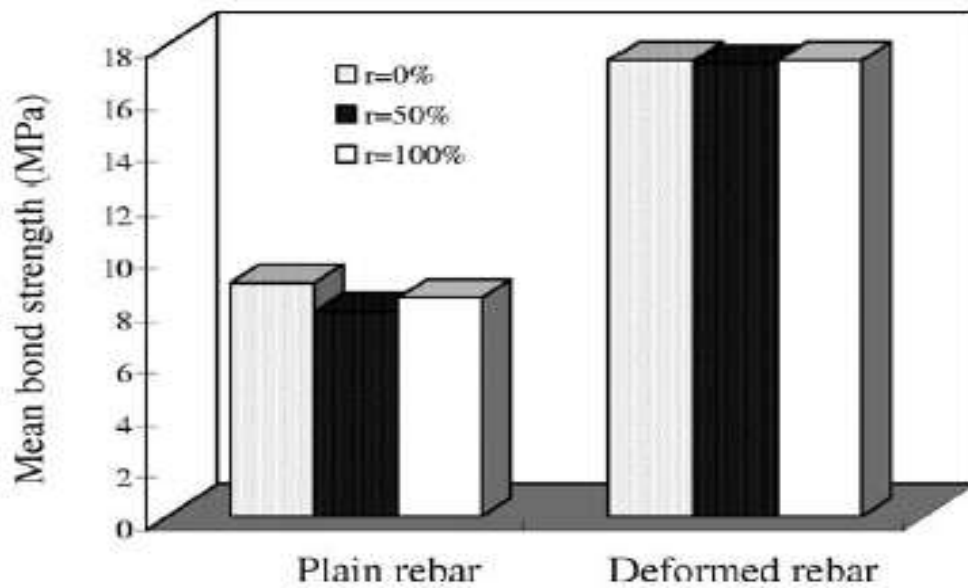


Fig 2.20: Comparison for the mean value of bond strength (Xiao et al. 2007)

Choiet al. (2008) investigate the bond performance between recycled coarse aggregate and reinforcing bar. The bond strength against slip relationship between RCA and reinforcing bar is reflected as the main characteristic of reinforced-concrete construction, and the shear strength and shear failure of concrete, which effect bond strength, are also investigated. In addition, this study also checks whether the three known equations that have been most commonly used to obtain the bond strength of concrete from the compressive strength of concrete are also applicable for recycled coarse aggregate. These equations are: the Ogura–Koichi model, CEB–FIP model and ACI 408 model. To investigate the bond behaviour between recycled aggregate concrete (RCA) and rebar, this paper considers recycled aggregates (RG of grade I and III and RS of grade II), w/c ratios (40% and 50%), and replacement ratios of recycled aggregates (0%, 30%, 50% and 100%). The results were as follows:

- (a) bond stress–slip shows tendencies like those of normal concrete up to a replacement ratio of 50%;
- (b) shearing stress–strain is influenced by grade and the replacement ratio of recycled aggregates ;
- (c) τ_b is influenced by grade and the replacement ratio of recycled aggregates , but at high w/c, τ_b is not influenced by the quality and the replacement ratio of RAs;

(d) $\tau_b / \sqrt{f_{ck}}$ is influenced by the w/c ratio; and

(e) τ_b between RCA and rebar is overestimated or underestimated by existing equations. As a result, a new equation (with modification of either the value, invariable value or others), or modified development length or lap splice length must be considered. In concrete mix design, the ratio of the amount of RA to that of the total aggregate is termed the RG and RS replacing ratio. Because the used RAs have high water absorption, they were pre-soaked with additional water before mixing, to make the aggregate state saturated and surface dry in this experiment. Two w/c ratios were used: 0.4 and 0.5. The target slump value for each was 150 mm and 120 mm. The mixtures were divided into six groups, the only difference between the groups being the replacing ratios of recycled aggregates, which were 0%, 30%, 50% and 100%.

The mean pull-out bond strength as a function of both RA ratios and w/c ratios. In w/c ratio 0.5, the bond strength decreased with the increasing RA ratio and the decrease grade/class of RA. The bond strengths of all specimens that used RA were, however, higher than those of normal concrete (N). The bond strength increased as the w/c ratio decreased. This may be because the bond strength between RAC and the rebar depends on the concrete type and properties, mechanical anchorage and friction resistance. That is, concrete type and properties are different according to the RA used, and this difference changed the mechanical anchorage and friction resistance between the two materials. The bond strength can therefore be considered to be strongly influenced by RA ratio, among numerous other factors. The average bond strength of RS-II concrete was lower than that of RG-III concrete

The type of RA (RG or RS) has a larger negative effect on the bond strength of RAC than the quality of the RA. Interestingly, concretes using relatively good quality RS still had a poorer performance than concretes that used RG in the bond.

In w/c ratio of 0.4, the bond strength between the RAC and the rebar decreased with an increasing RA ratio and a decreasing RA grade/class—a trend similar to that of the w/c ratio 0.5. In contrast, however, with the w/c ratio of 0.5, the bond strengths of all specimens that used RA were lower than that of normal concrete. When the RA ratio was 100% and the w/c ratios were the same, the bond strength—as a function of the RA ratio—increased by 22.7% (5RG-I 100), 13.6% (5RGIII100) and 0.1% (5RS-II 100) for a w/c ratio 0.5, and decreased by 7.1% (4RG-I 100), 16.3% (4RG-II 100) and

26.1% (4RS-II 100) for a w/c ratio of 0.4 more than that of normal concrete (5N and 4N). These results show that the bond strength of RAC was hardly influenced by the w/c ratio but was greatly influenced by the replacement ratio and the grade of the RA.

Kim et al (2012) Investigated to understand characteristics of recycled aggregate concrete and its bonding performance to the deformed re-bar and compare the bond strength to a natural aggregate concrete. Concrete specimens for two different mix proportions with varying levels of replacement of recycled coarse aggregate and recycled fine aggregate were made while diameter of deformed re-bar for the two specimens was kept same

Table 2.28. Bond strength results (Kim et al 2012).

Specimen	Mixed aggregate		Deformed re-bar diameter (mm)	Bond strength by test (MPa)
	Coarse aggregate	Fine aggregate		
NN	Natural 100%	Natural 100%	19mm	13.5
RN	Recycled 100%	Natural 100%	19mm	12.5
RR30	Recycled 100%	Recycled, 30% replaced	19mm	12.0
RR60	Recycled 100%	Recycled, 60% replaced	19mm	11.4
RR	Recycled 100%	Recycled, 100% replaced	19mm	9.9

In the occasion of replacing only coarse aggregate with the recycled, there was about 3% decrease of bond strength and additional replacing 30% of fines with the recycled, approximately 7% decrease while replacing the whole quantity, 18% decrease.

(B) Beam-End Specimens

Butler et al. (2011) investigate concrete bond strength by replacing natural coarse aggregate with recycled coarse aggregate (RCA). For the investigation two sources of RCA were used along with one natural aggregate source. All the aggregate properties were tested for all aggregate sources. Two different types of concrete mix proportions were developed in which 100% of the natural aggregate was replaced with RCA. In the first one the same water–cement ratio was maintained and in the second type the mix proportion was designed to achieve the same compressive strengths. Beam-end specimens were casted. The mix proportions obtained are shown in Table 2.29 & 2.30

Table 2.29: Control concrete mixture proportions and test results (Butler et al. 2011)

Material	NAC-30	NAC-50
Water(kg/m ³)	160	180
Cement(kg/m ³)	267	474
Coarse aggregate(kg/m ³)	1106	1106
Fine aggregate	861	633
w/c ratio	0.60	0.38
Slump(mm)	90	90
Compressive strength (MPa)	34.4	54.7

Table 2.30: Direct replacement concrete mix proportion and test results (Butler et al. 2011)

Material	RAC1-30	RAC1-50	RAC2-30	RAC2-50
Water(kg/m ³)	160	180	160	180
Cement(kg/m ³)	267	474	267	474
Coarse aggregate(kg/m ³)	975	975	949	949
Fine aggregate	863	635	863	635
w/c ratio	0.60	0.38	0.60	0.38
Slump(mm)	25	35	45	75
Compressive strength (MPa)	44.1	59.0	36.9	54

The strength-based mixtures were developed for two reasons:

1. To determine whether RCA mix proportions could be developed to obtain similar compressive strength and workability to that of natural aggregate concrete
2. To determine the effect that natural aggregate replacement with RCA has on bond strength. Fig 2.21 shows the test apparatus used in this investigation

