Advances in Concrete Construction, *Vol. 4, No. 1 (2016) 027-035*
DOI: http://dx.doi.org/10.12989/acc.2016.4.1.027

Mechanical properties of recycled aggregate concrete produced with Portland Pozzolana Cement

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(Received April 18, 2016, Revised June 15, 2016, Accepted June 23, 2016)

Abstract. The quantity of construction and demolition waste has been greatly increasing recently. It causes many problems to the environment. For this reason, demolition waste management becomes inevitable in order to overcome the environmental issues. The present study aims to evaluate the effects of using recycled coarse aggregate, which is generated from construction and demolition waste, on the properties of recycled aggregate concrete. An experimental investigation on the strength characteristics of concrete made with recycled coarse aggregate is presented and discussed in this paper. In this study, Portland Pozzolana Cement (fly ash based) is used instead of ordinary Portland cement. The results of this investigation show the possibility of the use of recycled coarse aggregates in the production of fresh concrete. Use of demolition waste as coarse aggregate will lead to a cleaner environment with a significant reduction of the consumption of natural resources. A comparative study on the strength characteristics of recycled aggregate concrete made with Ordinary Portland Cement and Portland Pozzolana Cement is presented and discussed in this paper.

Keywords: recycled coarse aggregates; construction and demolition waste; Portland Pozzolana Cement; Concrete

1. Introduction

Construction and demolition (C & D) waste is defined as the solid waste generated by the construction, remodelling, renovation, repair, alteration or demolition of residential, commercial, government or institutional buildings, industrial, commercial facilities and infrastructures such as roads, bridges, dams, tunnels, railways and airports etc. C & D waste constitutes a major portion of total solid waste production in the world. It consists of different materials such as concrete, metal, wood, plastics, bricks etc. In addition, it includes the materials generated as a result of natural disasters. C & D waste can be classified into two components; major components includes cement concrete, bricks, cement plaster, steel from RCC, doors & windows, roofing support systems, rubble, stones, timber etc. and minor components includes conduits, GI pipes/Iron pipes/Plastic pipes, electrical fixtures, panels, glass etc.

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http://www.techno-press.org/?journal=acc&subpage=7 ISSN: 2234-0912 (Print), 2234-179X (Online)

The quantity of C & D wastes is increasing day by day due to the rapid growth in the construction industry. Suman *et al.*. (2015) stated that the main reasons for the increase of the volume of demolition concrete waste are:

• Many old buildings and other structures have overcome their limit of use and need to be demolished

• Structures that, even though adequate for use, are demolished due to new regulations with stricter requirements and necessities.

• Creation of building wastes which result from natural destructive phenomena (earthquakes, storms, tsunami etc).

• New construction for better economic growth

• Creation of building waste resulting from manmade disaster or war.

Since aggregate represents about 70-80 % of concrete components, the use of recycled aggregates in concrete opens a whole new range of possibilities in the reuse of materials in the construction industry. The utilization of recycled aggregates is a good solution to the problem of an excess of waste material, provided that the desired final product will fit the standards.

The 2010 European Aggregates Association (UEPG) Annual Review (2012) reported recycled aggregates generated approximately 5% of the production of aggregates in the European Union (EU). Based on the same report, Germany is the greatest producer of recycled aggregates, with a production of approximately 60 million tonnes. Tam (2009) stated that in Australia, more than 50% of the total concrete residue generated from C&D activities is recovered for recycling, while the rest goes to landfills. Dosho (2007) reported that Japan has reached approximately a 98% rate for processing concrete waste to recycled aggregates. Kou and Poon (2012) have investigated the effects of incorporating Class F fly ash in the concrete mix design to mitigate the lower quality of recycled aggregates in concrete. Silva *et al.*. (2014) have examined the main physical properties and composition of recycled aggregates for use in concrete and undertook a statistical analysis of data available in the literature. Saravanakumara P. and Dhinakaran G. (2013) studied the durability of recycled aggregate concrete in which aggregate from the demolished structure of 20 years age was used. Based on the results, they concluded that recycled aggregate concrete shows less resistance against chemical attack and concrete containing 50% recycled aggregate may exhibit reasonable strength. Attaullah Shah *et al.* (2013) concluded that recycled aggregate concrete has a greater water requirement than conventional concrete and that concrete specimens made with recycled concrete aggregates exhibit higher compressive strength than those made with crushed brick aggregates. Mukharjee and Barai (2015) studied compressive and tensile strength of concrete made with recycled coarse aggregates and different percentages of nano-silica. They concluded that incorporation of 3% nano-silica enhances mechanical properties of recycled aggregate concrete. Shaikh *et al.* (2015) investigated the effect of micro-silica contents of 5, 10 and 15 wt. % as partial replacement of cement on mechanical and durability properties of high volume fly ash – recycled aggregate concretes. They concluded that micro-silica improves the mechanical property of recycled aggregate concrete.

