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New Investigation of Recycle Concrete Aggregate

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Summary

By means of the increase in the adoption of recycled aggregate for construction, study on ways to get better its quality has been wide spread. The major factor that affects the excellence of second hand aggregate is the large amount of cement mortar that remains on the surface of the recycled aggregate. This attached mortar results in higher porosity, higher water absorption rates, and thus a weaker interfacial zone between new cement mortar and aggregates, weakening the strength and mechanical performance of concrete made from recycled aggregate. This manuscript attempts to compare the effect of chemical as well as mechanical treatment approaches in reducing the mortar attached to aggregate. Six series of concrete mixtures are prepared using ordinary aggregate, recycled aggregate, recycled aggregate treated with HCl and H_2SO_4, recycled aggregate obtained after scrubbing treatment, and heating and scrubbing treatment. The physical and mechanical properties of these aggregates, and their strength and performance of recycled aggregate concrete are determined. The outcome show that treatment with H_2SO_4, and heating and scrubbing yield, aggregate with reduced water absorption and other preferred properties of natural aggregate. The concrete made out of these treated aggregates are able to achieve strength and performance characteristics on par with natural aggregate.

Keywords: *recycled aggregate for construction, cement mortar, chemical as well as mechanical treatment, HCl and H_2SO_4 and scrubbing treatment.*

Introduction

Concrete is the world's second most consumed material after water, and its widespread use is the basis for urban development. It is estimated that 25 billion tones of concrete are manufactured each year. Twice as much concrete is used in construction around the world when compared to the total of all other building materials combined. To be specific, According to an investigation conducted in 2002 by the Ministry of Land, Infrastructure and Transport (here in after referred to as MLIT), the amount of construction waste produced in average country is approximately 83 million tons per year, most of which is recycled in compliance with related laws and ordinances. Of the total construction waste, concrete waste accounts for approximately 35 million tons per year. Although the recycling rate of concrete waste has reached 98%, most of it is used for road bed gravel.

Figure 1 shows the breakdown and amount of construction waste that will be produced when these 5,800buildings are demolished. The total predicted amount of construction waste is about 7.8 million tons of which 7.6 million is concrete waste. If the total amount of construction waste is treated through dumping in public or private disposal facilities, the amount of CO2 emissions is predicted to be about 0.67 million tons. Moreover, thermal power plants, particularly those built in the 1970s, will be replaced by a new type of thermal power plant in the near future and a huge amount of concrete waste will be produced within a short-term construction period.

In view of this situation, establishing an effective recycling method for concrete waste is highly anticipated.

This situation leads to a question about the preservation of natural aggregates sources; many European countries have placed taxes on the use of virgin aggregates. A possible solution to these problems is to recycle demolished concrete and produce an alternative aggregate for structural concrete in this way.

Also Sustainability in the Concrete Industry is essential considering its carbon footprint, a full Life Cycle Assessment of the concrete structure, including the recycling phase at the end of its life, is required to assess the overall sustainable credentials of the structure. It is useful to place concrete in the context of the environmental impact.

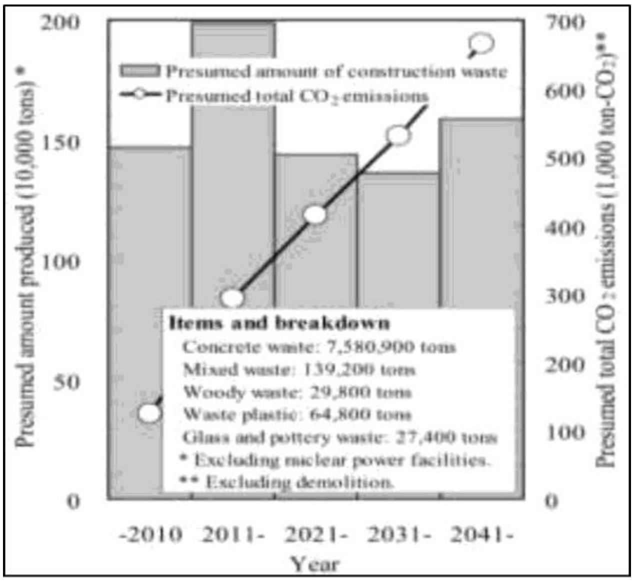

Fig. 1: supposed quantity of construction waste and CO_2 emissions

Strength of concrete is affected by the type of coarse aggregated used. It is necessary to know the characteristics of RCA and the effects of using RCA in concrete. There are limited reliable data on the use of RCA in concrete and thus, more researches on the utilization of RCA should be carried out. In this research, the main concern is the testing of RCA and the resulting concrete made by it.RCA is the main component of old concrete and for many reasons there is a need to re-use them. Such recycling operation adds benefit of reducing landfill disposal, while conserving primary resources and reducing transport costs. There are large amount of concrete wastages during construction and demolition stages. RCA can be obtained from these wastages for the production of new concrete.