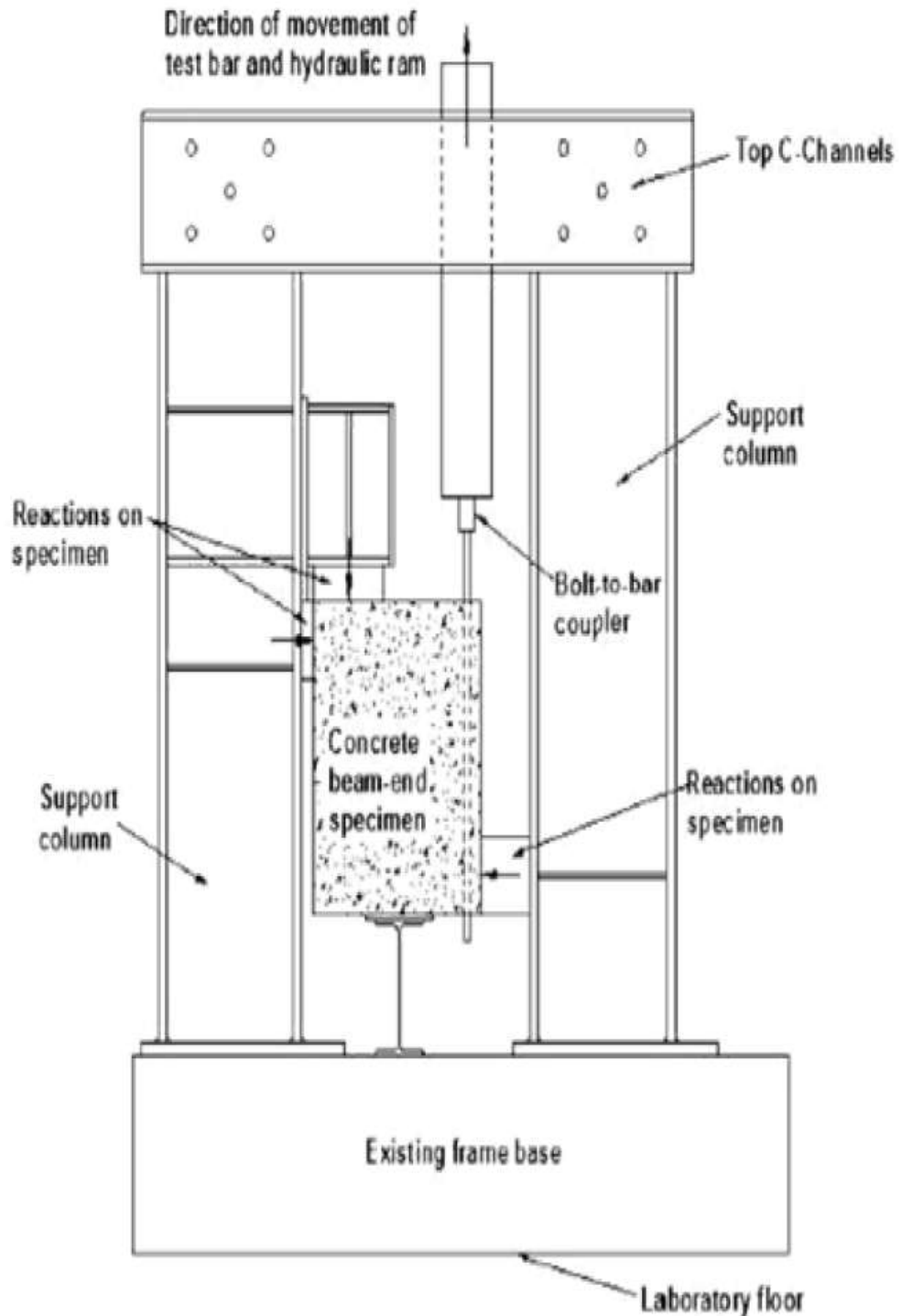
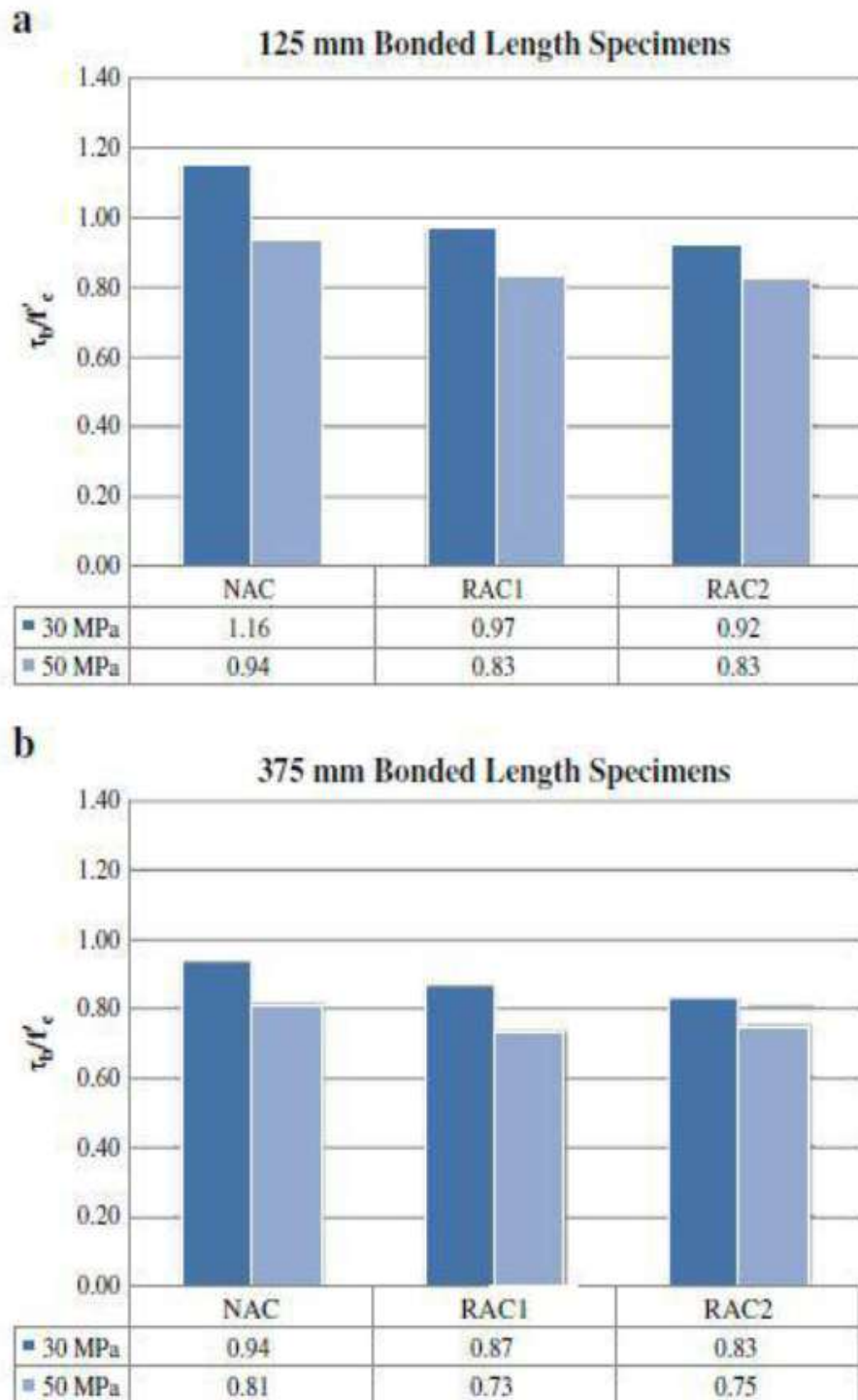


Fig 2.21: Beam-End test frame set-up (Butler et al. 2011)

Beam-end specimens were tested to investigate the relative bond strength of RCA and natural aggregate concrete. Average bond stress values, for the 125 mm and 375 mm bonded lengths are summarized in Fig. 2.22 (a) and (b), respectively. The natural aggregate concrete beam-end specimens with bonded lengths of 125 mm had average bond strengths that were 11.4 to 19.0% higher than the RCA-1 concrete specimens

and 13.2 to 21.3% higher than the RCA-2 specimens. It was concluded that, natural aggregate concrete specimens had 9 to 19% higher bond strength value than the equivalent RCA specimen



**Fig 2.22 (a) and (b): Average Bond Stress data for NAC, RAC1 and RAC2
(a) 125mm bonded length specimens.
(b) 375 mm bonded length specimens.(Butler et al. 2011)**

Darwin et al. (1992) studied the new bar geometries to determine the degree of improvement in bond strength. The parameters which played a critical role in bond strength were concrete cover, bar spacing, and confining reinforcement. Foremost among the changes is a switch from bond stress to bond force as the measure of strength. The switch was made because bond stress is usually expressed as an average value at failure, when, in fact, bond stress varies significantly over the length of a bar at failure. Since bond strength is a structural, rather than material property, bond force provides a better measure of member response than bond stress. The equation proposed was:

$$(Abfs)/\sqrt{fc'} = 6.67ld (C + 0.5db)(0.92 + 0.08) + 300Ab$$

Ab = Area of deformed bar

fc' = compressive strength

db = diameter of the deformed bar

C_{max} = $\max[\min (C_x, C_y, C_s/2), C_y]$

C_{min} = $\min (C_x, C_y, C_s/2)$

C_x = side cover

C_y = bottom cover

C_s = spacing between the bars

Orangun et al. (1977) studied the effect of development length and splices and gave a mathematical model. The equation was developed for calculating development length and splice length for deformed bars. The equation was based on the non linear regression analysis of test results of beams with lap splices and reflects the effect of length, cover, spacing, bar diameter, concrete strength and transverse reinforcement on the strength of anchored bars. The equation:

$$u^*/\sqrt{fc'} = 1.22 + 3.23 C/db + 53db/ld$$

u^* = average bond stress

fc' = compressive strength

db = diameter of deformed bar

ld = development length

2.5.2 Bond between RPA Concrete and Steel Rebars: sentry research work in literature to study the bond behaviour of plastic aggregates.

