International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 02 - Issue 11 || November 2017 || PP. 14-19

Study of Partial Replacement of Natural Aggregate by Recycled Aggregate on Concrete

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Abstract: In this industrialized world, the amount of Construction and Demolition Waste (CD&W) generated worldwide seems to be huge. Recycling of these Construction and Demolition Waste Aggregate (Recycled Aggregate) can play a vital role in economical as well as natural resources too. A study has been made on the properties of recycled aggregate which is to be used as coarse aggregate. The percentage of recycled aggregate that partially replaced natural aggregate by weight was 0%, 30%, and 100%. Concrete cubes and cylinders were casted and tested in laboratories. Properties of aggregate and comparison of recycled aggregate concrete against natural aggregate concrete is performed according to requirements as such for its workability, compressive strength test and also tensile strength test. The results show that up to 30% replacements of natural aggregate with recycled aggregate have the same strength as conventional concrete. Beyond 30% replacements of natural aggregate is not suggested as Specific Gravity, water Absorption and Impact value have almost surpass the permissible limit.

Keywords: Recycled Aggregate (RA), Recycled Aggregate Concrete (RAC), Natural Aggregate Concrete (NAC)

1. Introduction

According to the type of coarse aggregate used and the amount of aggregate percentage on RAC, the strength of concrete differs. So, it is necessary to study the aggregate properties of Recycled Aggregate since Coarse Aggregate is the main component of concrete and there is a need to re-use for many reasons instead of disposal in landfills. RCA plays a vital role in sustainable development in the protection programme of natural resources and decreases disposal of demolition waste from used concrete. Recycled aggregate concrete properties are studied and different comparisons are carried out. To work out the full advantages, it should undergo different test and even their mechanical and physical properties should be studied.

Concrete is a composite material, basically consisting of different constituents such as binding materials, water, aggregate and admixtures. Among these ingredients, aggregate plays a very crucial role in concrete which occupy the largest volume of about 60–75% of total concrete volume. The versatility of concrete as construction material for large construction work lies in its high strength, low maintenance cost, resistant to weathering effect, economical and excellent structural performance over other construction materials [1]. Moreover, the extensive increase in the rate of industrialization and urbanization due to the parallel growth in economy and population has made the use of concrete as the most non-sustainable material as it is consuming the maximum amount of natural resources. Concrete has a very important role in the economy development of a country due to its large volume utilization. It uses approximately 20 billion tons of raw materials (coarse aggregate) each year. With this increase in rate of consumption, it is expected that the demand of aggregate will be doubled in the next two to three decades [2].

Thus, the concrete industry consumes a large amount of natural resources that cause substantial environmental, energy and economic losses. So, In order to minimise the environmental impact, energy consumption and the decrease in CO_2 release in the production of concrete, RAC have become more evident for construction industry which can lead towards sustainable development.

1.1 Recycled Aggregate

Recycled aggregate are produced from aged concrete that has been demolished and removed from foundations, pavements, bridges or buildings. It has been crushed and processed into various size fractions. Recycled Aggregate are extracted through the processing of the debris generated from the demolition of concrete structures and other construction debris such as waste concrete, rejected precast concrete members, broken masonry, concrete road beds and asphalt pavement, leftover concrete from ready mix concrete plant and waste generated from different laboratories. Aggregate typically processed by the crushing of parent or old concrete such as demolished waste concrete is regarded as recycled concrete aggregate (RCA). Generally RCAs are mixed with bricks and metals. Earlier, it had been used as unbound sub-base materials for pavement. Now-a-days it is also being used for construction purposes [3].

1.2 Recycled Aggregate Concrete

Concrete made up of RA in terms of fine or coarse processed from C&D waste either as a partial or 100% replacement of conventional natural aggregate is known as Recycled Aggregate Concrete (RAC). RAC mainly consists of three phases such as the aggregate phase, mortar phase (i.e. the interfacial transition zones between the coarse aggregate and the matrix) and the adhered mortar as another matrix. These three phases are responsible for limiting the properties of RAC. So it needs more attention regarding the performance of concrete when RA is to be used in concrete. In practice, RA is obtained from different types of demolished construction structure. The properties of RA obtained from various sources also vary from structure to structure. Since the early 1980s, European countries have endeavoured to use RAs for new concrete structures. A diversified study on RAC demonstrates the feasibility of the use of RA in concrete and it can be an alternative source to natural aggregate [4].

2. Literature Review

Akash Rao, Kumar N. Jha, and Sudhir Misra (2007) [5]. conclude that use of recycled aggregate in concrete provides a promising solution to the problem of C&D waste management. Construction and Demolition (C&D) waste constitutes a major portion of total solid waste production in the world, and most of it is used in landfills. Research by concrete engineers has clearly suggested the possibility of appropriately treating and reusing such waste as aggregate in new concrete, especially in lower level applications.