Recycled coarse aggregate can also be widely used as sub base in road project and also for making lean concrete. Research works are in progress to establish it to be fit for structural concrete. Successful use of recycled aggregates in regular concrete works would lead to a considerable reduction in demand of natural aggregates. Recycled aggregate may be considered as a green material to some extent. It is quite well known that the porosity of recycled aggregate concrete is more than conventional natural aggregate concrete. Concrete, unless carefully managed and controlled, is likely to have a negative influence on most concrete properties, compressive strength, modulus of elasticity, shrinkage and creep, particularly for higher strength concrete.

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Also the use of fine recycled aggregate below 2 mm is uncommon in recycled aggregate concrete because of the high water demand of the fine material smaller than 150 mm which lowers the strength and increases the concrete shrinkage significantly. Many overseas guidelines or specifications limit the percentage replacement of natural aggregate The use of crushed aggregate from either demolition concrete or from hardened leftover concrete can be regarded as an alternative coarse aggregate, typically blended with natural coarse aggregate for use in new concrete. The use of 100% recycled coarse aggregate in.

Methodology

Materials

The entire experimental study was conducted at the concrete laboratory of Pondicherry Engineering College, Pondicherry, India. Ordinary Portland cement of 43 grade conforming to IS 8112-1989 (IS 1989) was used throughout the present work. As the present study aims to predict the effect of the treatment method on the performance of RAC, only conventional fine aggregate (locally available river sand) is used as fine aggregate. The physical properties of river sand determined as per IS 2386 (Part III)-1963 (IS1963) are presented in Table 1. Both NA and RA were used as the coarse aggregate in the concrete mixtures. Crushed granite obtained from the local quarry was used as NA. The tested/crushed concrete specimen waste available in the laboratory is used as the source of RA. These concrete chunks were crushed manually and subsequently crushed with a lab model jaw crusher and sieved. The aggregate passing in 20 mm sieve a retained on 4.75 mm sieve is used. Though there is no authentic information available to support that the virgin aggregates in NA and RA are from the same quarry, it is highly probable as there is only one quarry situated in the near vicinity of the study area. The nominal size of the natural and recycled coarse aggregates was 20 mm and their particle size distributions determined as per IS 383-1970 (IS 1970) are given in Table 2.

The mechanical properties of NA and RA were determined in accordance with IS 2386-1963 (IS 1963) and presented in Table 3.The RA was subjected to the treatment process as explained in section “Mechanical Treatment.” The physical properties of RA were also determined after every treatment process in order to assess the degree of improvement in the quality of RA through these treatment methods. Potable water available in the college campus was used for the entire study.

Table - 1. Properties of Natural Fine Aggregate River Sand

Serial Numbers	Test Properties	Result
1	Specific gravity	2.56
2	Fineness modulus	2.8
3	Bulk density(kg = m^3)	1,655
4	Water absorption (%)	1
5	Moisture content (%)	0.6
6	Zone	II

Table - 2. Sieve Analysis Results of Natural and Recycled Coarse Aggregate

Serial Numbers	Sieve Size	NA	RA
1	20	0.0	0.0
2	16	21.16	25.88
3	12.5	50.31	68.10
4	10.0	67.93	81.53
5	4.75	99.73	99.24

Treatments to get better the Recycled Aggregate

In the present study, the following four treatment techniques are adopted in order to improve the quality of RA and taken for comparison:

Chemical Treatment

The recycled aggregates were presoaked in an acidic environment at room temperature for 24 h and then washed with water to remove the acidic solvents afterward. Two acidic solvents are adopted, namely, hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) with a concentration of 0.1 mole. The RA obtained after HCl and H2SO4 treatment are abbreviated as RA Hcl and RAH_2SO_4 respectively.

Mechanical Treatment

The first technique is called mechanical scrubbing in which concrete rubbles are scrubbed by one another to remove adhering cement paste. In the present study, the recycled aggregates were subjected to a rubbing treatment with the Los Angeles abrasion machine to remove mortar. The number of revolutions and the weight of charges to be used in the Los Angeles abrasion machine are arrived at based on the abrasion results of natural coarse aggregate and recycled coarse aggregate. From Table 3, it can be seen that the abrasion value of RA is 45% and that of natural aggregate is 29%. It can be interpreted that the contribution of adhered mortar in RA in enhancing the abrasion value is only 15% approximately (45-29%) and the rest is due to the inherent property of the coarse aggregate itself. After some trials, the decision was made to rub the RA in the Los Angeles abrasion machine for 5 min with standard charges in order to remove the attached mortar only. The second technology is called heating-scrubbing in which concrete rubbles are charged in a hot air oven for 24 h at a temperature of around 300°C. Heating RA in hot air makes the cement paste brittle and weak.