Methew, P. et al (2013) suggested that by adding an admixture in water @ 0.4% by weight of cement to improve bonding between plastic aggregate and the matrix.

CHAPTER 3
EXPERIMENTAL PROGRAM

3.1 General

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

3.2 Material Properties

Cement, natural fine aggregates, natural coarse aggregates, recycled coarse aggregate, recycled plastic coarse aggregate silica fume, water and steel deformed bars are to cast specimen investigate. The physical properties of these materials are discussed in the following sections.

3.2.1 Cement

Portland –Pozzolana cement of grade – 33 under industrial name (Ultra teck) conforming to Indian standard IS:1489 -1991Part-I that was 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 Portland Pozzolana cement

S. No.	Characteristics	Units	Values obtained	Values as per IS 1489-1991
1.	Consistency	%	32.5	-
2.	Initial setting time	Minutes	147	Not less than 30
3.	Final setting time	Minutes	210	Not greater than 600
4.	Fineness	%	1.5	less than 10%
5.	Specific gravity	gm/cc	3.0	-
6.	Compressive strength (MPa)	(MPa)		
	3 days		18.4	16
	7 days		26.5	22
	28 days		36.8	33

3.2.2 Fine aggregates

The material which passes through 4.75 mm sieve is termed as fine aggregates. The sand used for the experimental works is locally procured from Patiala and conformed to grading zone II. The sieve analysis and physical properties of fine aggregates are listed in Tables 3.2. & Table 3.3

Table 3.2: Sieve analysis of fine aggregates

Sr. No.	Sieve No.	Cumulative Weight retained (grams)	Cumulative Percentage retained (%)	Percentage Passing (%)	Limits of zone II as per IS-383
1.	4.75 mm	14	1.4	98.6	90-100
2.	2.36 mm	80	8.0	92.0	75-100
3.	1.18 mm	322	32.2	67.8	55-90
4.	600 mm	518	51.8	48.2	35-59
5.	300 mm	720	72.0	28.0	8-30
6.	150 mm	947	94.7	5.3	0-10
7.	Pan	1000	-----	-	-
			$\Sigma F = 260.1$		

Table 3.3: Physical properties of fine aggregates

Sr. No.	Characteristics	Value
1.	Type	Natural sand
2.	Specific Gravity	2.60
3.	Fineness Modulus	2.60
4.	Grading Zone	Type II
5	Water absorption	1.4 %

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 of maximum size of 20 mm was used in the present work. The results of sieve analysis of the natural aggregate are presented in Table 3.4

Table 3.4: Sieve analysis of natural coarse aggregates

Sr. No.	Sieve size	Cumulative weight retained (gms)	Cumulative % retained	%passing for NCA	Limits as per IS-383
1.	40 mm	0	0	100	100
2.	20. mm	44	1.47	98.53	95-100
3.	10 mm	1796	59.87	40.13	25-55
4.	4.75 mm	2835	94.5	5.5	0-10
5	pan	3000	-----	---	---

3.2.4 Recycled concrete aggregate

Waste concrete in the form of tested cubes, cylinders and beams are lying in the dump yard of concrete laboratory at Thapar University were used as a source of RCA shows Plate 3.1 the waste concrete rubble used for obtaining RCA. To make RCA, the specimens without reinforcement were manually broken down into small pieces and then crushed using jaw crusher as shown inPlate 3.2 and the results of sieve analysis are presented in Table 3.5



Plate 3.1: Waste concrete rubble used for obtaining RCA



Plate 3.2: Jaw crusher to obtain RCA

Table 3.5: Sieve analysis of recycled concrete aggregates

Sr. No.	Sieve size	Weight retained (kg)	% retained For RCA	%passing For RCA	Limits of NCA
1.	40 mm	0	0	100	100
2.	20 mm	16	0.4	99.6	95-100
3.	10 mm	1052	70.13	29.87	25-55
4.	4.75 mm	1486	99.06	0.94	0-10
5	Pan	1500			

3.2.5 Recycled Plastic aggregate

Recycled plastic aggregates are purchased from Pardeep Plastic Industry, D253, focal point, Patiala. To produce plastic aggregates, plastic waste from various sources such as empty plastic bags, household plastics waste and used empty polythene bags was collected. This waste was sorted to choose the plastic of superior quality. To remove impurities, the plastic waste was washed with water and other solutions. After crushing the waste into small fractions, it was again washed to remove the foreign particles/impurities. It was heated at a particular temperature to obtain some brittleness. After extrusion of the molten plastic and cooling, boulders of approximately 100mm size were collected. These plastic boulders were crushed down to required size of 20mm-4.75mm. Table 3.6 shows the sieve analysis of recycled plastic aggregates. The physical properties of natural and recycled aggregates are presented in Table 3.7.

Table 3.6: Sieve analysis of recycled plastic aggregates

Sr. No.	Sieve size	Weight retained (kg)	% retained For RCA	%passing For RCA	Limits of NCA
1.	40 mm	0	0	100	100
2.	20 mm	138	9.2	90.8	95-100
3.	10 mm	1056	70.4	29.6	25-55
4.	4.75 mm	1347	89.8	10.2	0-10
5	Pan	1500	-----	---	---

Table 3.7: Physical properties of the natural, recycled concrete & recycled plastic course aggregate

Sr. No.	Properties	Natural aggregates	Recycled concrete aggregates	Recycled plastic aggregates
1.	Specific gravity	2.70	2.67	1.113
2.	Water absorption (%)	0.47	0.96	0.52
3.	Fineness modulus (%)	7.44	7.30	6.69

3.2.6 Silica fume

Silica fume, also known as micro silica or condensed silica fume, is a pozzolanic admixture. When used in concrete it will fill the void space between cement particles resulting in a more impermeable concrete. Silica fume is added as 10% cement replacement by weight. Silica fume was provided by TGS Impex India Pvt Ltd and conformed the IS code 15388 (2003) specifications.

3.2.7 Reinforcing Steel

High strength deformed steel bars (Fe 500) with a nominal diameter of, 16mm was used as main longitudinal reinforcements in all pull out test specimens. Along with the main bar, the cube is reinforced with a helix of 6 mm diameter plain mild steel reinforcing bar conforming to Grade I of IS: 432 (Part I)-1982 at pitch 25 mm pitch, such that the outer diameter of the helix is nearly equal to size of the cube.

3.2.8 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

A total of twelve mix combinations are as N-100 (control concrete), NC-70-30 (70% natural aggregate + 30% RCA), NP-70-30 (70% natural aggregate + 30% RPA), NCP-50-30-20(50%NCA+30%RCA+20%RPA),NCP-50-20-30 (50%NCA + 20%RCA + 30%RPA), NCP-50-25-25 (50%NCA+25%RCA+25%RPA), NS-100 (100%NCA+10% silica fume), NCS-70-30 (70%NCA+30%RCA+10% silica fume), NPS-70-30 (70%NCA+30%RPA+10% silica fume) & similarly other combinations are prepared in the laboratory. The slump test for workability of the mix was done by cone method and a desired slump of 25-75 mm was achieved. Concrete mixture proportion presented in Table 3.9. The mix proportion of corresponding mixes is prepared by replacing natural aggregate by recycled coarse aggregate & recycled plastic aggregate. In this, mixture proportions for the natural coarse aggregate and the recycled coarse aggregate concretes were nominally kept the same, except for replacement of NCA with RCA & RPA, depending upon the desired recycled coarse aggregate replacement percentage.

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

$$\text{Wt of RCA at any replace \%} = \frac{\% \text{ replacement} \times \text{total wt of NCA}}{\times 100}$$

$$\text{Wt of RPA at any \% replacement} = \frac{\% \text{ replacement} \times \text{total wt of NCA} \times \text{Specific gravity of RPA}}{\text{Specific gravity of NCA} \times 100}$$

The following weight combinations of NCA and RCA & RPA adopted are: 100 % NCA (control mixture) & different proportions of NCA, RCA & RPA. Silica fume is added as cement replacement (10%). The concrete mixture proportions and the corresponding mix designations are presented in Table 3.8 and 3.9.