It is clear that RAC can be used in lower end applications of concrete based on a survey of production, utilization of RA in RAC and the properties of RA & RAC. With tailor made pilot studies, RA can be used for making normal structural concrete with the addition of fly ash, condensed silica fume, etc.

Sudhir P.Patil, Ganesh S.Ingle, and Prashant D.Sathe (2013) [6] had a study on recycled coarse aggregate and aims to evaluate physical properties of concrete using recycled coarse aggregate. Research concrete waste has been collected from demolished structure (Near Kamla Nehru Park, Bhandarkar Rd, Pune) and coarse aggregate of different percentage is used for preparing fresh concrete. Many researchers stated that recycled aggregate are only suitable for non-structural concrete application. This research; however, shows that the recycled aggregate that are obtained from concrete specimen make good quality concrete. The compressive strength of concrete containing 50% RCA has strength in close proximity to that of normal concrete. Tensile splitting test shows that concrete has good tensile strength when replace up to 25-50%.The strength of concrete is high during initial stages but gradually reduces during later stage. Water absorption of RCA is higher than natural aggregate. At the end, it can be said that the RCA up to 50 % can be used for obtaining good quality concrete.

3. Materials and Methodology

Laboratory investigations carried out on the physical properties of various materials used throughout the experimental work such as cement, fine aggregate, natural coarse aggregate, and recycled aggregate.

3.1 Tests on Cement

For the present work, Ordinary Portland Cement of 53 grade conforming to IS: 12269-1987 has been used.

The physical properties of the cement obtained on conducting appropriate tests as per IS: 269/4831 and the requirements as per IS 12269-1987 are given below:

Table 3.1 Summary of test results on M-53 grade cement

SI.No	Properties	Values obtained	Requirements as per IS:12269-1987
1	Fineness	4%	Not more than 10%
2	Initial Setting Time	80mins	Not less than 30 min
	Final Setting Time	180mins	Not more than 600 min
3	Standard consistency	31%	----
4	Specific gravity	3.15	

3.2 Tests on Fine Aggregate

Locally available clean river sand passing through 4.75 mm sieve is used and are classified as per the specifications of IS 383-1970.

Table 3.2 Summary of test results on Fine Aggregate

SI. No	Properties	Values obtained
1	Specific gravity	2.60
2	Water absorption	2%
3	Fineness Modulus	3.58(ZONE II)

3.3 Tests on Natural Course Aggregate and Recycled Aggregate

The coarse aggregate used is crushed (angular) aggregate conforming to IS 383: 1970. The coarse aggregate used is 20 mm downsize.

The recycled aggregate used in this work are collected from the demolished building around Madambakam area. Debris concrete were taken in one place and were crushed with a hammer and broken into pieces like natural aggregate even though matrix of concrete cannot be completely removed. After crushed into pieces, all the recycled aggregate were sieved in 20 mm sieve and those passing through 20 mm sieved were used in this experimental work. Tests conducted on various properties of the coarse aggregate used are given table 3.3

Table 3.3 Tests result comparison on Natural Coarse Aggregate and Recycled Aggregate

SI. No	**Properties**	**Natural Coarse Aggregate**	**Recycled Aggregate**
1	Specific gravity	2.67	2.26
2	Water absorption	1	2.13
3	Aggregate Impact test	28.21%	34.26%
4	Aggregate abrasion values	15.58	26.35%

Table 3.4 Mix proportion per m^3 of concrete

Water	**Cement**	**Fine Aggregate**	**Coarse Aggregate**
186 litres	465 kg/m^3	622.44 kg	1127.84 kg
0.4	1	1.33	2.42

Therefore, mix proportion adopted is **1:1.33:2.42**

3.4 Casting

Concrete cubes were prepared for Compressive Strength Test and cylinder for Split Tensile Strength Test. Three cubes and cylinder each for the concrete age of 7 days, 14 days and 28 days were prepared and put them for curing.

The test is carried out for three numbers each of cubes and cylinders for one particular type of each of Natural aggregate concrete, 30% and 100% replacement of natural aggregate with recycled aggregate.
Three cubes and cylinder of samples each were prepared with

(1) Pure Natural Aggregate,
(2) Mixture of 30% Recycled Aggregate and 70% of Natural Aggregate.
(3) Replacement of Natural Aggregate fully (100%) with Recycled Aggregate.

The grade of concrete used is M30 grade of concrete.