It is then cooled and then scrubbed in the Los Angeles abrasion machine for 5 min. The RA obtained after the scrubbing technique and the heating and scrubbing technique are abbreviated as RAS and RAHS, respectively.

Mix Proportioning and Specimen Preparation

As there is no standard method, available for proportioning of RA concrete mixes, Indian standard method [IS 10262 (IS 2009)] applicable for natural aggregate is adopted. Mix proportioning was done for M 30 grade concrete with target cube strength of 38 MPa at 28 days. The mix proportion (by weight) was arrived at as 1:1.91:3.12, (cement: fine: coarse) with a cement content of 380 kg=m^3, adopting 0.45 as the water-cement ratio.

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ijates
ISSN 2348 - 7550

A concrete mix was prepared in the above proportion using conventional ingredients such as natural coarse aggregate and natural fine aggregate for reference and designated as NAC. Another concrete mix was prepared in the same proportion replacing NA completely with RA and designated as RAC.

Concrete mixes were also prepared with RA-HCl, RAH2SO4, RAS, and RAHS and are designated as RA-CHCl, RACH2SO4, RACS, and RACHS, respectively. Appropriate modifications are made in the mix design calculation to account for the variability in the physical properties of various RAs. The ingredients of these concrete mixes are given in Table 4. The coarse aggregates were maintained at saturated surface dry condition (SSD) before mixing and hence no additional water was added to account for the increased water absorption of RAs. A total of six series of concrete mixes were prepared and 18 150-mm size cubes and three 150-mm diameter, 300-mm long cylinders were cast in each of the mix series. These test specimens were cured in water under laboratory conditions until the age of testing. The compressive strength of the cube specimen was determined at 7, 28, 56, and 90 days of age. Static modulus of elasticity, water absorption, and drying tests were conducted at 28 days of age.

Testing of Specimens

Compressive Strength and Static Modulus of Elasticity

The compressive strength and static modulus of elasticity were determined as per IS 516-1959 (IS 1959), using a compression machine with a loading capacity of 3,000 kN. The compressive strength was determined with cube specimens and static modulus of elasticity was determined with cylinder specimens. The results of the compressive strength test are given in Table 5 and the results of static modulus of elasticity are shown in Fig. 1 for various concrete mixes.

Table - 3 Mix Proportions for Various Concrete Mixtures (kg=m^3)

Serial No	Mix series	Cement	Fine aggregate	Coarse aggregate	Water
1	NAC	380	726	1187	171
2	RAC	380	726	1012	171
3	RACHCL	380	726	1038	171
4	$RACH_2SO_4$	380	726	1093	171

Table - 4 Properties of Coarse Aggregate

Serial Numbers	Properties	NA	RA	RA-HCl	RACH$_2$SO$_4$	RACS	RACHS
1	Specific gravity	2.79	2.38	2.44	2.57	2.49	2.69
2	Water absorption	0.3	1.57	0.92	0.82	0.95	0.79
3	Bulk density (kg = m3)	1,508	1,239	1,438	1,453	1,462	1,483
4	Crushing value (%)	27	36	33	33	31	30
5	Impact value (%)	23	31	29	27	29	26
6	Abrasion value (%)	29	45	30	28	30	29

Alkalinity Test

Alkalinity test was conducted at 28 days of age for samples RA- CHCl and RA- CH$_2$SO$_4$ and compared with the results of samples from the NAC. The specimens were taken out from the curing tank and dried in oven at 105°C for 24 h. The dry specimens are cooled to room temperature and broken to separate the mortar from it. This mortar is ground into powder form and sieved in 150 ***H*** sieve. Ten gm of powdered mortar is taken and diluted in 50 mL of distilled water and completely stirred in.

Then, the pH meter is immersed into the solution and the pH value is noted. A pH value greater than 12 indicates low potential for corrosion. The results of the alkalinity test are given in Table 6, from which, it is clear that all the concrete mixtures have low potential of corrosion.