Table 3.8: Mix proportion of control sample

w/c ratio	Cement (kg/m ³)	Fine aggregate (kg/m ³)	Natural coarse aggregate (kg/m ³)	Water (kg/m ³)
0.43	443	633.15	1144	190.82

Table 3.9: Mix proportions for different samples

Designation	Replacement(%)	Cement (kg/m ³)	F A (kg/m ³)	N C A (kg/m ³)	Recycled coarse aggregate (kg/m ³)	Recycled plastic aggregate (kg/m ³)	Silica fume (kg/m ³)	Water (kg/m ³)
Control Mix-N-100	-	443	633.15	1144	-	-	-	190.82
NC-70-30	30%	443	633.15	800.8	343.2	-	-	190.82
NP70-30	30%	443	633.15	800.8	-	141.5	-	190.82
NCP-50-30-20	50%	443	633.15	572	343.2	94.3	-	190.82
NCP-50-20-30	50%	443	633.15	572	228.8	141.5	-	190.82
NCP-50-25-25	50%	443	633.15	572	286.0	117.9	-	190.82
NS-100	-	398.7	633.15	1144	-	-	44.3	190.82
NCS-70-30	30%	398.7	633.15	800.8	343.2	-	44.3	190.82
NPS-70-30	30%	398.7	633.15	800.8	-	141.5	44.3	190.82
NCPS-50-30-20	50%	398.7	633.15	572	343.2	94.3	44.3	190.82
NCPS-50-20-30	50%	398.7	633.15	572	228.8	141.5	44.3	190.82
NCPS-50-25-25	50%	398.7	633.15	572	286.0	117.9	44.3	190.82

3.4. Casting of Specimens

In this section the casting procedure for compressive test, and pullout test specimen are discussed.

3.4.1 Compressive strength test specimens

Three cube specimens of size 150×150×150mm were cast for static compressive testing. The quantity of cement, coarse aggregate, fine aggregate, silica fume and water for each mix is weighed separately. The cement and silica fume are mixed dry to attain a uniform mix separately. Fine aggregate is 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 then remaining water add in mixture and mixed . The cubes are filled with fresh concrete using vibrating Table. After casting cubes, the specimens are kept in lab for 24 hours. Next day the specimen are take out from mould and the specimen are kept in curing tank. For each mix 6 cube were cast for 7 days and 28 days compressive strength test. . The cubes after casting are shown in Plate 3.3.



Plate 3.3: Casting of cubes

3.4.2 Pullout specimen test

Pullout specimens are widely used for investigation the of bond behaviour between rebar and concrete because the simplicity of the test. Pullout tests provide a simple

means of comparing normalized bond behaviour. In the present investigation, 150 mm size cube specimen are used for carrying out the pull out strength test. The specimen are prepared as per the codal guidelines of IS: 2770 (Part I) – 1967 (Methods of testing bond in reinforced concrete). In this, rebar of 16 mm diameter is used as concentric reinforcement that will be pulled for finding pull out strength. The pulls out specimens are cast in a vertical position in the laboratory using steel moulds. The embedded length is kept five times the rebar diameter and was so selected to avoid yielding of the steel bar under pullout load. Contact between the concrete and the rebar along the de-bonded length was broken using a coaxially placed soft plastic tube and the annular space between the rebar and the plastic tube was filled with clay. Steel bars for pullout tests are shown in plate 3.4 Along with this, a helix reinforcement (as specified by IS: 2770 (Part I) – 1967) of 6 mm diameter conforming to grade I of IS: 432 (Part I) – 1966 at pitch of 25 mm such that the outer diameter of the helix is equal to the size of the cube as shown in plate 3.6. In present test for casting of the cubes, steel moulds are taken and helix is placed in the moulds leaving a small cover at the bottom and sides. Then the 16mm dia. bar is placed exactly in the centre. Then in the mould, the concrete mixed is poured and compacted using vibrating Table. After casting cubes, the specimens are kept in lab for 24 hours. Next day the specimen are take out from mould and the specimen are kept in curing tank. For each mix 3 cube were cast for 28 days pullout strength test. The typical sample specimens are shown in Plate 3.5



Plate.3 .4 Steel bars for pullout tests



Plate 3.5.: Pull out test concrete specimens



Plate: Helical Reinforcement in pullout specimen as per IS: 2770 (Part 1)

3.5 Test method

In this section the test setup used obtaining the tests compressive strength test and bond strength test is discussed.

3.5.1 Compressive strength test

Three identical specimens are crushed at 7days and three identical specimens are crushed at 28 days. The compressive strength is calculated by dividing the failure load by average cross sectional area. The average value of the three samples was taken as the compressive strength of the batch. .

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 Plate 3.7. 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



Plate 3.7: Testing for compressive strength

3.5.2 Pullout Strength test

Pull out strength test are carried out on universal testing machine of 1000 kN capacity shown in Plate 3.8



Plate 3.8: Pull out test machine

The test setup for pull out test is shown in Plate 3.9. A special arrangement of 40 mm thick steel plate is made to carry out the test. The plates are connected by four nut-bolts of 25 mm diameter. Lower plate is welded with rod having diameter 25mm. And opening at the top plate just allow the deformed steel bar to pass. 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



Plate 3.9 Test setup for pull out test

To carry out test, the rod of 25 mm is welded to lower plate of the setup 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 16mm diameter rebar (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. The rebar is pulled out at the rate of 2.25 kg/min for all test 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:

$$\text{Bond Strength} = \frac{P}{\Pi DL}$$

Where,

P: pull out load, (Kn)

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

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

The pull out strength test is carried out at the age of 28 days. Three samples are tested for each mix at the specified age. The average value of the three samples was taken as the bond strength of the batch. After completion of test, sample was removed from the test setup, physical verification of crack and type of slip is observed as shown in Plate.3.10. It is observed that specimen failed by pullout rather than by splitting of concrete.



Plate 3.10 Crushing due to pullout bar lugs after pullout test

For the further analysis of bond strength characteristics different bond strength equations presented in Table 3.10 were used. These equations were developed for natural aggregates concrete CEB-FIP MC90, ACI 408-03 , Orangun, C. O.,1977 and MacGregor, MacGregor,J. G.,1997. Equations (1-4) are function of compressive strength of concrete, developed or embedded length of re-bars and rebar diameter and are used to predict bond strength shown in Table 3.6 for the concrete containing only natural aggregates. Kim et al 2008 developed Eq. (5) for bond strength perdition of recycled concrete aggregates.

Table: 3.10. Different Bond Strength Equations

Equation	Bond strength equation	Simplified Bond strength eq. used for present study	Eq.no.
CEB-FIP MC90	$\tau_{\max} = 2.0\sqrt{f_{ck}}$	$\tau_{\max} = 2.0\sqrt{f_{ck}}$	Eq. (1)
ACI 408-03	$\tau_{\max} = 20\sqrt{f_{ck} / d_b}$	$\tau_{\max} = 1.25\sqrt{f_{ck}}$	Eq. (2)
Orangun 1977	$\tau_{\max} = [0.2652 \times (1.2 + \frac{3C}{D} + \frac{50D}{L})]X\sqrt{f_{ck}}$	$\tau_{\max} = 1.4\sqrt{f_{ck}}$	Eq. (3)
Mac Gregor 1997	$\tau_{\max} = \left[0.59 \sqrt{f_{ck}} \left(\frac{C}{D} - 0.5 \right) \right]$	$\tau_{\max} = 2.47\sqrt{f_{ck}}$	Eq. (4)
Kim et al 2008	$\tau_{\max} = 0.614 \sqrt{f_{ck}} \left(\frac{C}{D} - 0.55 \right) - (0.4203e^{0.0172S} + 0.007G)$	$\tau_{\max} = 2.54\sqrt{f_{ck}} - 0.4203 + 0.007G$	Eq. (5)

τ_{\max} : maximum bond stress of aggregate concrete

f_{ck} : compressive strength of aggregate concrete

C: distance from the deformed steel re-bar core to the concrete surface=-75mm

D: diameter of deformed steel re-bar=16mm

L= embedded length of re bars=80mm

S: replacement ratio of recycled fine aggregate=0%

G: replacement ratio of recycled coarse aggregate

3.6. Closing Remarks

The experimental program described in this Chapter includes the properties and specifications of the material of concrete. Test methods of compressive strength and pullout test are also discussed.

RESULT AND DISCUSSION

4.1 General

This chapter presents the results of compressive strength, and bond strength of various concrete mix proportions. All the tests were conducted in accordance with the test methods as described in Chapter 3. To analyse the bond strength characterises the experimental/ measured bond strength of all the mix combinations are compared with bond strength Eq. reported in the literature.

4.2. Compressive Strength

Compressive strength test results of cube specimens for all mix proportion at 7 and 28 days are presented in Table 4.1. The data is further represented in the form of graphs in Fig 4.1 - 4.3.