2. Objectives and scope

The objectives of the study are to investigate the strength characteristics of recycled aggregate concrete and determine the factors that influence the compressive and tensile strengths of concrete made with coarse aggregates obtained from crushed old concrete as partial or full replacement of

Table 1 Properties of OPC and PPC

Characteristics	OPC	PPC	Standard Values
Normal Consistency	29 %	31 %	-
Initial Setting Time	85 mins	55 mins	Not to be less than 30 mins
Final Setting Time	235 mins	170 mins	Not to be greater than 600 mins
Specific Gravity	3.05	2.828	-

natural coarse aggregates. The scope of the investigation covers different concrete mix designs, one that results in low strength with respect to control mix.

3. Experimental programme

The whole experimental programme is discussed in the following subsections. This study aims to an investigation on the possible influence of the usage of recycled coarse aggregates as coarse aggregates on the strength properties of Portland Pozzolana Cement (PPC) based concrete. For this purpose, the strength behaviour of five different concrete mixes made with recycled coarse aggregates as partial or full replacement of natural coarse aggregates and PPC has been studied.

3.1 Materials

The materials used in the present investigation are OPC, PPC, Natural Coarse Aggregates (NCA), Recycled Coarse Aggregates (RCA), Fine Aggregates (FA) and Water. The properties of these materials are discussed in the following sections.

3.2 Ordinary Portland Cement (OPC)

Ordinary Portland cement is the most commonly used cement for a wide range of applications in the construction industry. Ordinary Portland cement of grade-43 (Ultratech cement) conforming to Indian standard IS: 8112-1989 was used in the present study. The results of the various tests on cement properties are given in Table 1.

3.3 Portland Pozzolana Cement (PPC)

Portland Pozzolana Cement is Ordinary Portland Cement intimately blended or inter-ground with pozzolanic materials such as fly ash, calcined clay, rice husk ash etc. Portland Pozzolana cement-Fly Ash Based (ACC cement) conforming to Indian Standard IS: 1489-1991 (Part 1) was used. The results of the various tests on PPC properties are given in Table 1.

3.4 Natural Coarse Aggregate (NCA)

Locally available coarse aggregate with a maximum size of 20 mm was used in the present work. In order to determine the specific gravity of aggregates, saturated NCA and RCA with dry surface were taken for the test. The properties of natural coarse aggregate are presented in Table 2.

Table 2 Properties of Natural Coarse Aggregates and Recycled Coarse Aggregates

Characteristics	NCA	RCA
Type	Natural	Recycled
Specific Gravity	2.72	2.35
Water Absorption	0.1 %	2.60 %