Table 3.5 Tabular representation of specimen casted

Specimen Type	**7days**		**14days**		**28 days**	
	Cube	**Cylinder**	**Cube**	**Cylinder**	**Cube**	**Cylinder**
Natural Aggregate Concrete	3	3	3	3	3	3

30% replacement of natural aggregate with recycled aggregate	3	3	3	3	3	3
100% replacement of natural aggregate with recycled aggregate	3	3	3	3	3	3

No. of cubes casted = 27
No. of cylinder casted = 27
Total number of specimen casted = 54
In this study, 145 kg of Cement, 202 kg of Fine aggregate and 342 kg of Coarse Aggregate approximately were used.

Table 3.6 Comparison of Workability of different Concrete

Specimen type	**Slump value (mm)**	**Vee-bee in seconds**	**Compacting factor**
Natural Aggregate Concrete	40	5	0.94
30% replacement of natural aggregate with recycled aggregate	25	6	0.92
100% replacement of natural aggregate with recycled aggregate	No slump	11	0.85

Table 3.7 Average compressive strength of all specimens

Specimen type	**Compressive strength (N/mm^2)**		
	7 days	**14 days**	**28 days**
Natural Aggregate Concrete	22.524	29.79	36.624
30% replacement of natural aggregate with recycled aggregate	19.910	28.776	37.786
100% replacement of natural aggregate with recycled aggregate	17.64	24.416	30.229

Table 3.8 Average Split Tensile Strength of all specimens

Specimen type	**Split tensile strength (N/mm^2)**		
	7 days	**14 days**	**28 days**
Natural Aggregate Concrete	1.716	2.015	2.201
30% replacement of natural aggregate with recycled aggregate	1.74	2.018	2.110
100% replacement of natural aggregate with recycled aggregate	1.573	1.758	1.739

4. Result and Discussions

4.1 Particle Size Distribution

Sieve analysis is carried out as per IS-2386 for crushed recycled concrete aggregate and natural aggregate. It is found that recycled coarse aggregate are reduced to various sizes during the process of crushing and sieving, which gives the best particle size distribution.

The particle shape analysis of recycled aggregate indicates similar particle shape of natural aggregate obtained from crushed rock. The recycled aggregate generally meets all the standard requirements of aggregate used in concrete.

4.2 Specific Gravity

The specific gravity in saturated surface dry condition of recycled concrete aggregate was found at 2.26 which is less but satisfying the results. If specific gravity is less than 2, it may cause segregation; honeycombing & also yield of concrete may get reduced.

4.3 Water Absorption

The RAC from demolished concrete consist of crushed stone aggregate with old mortar adhering to it, the water absorption is 2.13 which is relatively higher than that of the natural aggregate. Thus the water absorption results are satisfactory.

4.4 Crushing and Impact Values

The recycled aggregate is relatively weaker than the natural aggregate against different mechanical actions. As per IS 2386 part (IV), the crushing and impact values for concrete wearing surfaces should not exceed 30% & for other than wearing surfaces 45% respectively. The impact values of recycled aggregate which is little bit higher, but can be considered. From abrasion & impact test, it is found that use of recycled aggregate is possible to apply on the building as well as the road.

4.5 Compressive test on cubes

The average compressive strengths of cubes are determined as per IS 516 using RAC and natural aggregate at the age 7, 14 & 28 days. As expected, the compressive strength of RAC is slightly lower than the conventional concrete made from similar mix proportions. The reduction in strength of RAC found at age of 3 days and 14 days except at the age of 28 days. The amount of reduction in strength depends on parameters such as grade of demolished concrete, replacement ratio, w/c ratio, processing of recycled aggregate etc. As per test results, the strength of recycled aggregate cube is slightly higher than NAC, so RAC can be used for construction purpose.

4.6 Split Tensile Strength on cylinders

The average split tensile strengths of cylinders are determined using RAC and natural aggregate at the age 7, 14 & 28 days. As expected, split tensile strengths of RAC is slightly lower than the conventional concrete made from similar mix proportions (M-30).