Table 4.1: Compressive strength of all mix combination at 7 and 28 days

Mix Type	Compressive strength (7 days)	Average 7 days Compressive strength	Compressive strength (28 days)	Average 28 days comp. strength	Percent different
Control Mix-N-100	25.43	23.39	35.13	34.17	
	22.77		34.24		
	21.97		33.14		
NC-70-30	20.71	19.72	32.92	31.45	-7.96
	19.53		31.44		
	18.92		30.00		
NP-70-30	17.89	16.82	27.74	27.88	-18.40
	16.02		30.64		
	16.55		25.26		
NCP-50-30-20	21.23	20.11	32.47	30.97	-9.36
	18.41		30.52		

	20.68		29.92		
NCP-50-20-30	18.08	19.3	31.30	29.44	-13.84
	18.86		27.35		
	20.96		29.68		
NCP-50-25-25	22.66	20.25	30.85	33.14	-3.01
	19.88		35.21		
	18.22		33.36		
NS-100	28.45	28.31	40.06	41.36	21.04
	26.85		42.04		
	29.63		41.98		
NCS-70-30	25.19	25.76	39.83	38.35	12.23
	24.01		37.81		
	28.08		37.41		
NPS-70-30	27.19	25.33	36.89	37.74	10.45
	23.48		38.82		
	25.34		37.51		
NCPS-50-30-20	22.69	23.98	35.74	36.11	5.68
	26.24		36.92		
	23.01		35.67		
NCPS-50-20-30	23.03	23.48	32.06	33.78	-1.14
	25.42		34.32		
	21.99		34.96		
NCPS-50-25-25	22.76	24.73	36.19	37.01	8.31
	24.02		35.99		
	27.41		38.85		

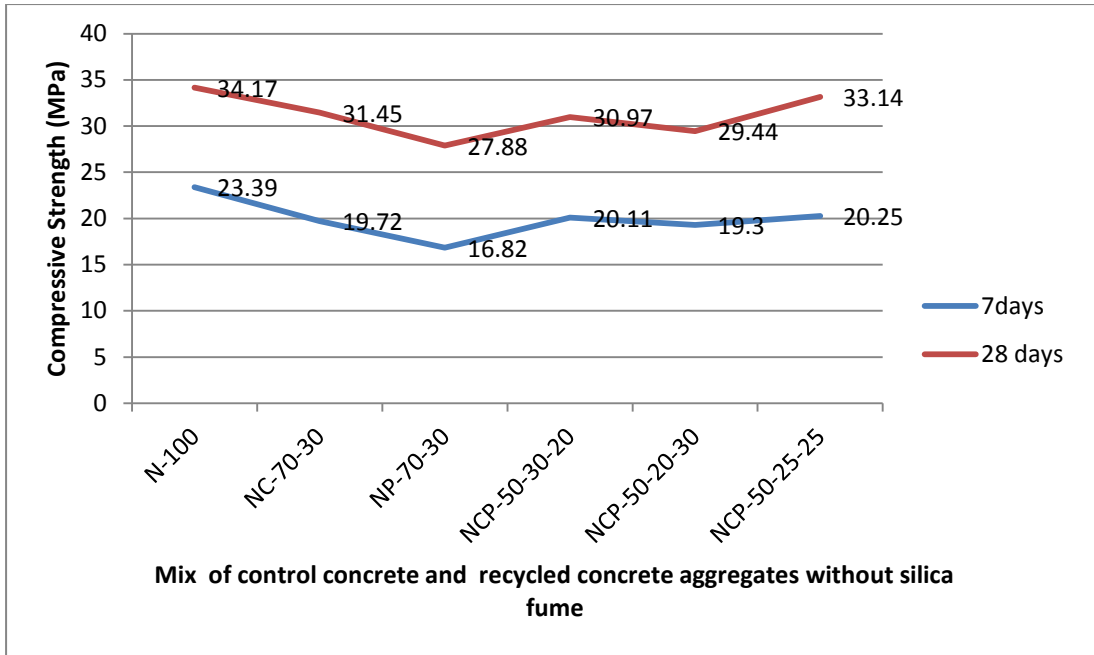


Fig 4.1: Average Compressive strength values of control concrete and concrete containing recycled aggregates without silica fume.

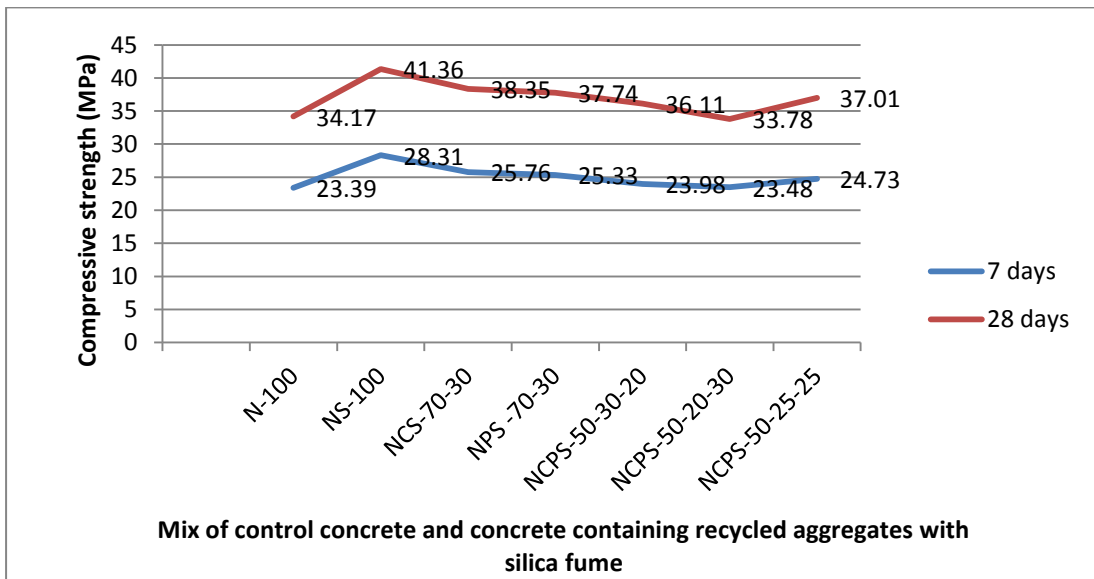


Fig 4.2: Average Compressive strength values of control concrete and concrete containing recycled aggregates with silica fume.

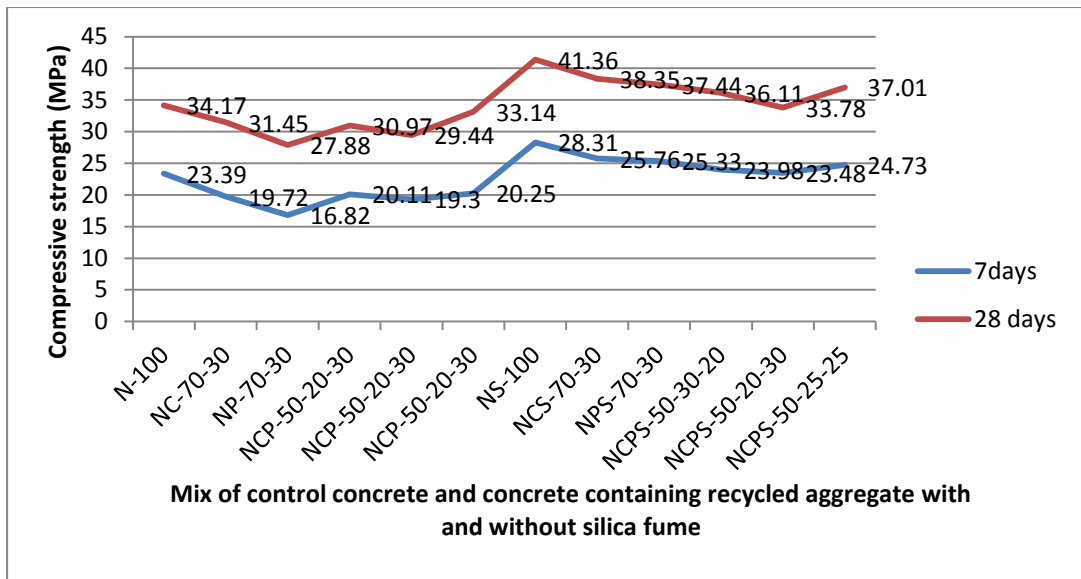


Fig 4.3: Average Compressive strength value at 28 days of control concrete and concrete containing recycled aggregates with and without silica fume.

Following observations can be made from Table 4.1 and Fig. 4.1-4.3

- For mix combinations without silica fume the compressive strength decreases with addition of recycled aggregate, which may be due to the strength drop with the recycled can be attributed to the remained mortar on the surface of the recycled aggregate, cracks in the aggregates itself (which could occur during the crushing). However addition of silica fume helps to improve the bonding properties in all mix combinations.
- It can be observed from Fig. 4.2 that concrete containing 25% RPA and 25 % RCA mix shows better result as control concrete.

4.3. Bond Strength Test

Bond strength test results of cube specimens for all mix proportion at 28days are presented in Table 4.2. The data is further represented in the form of Fig 4.4 - 4.6.