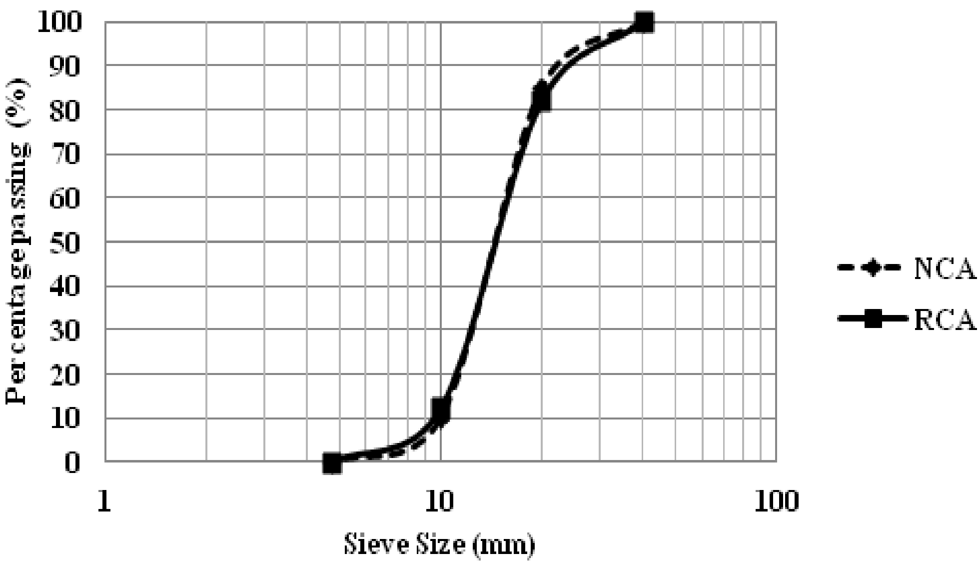

Fig. 1 Particle Size distribution curve of NCA and RCA

3.5 Recycled Coarse Aggregates (RCA)

Large quantity of tested concrete specimens e.g. cubes, cylinders, beams etc. was available in the concrete laboratory of Department of Civil Engineering and was used as the source of RCA. To make RCA, the specimens without reinforcement are first crushed by hydraulic machine and then manually using hammer broken down into small pieces. Water absorption capacity of recycled coarse aggregate is greater than that of natural coarse aggregates. The difference is due to cement paste adhered to aggregate and other types of impurities in recycled aggregates. The properties of recycled coarse aggregate are presented in Table 2. While making RCA concrete, the different sizes of RCA are mixed in a suitable proportion so that the particle size distribution curve (as shown in Fig. 1) of the RCA is similar to that of the natural coarse aggregate.

3.6 Fine aggregates

The aggregate material, which passes through 4.75 mm IS sieve and retained on 75 micron IS sieve, is termed as fine aggregate. The sand used for the experimental works is locally procured and conformed to grading zone II (IS: 383-1970). Table 3 represents the properties of fine aggregates.

Table 3 Properties of Fine Aggregates

Characteristics	Value
Type	Sand
Specific Gravity	2.61
Fineness Modulus	2.78
Grading Zone	II

3.7 Water

In the present investigation, tap water was used for both mixing and curing purposes. The pH value of the water, which is used for the present study, was of 8.3. According to IS 456: 2000, pH value of water should not be less than 6.

3.8 Concrete mixes

In this study, the mix proportions of the concrete of M30 grade were calculated according to IS

Table 4 Quantity of Materials per 1 m^3 OPC based concrete

Mix Name	W/C Ratio	Replace-ment of NCA (%)	Cement (kg)	FA (kg)	NCA (kg)	RCA (kg)	Water (kg)	Extra Water (kg)	Total W/C
$MOPC_0$		0	410	656.68	1165.25	0	186	0.932	0.45
$MOPC_{25}$		25	410	656.68	873.94	291.31	186	8.273	0.47
$MOPC_{50}$	0.45	50	410	656.68	582.625	582.625	186	15.650	0.49
$MOPC_{75}$		75	410	656.68	291.31	873.94	186	22.955	0.51
$MOPC_{100}$		100	410	656.68	0	1165.25	186	30.296	0.53

$MOPC_0$: Concrete mix with zero percentage of RCA (Control Mix); $MOPC_{25}$: Concrete mix with 25 percentage of RCA; $MOPC_{50}$: Concrete mix with 50 percentage of RCA; $MOPC_{75}$: Concrete mix with 75 percentage of RCA; $MOPC_{100}$: Concrete mix with 100 percentage of RCA; W/C: water-cement ratio;

Table 5 Quantity of Materials per 1 m^3 PPC based concrete

Mix Name	W/C Ratio	Replace-ment of NCA (%)	Cement (kg)	FA (kg)	NCA (kg)	RCA (kg)	Water (kg)	Extra Water (kg)	Total W/C
$MPPC_0$		0	410	646.05	1146.40	0	186	1.14	0.45
$MPPC_{25}$		25	410	646.05	859.80	286.60	186	8.31	0.47
$MPPC_{50}$	0.45	50	410	646.05	573.20	573.20	186	15.47	0.49
$MPPC_{75}$		75	410	646.05	286.60	859.80	186	22.63	0.51
$MPPC_{100}$		100	410	646.05	0	1146.40	186	29.80	0.53

$MPPC_0$: Concrete mix with zero percentage of RCA; $MPPC_{25}$: Concrete mix with 25 percentage of RCA; $MPPC_{50:}$ Concrete mix with 50 percentage of RCA; $MPPC_{75}$: Concrete mix with 75 percentage of RCA; $MPPC_{100}$: Concrete mix with 100 percentage of RCA; W/C: water-cement ratio;

code 10262:2009. Concrete mixes have been designed by keeping the w/c ratio constant. In this,mixture proportions for the natural coarse aggregate concrete and the recycled aggregate concretes are nominally kept the same, except for replacement of NCA with RCA, depending upon the desired replacement percentage. Extra quantity of water was added to take care of the water absorption properties of NCA and RCA. The quantity of the different materials, required for one m^3 OPC based concrete and PPC based concrete is presented in Table 4 and Table 5, respectively.