Water Absorption Test

This test is used to find the water absorption of hardened concrete based on ASTM C 642-1981 (ASTM 1981). After 28 days curing the cube specimens are taken out of the curing tank and kept in an oven at 105°C for 24 h. The dry specimens are cooled to room temperature weighed accurately and noted as dry weight. Dry specimens are to be immersed in a tub containing water. Weight of the specimen at 2 h intervals are to be taken after wiping the surface with dry cloth. This process is to be continued up to constant weight are to be obtained in two successive observations. Percentage of absorption is evaluated as %Absorption = (Saturated weight - Dry weight / Dry weight) × 100

Drying Test

The concrete cube specimens were cured in water for 28 days. The specimens were taken out and weighed after wiping the surface with a dry cloth. This weight is taken as saturated surface dry weight. These specimens were kept inside oven at 100°C and the weight of these specimens at every 2 h interval was taken until the concordant readings were achieved. The total weight loss ratio of the specimen is calculated from the expression as

Table - 4 Compressive Strength of Concrete Specimens

Serial Mix series	7 days	28 days	56 days	90 days
NAC average	26.6	44.6	46.5	50.6
	24.7	41.8	44.9	47.8
	24.3	40.8	44.7	46.7
	25.2	42.4	45.4	48.5
RAC average	18.8	33.5	38.4	41.6
	21.3	36.4	39.3	42.6
	20.5	33.8	34.8	38.6
	20.2	34.5	37.5	40.6
RACHCl	23.6	40.1	43.2	46.6
	21.7	37.2	40.2	43.5
	23.1	39.4	40.3	43.8
	22.8	38.4	41.3	44.5
RACH2SO4	25.2	41.4	44.5	48.5
	24.6	40.2	42.8	46.3
	22.8	39.3	41.9	45.8
	24	40.3	43.6	46.9
RACS average	23.9	41.3	46.6	48.4
	22.2	40.8	44.3	45.9
	22.1	39.4	43.8	44
	22.5	28.7	44.9	46.1
RACHS	26.4	43.6	47.1	49.2
	25.2	42.2	46.4	46.7
	23.8	39.6	44.8	46
	24.9	41.8	46.1	47.3

Total weight loss ratio = *(ws - **wc)*** **H-** WS)×100 Ws = saturated surface dry weight;

Wc = weight of specimen after drying in oven to a constant weigh. Table 7 gives the water absorption and weight loss ratio of various concrete mixes.

RESULTS AND DISCUSSION

Properties of Recycled Aggregate

The physical and mechanical properties of coarse aggregate are given in Table 3. The properties of RA are compared with those of NA, and the salient aspects are discussed below.

International Journal of Advanced Technology in Engineering and Science
Vol. No.7, Issue No. 03, March 2019
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ijates
ISSN 2348 - 7550

Table - 7. Water Absorption and Weight Loss Ratio of Various Concrete Mixes

Serial No	Mix series	Water absorption (%)	Loss of weight on drying (%)
1	NAC	2,97	4.12
2	RAC	5.16	10.94
3	RA-CHCl	4.54	6.11
4	$RACH_2SO_4$	3.71	5.01
5	RACS	4.34	5.59
6	RACHS	3.94	4.79

CONCLUSION

The following conclusions can be made based on the results of this study:

Quality of recycled concrete aggregate is lower than natural aggregate quality, due to the mortar that remains attached on the surface. The physical and mechanical properties of recycled aggregates such as specific gravity, water absorption, bulk density, crushing value, impact value and abrasion value can be improved by suitable chemical or mechanical treatments.

The quality of recycled aggregates obtained after treatment are comparable (but still inferior) to the quality of natural aggregate. The compressive strength and static modulus of elasticity of recycled aggregate concrete are lower than natural aggregate concrete. However, the compressive strength and static modulus of elasticity of recycled aggregate concretes prepared with recycled aggregate obtained from sulphuric acid treatment and heating and scrubbing treatment are as good as natural aggregate concretes. It holds good especially for aggregates (both NA and RA) from the same source.

The long term performance of recycled aggregate concrete evaluated in terms of water absorption and loss of weight on drying are improved by sulphuric acid and heating and scrubbing treatments. Presoaking recycled aggregate in H2SO4 is more efficient than HCl in removing the attached mortar of recycled aggregate. Hence, the properties of recycled aggregate as well as the recycled aggregate concrete are improved.

Among the mechanical treatment methods, heating and scrubbing technique seems to improve the quality of recycled aggregate and hence the property of recycled aggregate concrete also. However, this technique is suitable, when infrastructures that provide the heat sources for this treatment are available economically. The treatment methods such as presoaking and mechanical treatments also have significant environmental effects. There can be remarkable environmental gain, if the recycling plants are located close to the building sites. The environmental gain of utilizing RA in construction can be better achieved by proper location and networking.

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