Table 4.2: Test results of pullout Bond strength of specimen at 28 days

S. no	Mix Type	Pullout load (KN)	Bond strength (MPa)	Average bond strength (MPa)	Percent Difference
1	Control concrete (N-100)	57.580	14.31	14.40	
		55.395	13.78		
		60.760	15.11		
2	NC-70-30	54.420	13.53	13.75	-4.51
		58.955	14.66		
		52.520	13.06		
3	NP-70-30	50.215	12.49	12.25	-14.93
		48.325	12.02		
		49.260	12.25		
4	NCP-50-30-20	55.010	13.68	13.45	-6.60
		48.645	12.10		
		58.590	14.57		
5	NCP-50-20-30	57.505	14.30	13.02	-9.58
		46.685	11.61		
		52.895	13.15		
6	NCP-50-25-25	57.425	14.28	14.18	-1.53
		62.570	15.56		
		51.070	12.70		
7	NS-100	64.140	15.95	15.79	9.65
		68.200	16.96		
		58.145	14.46		
8	NCS-70-30	61.785	15.36	14.56	1.11
		57.025	14.18		
		56.860	14.14		
9	NPS-70-30	62.130	15.45	14.52	0.83
		56.500	14.05		
		56.525	14.06		

10	NCPS-50-30-20	54.865	13.64	13.62	-5.42
		57.665	14.34		
		51.795	12.88		
11	NCPS-50-20-30	52.120	12.96	13.46	-6.52
		53.115	13.21		
		57.145	14.21		
12	NCPS-50-25-25	62.610	15.57	14.82	2.92
		56.740	14.11		
		59.435	14.78		

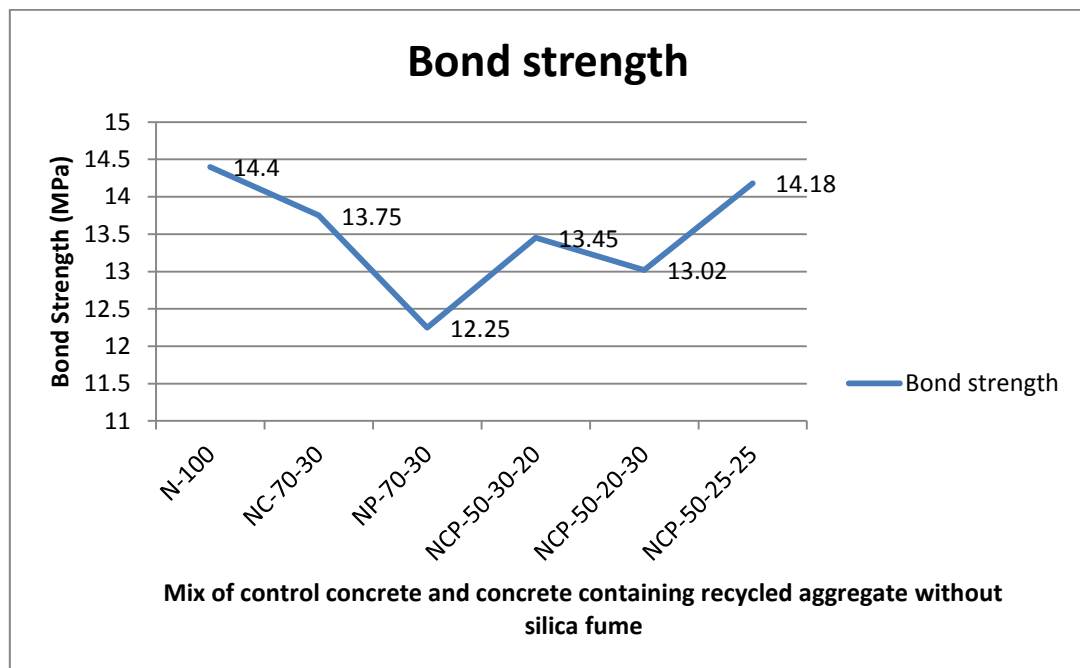


Fig 4.4: Average Bond strength value of control concrete and concrete containing recycled aggregates without silica fume.

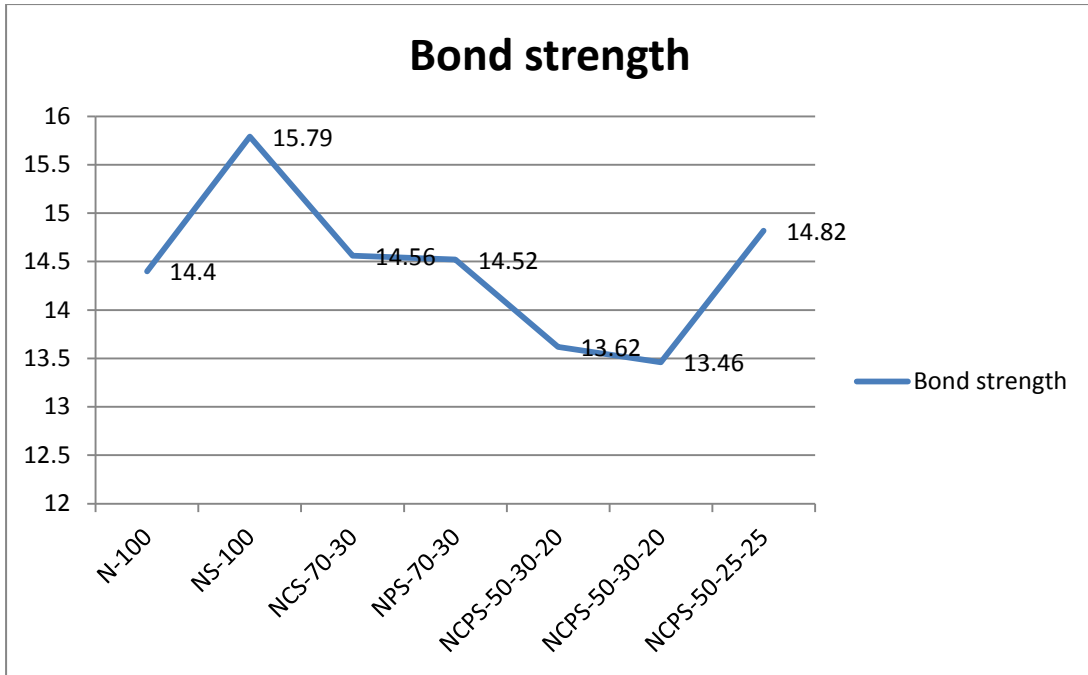


Fig 4.5: Average Bond strength values of control concrete and concrete containing recycled aggregates with silica fume.

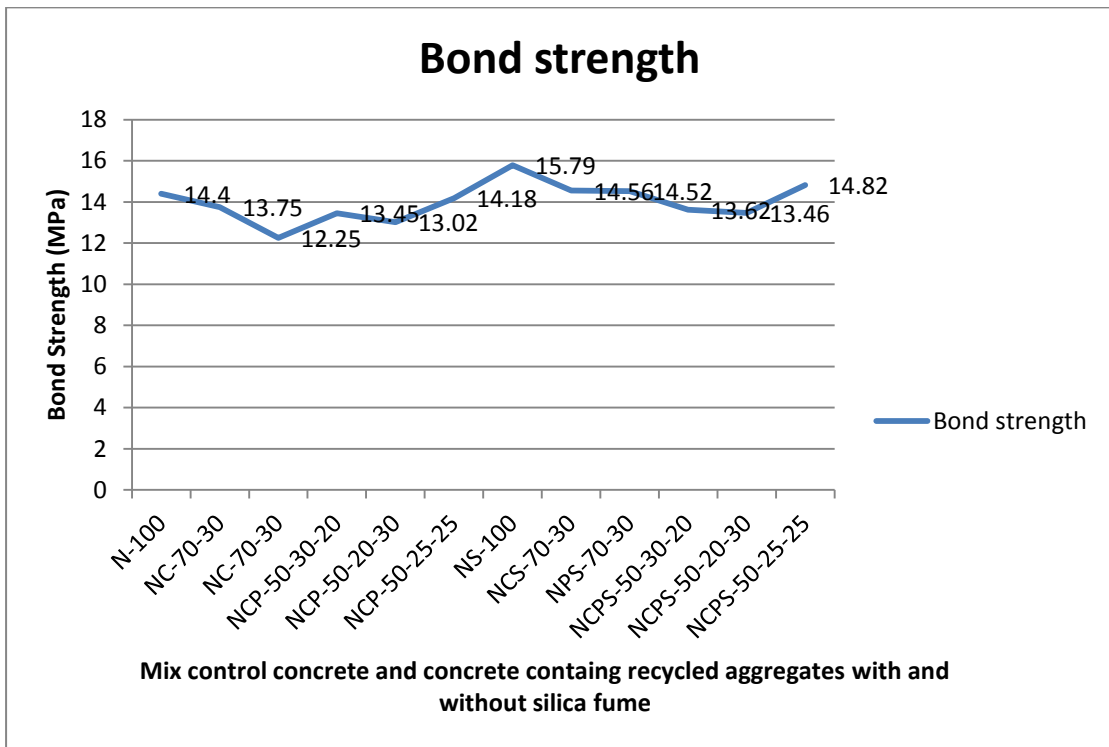


Fig 4.6: Bond strength values of mixture RCA and RPA concrete with and without silica fume.