3.9 Tests on concrete mixes

First NCA and RCA are added in the mixer, subsequently, fine aggregates and cement are added to the mixer the ingredients are dry mixed in the mixer for two minutes. Then water is added and again mixed for two to five minutes. The mixture was then poured in the moulds. 150 mm × 150 mm × 150 mm cubes were casted to study the compressive strength, Cylinders having dimension 150 mm (diameter) × 300 mm (height) were casted to study the splitting tensile strength and prismatic specimens, having dimension 100 mm × 100 mm × 500 mm were casted to study the flexural strength of various mixes. After careful demoulding, the specimens i.e. cubes, cylinders and prisms were kept in water chamber, which is filled with normal tap water at the room temperature in the laboratory. Casted samples were tested after moist curing of 7 days and 28 days. According to the guidelines of IS: 516-1959, cubes are tested for compressive strength, cylinders are tested to find out splitting tensile strength and prisms are tested to find out flexural strength of concrete.

4. Results and discussions

The results of experimental tests, which have been mentioned in the previous sections, are discussed in the followings. Effects of RCA and Portland Pozzolana Cement in the concrete mixes are also discussed. The concrete mix with zero percentage RCA is considered as control mix.

4.1 Compressive strength

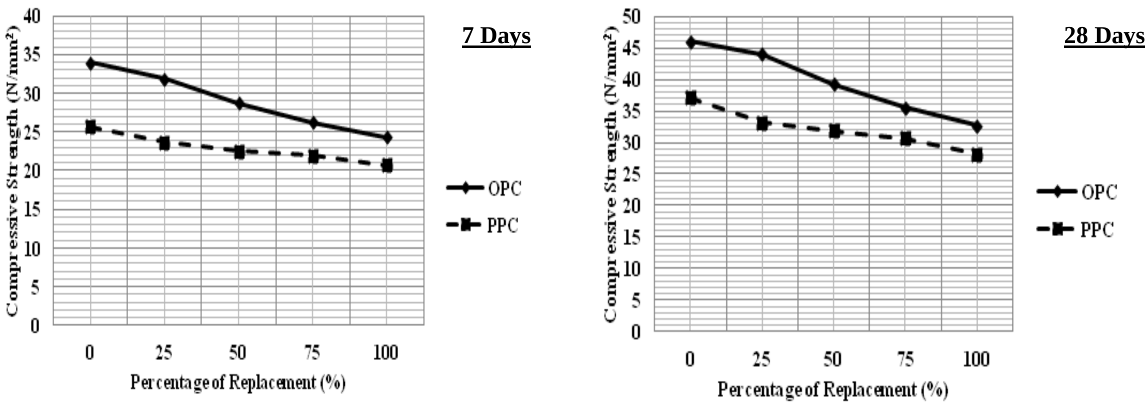

Fig. 2 Profile of compressive strength of concrete at 7 days and 28 days

Compressive strength decreased with the increment of the replacement percentage of natural coarse aggregate with RCA. To take care of high water absorption of RCA and to produce recycled aggregate concrete with the same consistence as that of the control concrete, extra water was added. This additional quantity of water is one of the reasons why the compressive strength decreased. The other one is the relatively weaker adhered mortar of RCA, which will fail first when loaded. Fig. 2 shows the profile of the loss of compressive strength with the increase of the percentage of replacement of NCA by RCA.

4.2 Flexural strength

Experimental results show that the flexural strength of the prismatic specimens for 7 days and 28 days both decreased with the increment of the replacement percentage of natural coarse aggregate with recycled coarse aggregates. The reason behind the decrease of flexural strength may be high water absorption properties of RCA and also of their relatively weaker adhered mortar in comparison to the new cement paste. The loss of flexural strength of prismatic specimens tested at 7 and 28 days is shown in Fig. 3.