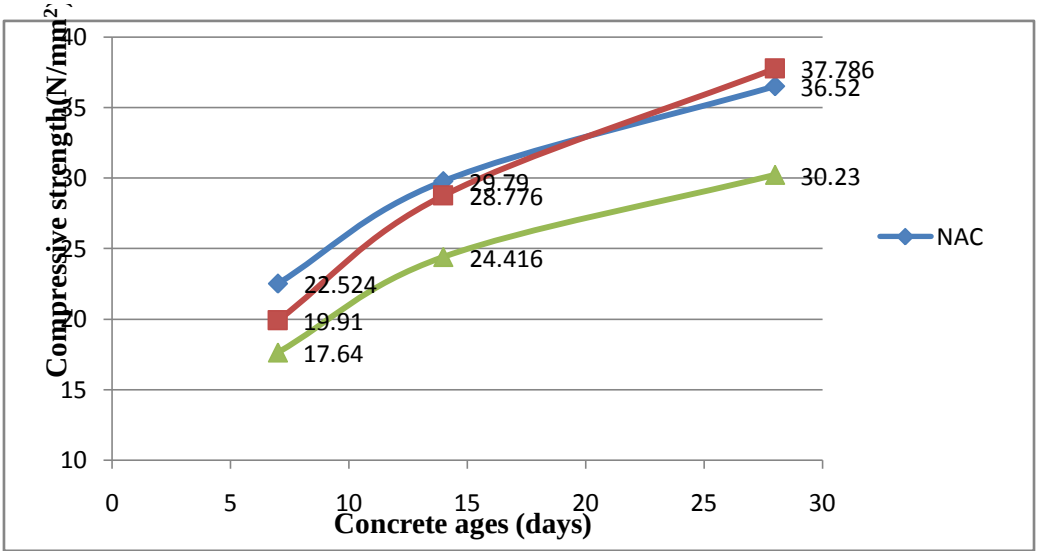

Figure 4.1: Graphical representation of Cube Compressive Strength of Natural Aggregate Concrete (NAC), 30% replacement and 100% replacement

Figure 4.1 has shown that that the compressive strength of conventional concrete(NAC) and 30 % replacement of natural aggregate were in close proximity while 100% replacement has a low compressive strength.

It is also observed that Recycled Aggregate Concrete (RAC) has lower compressive strength at early stages but gains more strength at later stages compare to Conventional concrete.

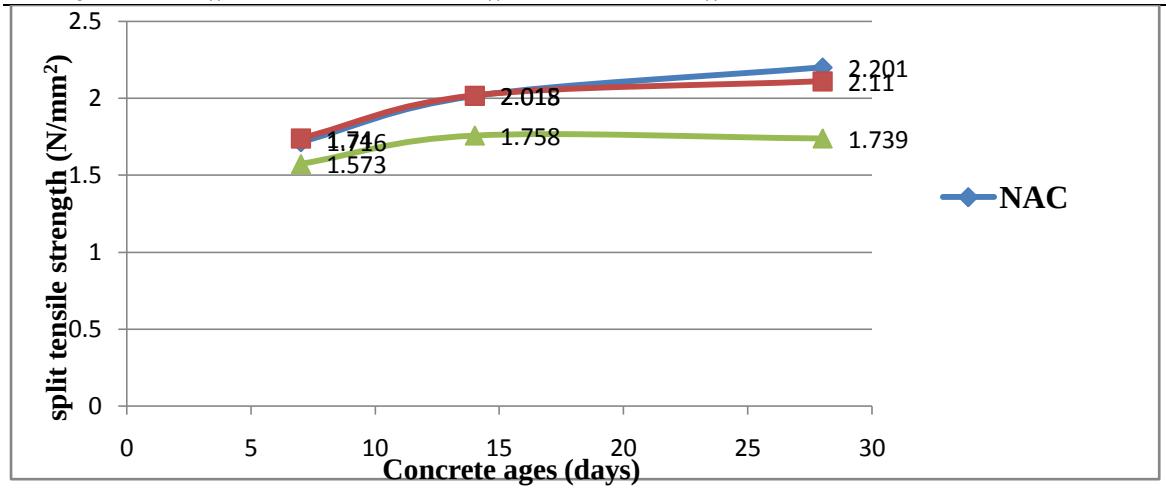

Figure 4.2: Comparison of Split tensile strength of Natural Aggregate Concrete (NAC), 30% replacement and 100% replacement

Figure 4.2 has shown that the split tensile strength of conventional concrete (NAC) and 30 % replacement of natural aggregate with recycled aggregate were in close proximity while 100% replacement has a very low split tensile strength with a slightly decrease of strength at later stages.

It is also observed that Recycled Aggregate Concrete (RAC) has higher Split tensile strength at early stages but gains strength at a lower rate during later stages.

Conclusion

Based on the results of experimental investigation done the following points can be concluded:

(1) Use of Recycled Aggregate as a replacement of Natural Coarse Aggregate provides environmental friendly and a promising solution to the problem of Construction and Demolition waste management.

(2) Under the same mix proportions (M-30), the percentage of recycled aggregate that partially replaced natural aggregate by 30% share same strength value with natural coarse aggregate. Up to 30% replacement, the same strength as conventional concrete is achieved. Beyond 30% replacements of natural aggregate is not suggested as Specific Gravity, water Absorption and Impact value have almost surpass the permissible limit.

(3) The amount of reduction in workability increases with further replacement of natural aggregate by recycled aggregate increases.

(4) 100 % replacement of natural aggregate with recycled aggregate is not suggested as it has low workability, Compressive strength and Split tensile strength of concrete.

Seeing future aspects from the study, we had seen that at the time of scarcity of aggregate, recycling aggregate will the best option which is environmental friendly as well as a sustainable mode of conservation of natural resources.

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