Following observations can be made from Table 4.2 and Fig. 4.4-4.6

- For mix combinations without silica fume the bond strength decreases with addition of recycled aggregate, which may be due to the strength drop with the recycled can be attributed to the remained mortar on the surface of the recycled aggregate, cracks in the aggregates itself (which could occur during the crushing). However addition of silica fume helps to improve the bonding properties in all mix combinations.
- It can be observed from Fig. 4.5 that concrete containing 25% RPA and 25 % RCA mix shows better bond strength result as control concrete.

Table 4.3 presents simplified Eq. taken from literature (Table 3.6) used to predict the bond strength of all mix combinations

Table No.4.3 Bond strength equation from literature

Equation	Bond strength equation	Simplified Bond strength eq. used for present study	Eq. no
CEB-FIP MC90	$\tau_{max} = 2.0\sqrt{f_{ck}}$	$\tau_{max} = 2.0\sqrt{f_{ck}}$	Eq. (1)
ACI 408-03	$\tau_{max} = 20\sqrt{f_{ck} / d_b}$	$\tau_{max} = 1.25\sqrt{f_{ck}}$	Eq. (2)
Orangun 1977	$\tau_{max} = [0.2652 \times (1.2 + \frac{3C}{D} + \frac{50D}{L})]X\sqrt{f_{ck}}$	$\tau_{max} = 1.4\sqrt{f_{ck}}$	Eq. (3)
Mac Gregor 1997	$\tau_{max} = \left[0.59 \sqrt{f_{ck}} \left(\frac{C}{D} - 0.5 \right) \right]$	$\tau_{max} = 2.47\sqrt{f_{ck}}$	Eq. (4)
Kim et al 2008	$\tau_{max} = 0.614 \sqrt{f_{ck}} \left(\frac{C}{D} - 0.55 \right) - (0.4203e^{0.0172S} + 0.007G)$	$\tau_{max} = 2.54\sqrt{f_{ck}} - 0.4203 + 0.007G$	Eq. (5)

Table No.4.4 Results of bond strength assessment

Mix type	Compressive Strength (MPa)	Bond strength (MPa)	CEB-FIP MC90 (MPa)	ACI 408-03 (MPa)	Orangun (MPa)	Mac Gregor (MPa)
Control concrete (N-100)	34.17	14.40	11.69	7.31	8.18	14.44
NC-70-30	31.45	13.75	11.22	7.01	7.85	13.85
NP-70-30	27.88	12.25	10.56	6.6	7.39	13.04
NCP-50-30-20	30.97	13.45	11.13	6.95	7.79	13.74
NCP-50-20-30	29.44	13.02	10.85	6.78	7.60	13.40
NCP-50-25-25	33.14	14.18	11.51	7.20	8.06	14.22
NS-100	41.36	15.79	12.86	8.04	9.00	15.88
NCS-70-30	38.35	14.56	12.39	7.74	8.67	15.30
PNPS-70-30	37.74	14.52	12.29	7.68	8.60	15.17
NCPS-50-30-20	36.11	13.62	12.02	7.51	8.41	14.84
NCPS-50-20-30	33.78	13.46	11.62	7.26	8.13	14.35
NCPS-50-25-25	37.01	14.82	12.16	7.60	8.51	15.02

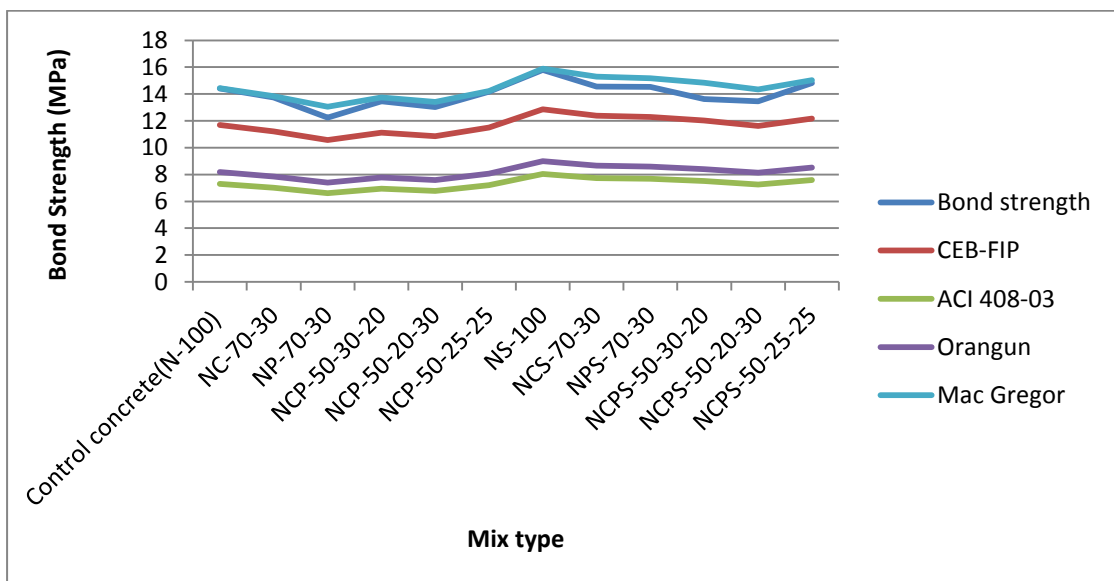


Fig 4.7. Comparison of bond strength perditions.

Experimental results shows that in a case of natural aggregate concrete, the bond strength prediction equation by Macgregor 1997 seems to be relatively accurate ie. The measured bond strength of control mix is almost same as predicted by eqⁿ (4) The prediction equation of natural aggregate concrete is thought to be inappropriate for recycled aggregate concrete. Therefore, Kim et al 2008 suggested new equation suitable to predict bond strength of recycled aggregates concrete . The modified equation also represented as Eq (5) is suitable to predict the bond strength of recycled aggregate concrete

$$\tau_{\max} = 0.614 \sqrt{f_{ck}} \left(\frac{C}{D} - 0.55 \right) - (0.4203e^{0.0172S} + 0.007G) \quad \text{Eq (5)}$$

where, τ_{\max} : maximum bond stress of aggregate concrete

f_{ck} : compressive strength of recycled aggregate concrete according to replacement ratio

C: distance from the deformed steel re-bar core to the concrete surface=75mm

D: diameter of deformed steel re-bar=16mm

L= embedded length of re bars=80mm

S: replacement ratio of recycled fine aggregate=0%

G: replacement ratio of recycled coarse aggregate

The simplified equation for present study becomes

$$\tau_{\max} = 2.54 \sqrt{f_{ck}} - 0.4203 + 0.007G$$

Table 4.5 present a comparison of bond strength by experiment, Prediction equation by MacGregor and Prediction equation by Kim et al 2008

Table 4.5: Comparison of measured and predicted bond strength

Mix type	Bond strength by test (MPa)	Prediction equation by MacGregor (MPa)	Suggested equation by Kim et al 2008 (MPa)
Control concrete(N-100)	14.40	14.44	14.43
NC-70-30	13.75	13.85	13.83
NP-70-30	12.25	13.04	12.99
NCP-50-30-20	13.45	13.74	13.72
NCP-50-20-30	13.02	13.40	13.36
NCP-50-25-25	14.18	14.22	14.20
NS-100	15.79	15.88	15.91
NCS-70-30	14.56	15.30	15.31
NPS-70-30	14.52	15.17	15.18
NCPS-50-30-20	13.62	14.84	14.85
NCPS-50-20-30	13.46	14.35	14.34
NCPS-50-25-25	14.82	15.02	15.03

Following observations can be made from Table 4.5

- From the comparison it is known that the suggested equation can predict the bond strength of recycled aggregate concrete (NC-70-30) with varying replacement ratio with in a very appropriate error level.
- Equation (5) represents the experiment correlation corresponding to RCA only i. e. same equation in the present form is unsuitable to predict the bond strength of concrete containing RPA within fair accuracy.
- Equation (5) can further be modified considering that recycled plastic aggregate replacement ratios and its consequent compressive strength reduction.

5.1 General

The reuse of recycled materials derived from construction and plastic waste is growing all over the world. One of the most environmentally responsible ways of meeting the challenges of sustainability in construction is the use of recycled aggregates and plastic aggregate in new construction. The main objective of the study is to investigate the effect of using recycled aggregates in lieu of natural aggregate on strength and bond strength of concrete. The observations from this study are as under.

- For mix combinations without silica fume the compressive strength decreases with addition of recycled aggregate, which may be due to the strength drop with the recycled can be attributed to the remained mortar on the surface of the recycled aggregate, cracks in the aggregates itself (which could occur during the crushing). However addition of silica fume helps to improve the bonding properties in all mix combinations.
- It can be observed that concrete containing 25% RPA and 25 % RCA mix shows better compressive strength result as control concrete.
- Bond strength of recycled aggregates concrete and rebar gets reduced depending on the rebar type and replacement level of recycled aggregates.
- For mix combinations without silica fume the bond strength decreases with addition of recycled aggregate, which may be due to the strength drop with the recycled can be attributed to the remained mortar on the surface of the recycled aggregate, cracks in the aggregates itself (which could occur during the crushing). However addition of silica fume helps to improve the bonding properties in all mix combinations.
- It can be observed from that concrete containing 25% RPA and 25 % RCA mix shows better bond strength result as control concrete.