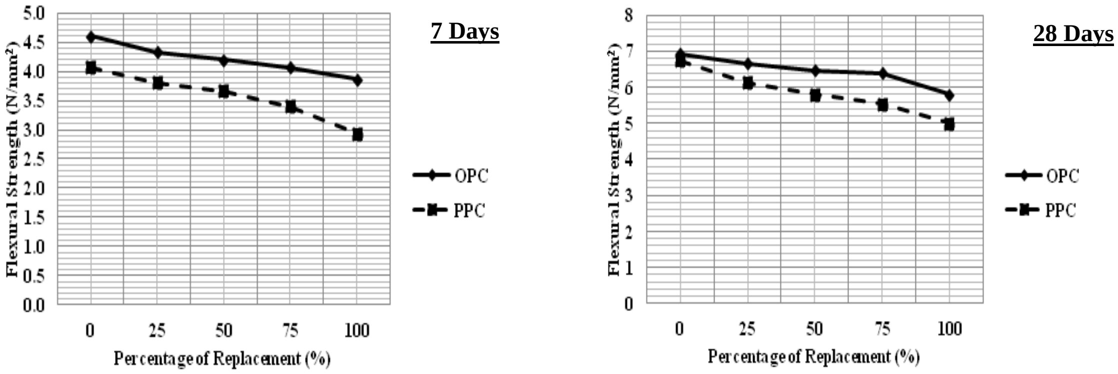

Fig. 3 Flexural strength of concrete after 7 days and 28 days

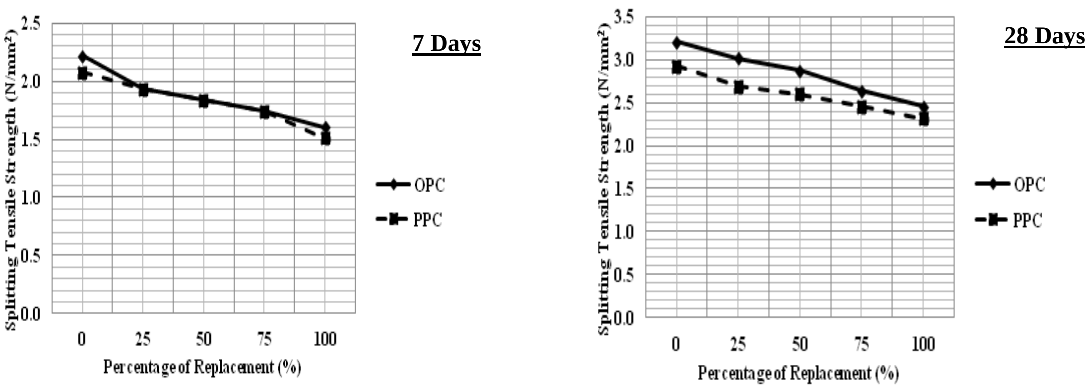

Fig. 4 Splitting tensile strength of concrete after 7 days and 28 days

4.3 Splitting tensile strength

It has been observed that the splitting tensile strength of the cylinder specimens for 7 days and 28 days both decreased with the increment of the replacement percentage of natural coarse aggregate with recycled coarse aggregates. Either the additional quantity of water or the relatively weaker adhered mortar of RCA, which will fail first when loaded, may be the key reasons for the decrement of splitting tensile strength. Fig. 4 represents the loss of splitting tensile strength at 7 days and 28 days in the form of graphs.

5. Conclusions

In this paper, experimental results for the strength properties of recycled aggregate concrete using PPC are presented and discussed. Environmental benefits may be able to compensate to some extent the negative effect of incorporating recycled coarse aggregate concrete and thereby leading us significantly closer toward green infrastructure. The combined use of PPC with RCA translates not only in the production of concrete with a much lower carbon footprint but is also more economical when compared to a conventional concrete. From this investigation, the following conclusions can be drawn:

• Water absorption capacity of recycled coarse aggregates is greater than that of natural coarse aggregates, which may make it difficult to achieve the necessary workability levels. In this study, it was observed that water absorption capacity of recycled aggregates is 2.60 % whereas water absorption capacity of natural coarse aggregates is almost zero. Attaullah Shah *et al.* (2013) also mentioned about high water requirements for the recycled aggregate concrete in their study.

• Experimental results showed significant loss of compressive strength, flexural strength and splitting tensile strength of concrete when the replacement percentage level of NCA increases for the both type of mixes. When NCA is fully replaced, after 28 days, 24 % loss of compressive strength, 26 % flexural strength and 21 % splitting tensile strength were observed for PPC based recycled aggregate concrete. Most of the researches on recycled aggregate concrete found similar results.

• Even though loss of strength is there, experimental results show that up to 25 % replacement of natural coarse aggregate by recycled coarse aggregate is acceptable for the production of the concrete.

• High water absorption capacity, adhered mortar of RCA, etc. may be the reasons behind the reduction of strength. Additional water was added to each mixes in this study due to high water absorption of RCA. As water-compensated, the recycled aggregates will not absorb the mixing water but may bleed and increase the local w/c ratio. The other main factor is the lower strength of the adhered mortar when compared to that of the original natural aggregate. Because of this, the final strength of the material decreased with increasing replacement ratio.

Acknowledgements

The authors would like to thank Department of Civil Engineering of National Institute of Technology Karnataka, Surathkal for the support to do this research.

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