Andreu G., Miren E. (2014). "Experimental analysis of properties of high performance recycled aggregate concrete." *Construction and Building Materials* Vol. 52 pp 227-235.

Ashraf Shalaby, Azza Ward, Abeer Refaee, Salwa Abd-El-Messieh, Kamal Abd-El-Nour, Doaa El-Nashar and Hamdia A. Zayed,(2013) "Compressive Strength and Electrical Properties of Cement Paste Utilizing Waste Polyethylene Terephthalate Bottles" *Journal of Applied Sciences Research*, 9(7): 4160-4173, 2013 ISSN 1819-544

Butler L., West J.S., Tighe S.L. (2013). "Effect of recycled concrete coarse aggregate from multiple sources on the hardened properties of concrete with equivalent compressive strength." *Construction and Building Materials* Vol. 47 pp 1292-1301

Choi H.B, Kang K.I,(2008). "Bond behaviour of deformed bars embedded in RAC", *Magazine of Concrete Research*, 2008, 60, No. 6, August, 399–410

Consorzio Cetma, "Lightweight aggregate for concrete from recycling of plastic waste" *Eco-innovation*

Corinaldesi V., Moriconi G. (2009). "Influence of mineral additions on the performance of 100% recycled aggregate concrete." *Construction and Building Materials* Vol. 23 pp 2869-2876.

Dilbas H., Simsek M., Cakir O. (2014). "An investigation on mechanical and physical properties of recycled aggregate concrete (RAC) with and without silica fume." *Construction and Building Materials* Vol. 61 pp 50-59

H. A. Toutanji,(1996) "The Use of Rubber Tire Particles in Concrete to Replace Mineral Aggregates" *Cement & Concrete Composkes* 18 (1996) 135-139

Hanif BINICI,(2013) "Effect of aggregate type on mortars without cement" *European Journal of Engineering and Technology* Vol. 1 No. 1, September 2013

IS: 10262-1982 (Reaffirmed 2004): Recommended guidelines for concrete mix design, Bureau of Indian Standard, New Delhi-2004.

IS: 15388-2003: Silica fume specification, Bureau of Indian Standard, New Delhi-2003.

IS: 2386 (Part I, III)-1963: Methods of Test for Aggregates for Concrete, Bureau of Indian Standard, New Delhi-1963.

IS: 383-1970: Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian Standard, New Delhi-1970.

IS: 516-1959 (Reaffirmed 2004): Methods of tests for strength of concrete, Bureau of Indian Standard, New Delhi-2004.

IS 2770 (Part I) (1967) (Reaffirmed 2002) "Methods of testing bond in reinforced concrete. Part I: Pull-out test". Bureau of Indian Standards, New Delhi, p 10.

IS:1489 (Part I) -1991 : Specification for Portland pozzolana Cement, Bureau of Indian Standard, New Delhi-2005

Ismail S., Ramli M. (2013). "Engineering properties of treated recycled concrete aggregate (RCA) for structural applications." Construction and Building Materials Vol. 44 pp 464-476

José Guilherme Colaço Alegre Saraiva Lima, (2012) "Fire behaviour of concrete produced with selected plastic waste aggregates" Técnico Lisboa

Kim et al (2008), "Bond characteristics of reinforced concrete by replacing ratio of recycled aggregate" ISBN 978-602-8605-08-3

K. Flaga (2000) "Advances in materials applied in civil engineering" Journal of Materials Processing Technology 106 (2000) 173-183

Kou S.C., Poon C.S., Agrela F. (2011). "Comparisons of natural and recycled aggregates concretes prepared with the addition of different mineral admixtures." Cement and Concrete Composites Vol. 33 pp 788-795.

Kou S.C., Poon C.S. (2013). "Long-term mechanical and durability properties of recycled aggregate concrete prepared with the incorporation of fly ash." Cement and Concrete Composites Vol. 37 pp 12-19.

- Kou S.C., Poon C.S., Wan H.W. (2012). "Properties of concrete prepared with low-grade recycled aggregates." *Construction and Building Materials* Vol. 36 pp 881-889
- Lakshmi R Nagan. S,(2010) "Studies on Concrete containing E plastic waste" *International journal of environmental sciences* Volume 1, No 3 ,2010
- Lima C., Caggiano A., Faella C., Martinelli E., Pepe M., Realfonzo R. (2013). "Physical properties and mechanical behaviour of concrete made with recycled aggregate and fly ash." *Construction and Building Materials* Vol. 47 pp 547-559.
- M. Elzafraney; P. Soroushian; and M. Deru (2005), "Development of Energy-Efficient Concrete Buildings Using Recycled Plastic aggregates" *Journal of architectural engineering* © ASCE
- Malek Batayneh *, Iqbal Marie, Ibrahim Asi,(2007) "Use of selected waste materials in concrete mixes" *Waste Management* 27 (2007) 1870–1876
- Nabajyoti Saikia, Jorge de Brito,2012 "Use of plastic waste as aggregate in cement mortar and concrete" *Construction and Building Materials* 34 (2012) 385–40
- Praveen Mathew¹, Shibi Varghese², Thomas Paul³, Eldho Varghese⁴ru,(1996) "Recycled Plastics as Coarse Aggregate for Structural Concrete", *International Journal of Innovative Research in Science, Engineering and Technology* Vol. 2, Issue 3, March 2013
- Poon C.S., Shui Z.H., Lam L., Fok H., Kou S.C. (2004). "Influence of moisture states of natural and recycled aggregates on the slump and compressive strength of concrete." *Cement and Concrete Research* Vol. 34 pp 31-36
- Raghatate Atul M.(2012), "Use of plastic in a concrete to improve its properties" *International Journal of Advanced Engineering Research and Studies*, ijaers/vol. I/ Issue III/April-June, 2012/109-111
- R. Lakshmi and S. Nagan,(2011) "Investigations on durability characteristics of e-plastic waste incorporated concrete" *Asian journal of civil engineering (building and housing)* vol. 12, no. 6 (2011) pages 773-787
- R. N. Nibudey, Dr. P. B. Nagarnaik, Dr. D. K. Parbat, Dr. A. M. Pande,(2013) "Strengths Prediction of Plastic fiber Reinforced concrete (M30)" *International Journal of Engineering Research and Applications (IJERA)* ISSN: 2248-9622 Vol. 3, Issue 1, January -February 2013, pp.1818-1825

.Radonjanin V., Malesev M., Marinkovic S., Al Maly A.E.S. (2013). “Green recycled aggregate concrete.” *Construction and Building Materials* Vol. 47 pp 1503-1511.

RILEM. (1994) “Specifications for concrete with recycled aggregates.” *Materials and Structures* Vol.27pp 557–559.

Suganthi, Dinesh Chandrasekar, Sathish Kumar. P. K,(2013)“utilization of pulverized plastic in cement concrete as fine aggregate” *International Journal of Research in Engineering and Technology*, Volume: 02 Issue: 06 | Jun-2013.

Tomas U. Ganiron Jr,(2014) “Effect of Thermoplastic as Fine Aggregate to Concrete Mixture” *International Journal of Advanced Science and Technology* Vol.62, (2014

Tarun R. Naik, Shiw S Singh, Calvin O. Huber, and Brian S Brodersen,(1996) “Use of post consumer waste plastic in cement-based composites” *Cement and Concrete Research*, Vol. 26, No. 10, Oct. 1996, pp. 1489-1492.)

T.R. Naik,* S.S. Singh,” C.O. Huber** and B.S. Brodersen (1996) , “Use of post consumer waste plastic in cement-based composites” *cement and concrete research*, vol 26 ,no. pp. -1492

Xiao Jianzhuang, Falkner H.,(2007). “Bond behaviour between recycled aggregate concrete and steel rebars”. *Construction and Building Materials* 21 (2007) 395–401.

.Yazoghli Marzouk Oumaya, Dheilily Rose-Marie, Laidoudi Boubker, Quéneudec* Michèle, “Valorisation of Plastic Waste: thermal Conductivity of Concrete Formulated with PET” *Laboratoire des Technologies Innovantes (EA 3899)*

Youcef Ghernouti, Bahia Rabehi, Brahim Safi and Rabah Chaid, “ use of recycled plastic bag waste in the concrete ” *Journal of International Scientific Publications: Materials, Methods and Technologies* Volume 8, ISSN 1314-7269 (Online).

Zaher K. Khatib ,Fouad M. Bayomy, (1999). “Rubberized portland cement concrete” , *Journal of materials in civil engineering*, J. Mater. Civ. Eng. 1999.11:206-21 s