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Removal of Adhered Mortar from Recycled Aggregates

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ABSTRACT

While recycled aggregates can replace natural aggregate in making concrete without compromising strength, it is imperative to appraise the quality of the former. Quality of recycled aggregates depends upon the composition and strength of concrete from which it is derived. Thus it is necessary to identify and evaluate significant parameters characterizing a typical recycled aggregate. Adhered mortar present on recycled aggregates has been observed to adversely affect the performance of aggregates in concrete, thus its removal without affecting the properties of aggregate is essential. In this work a comparative study of various methods for removal of adhered mortar content is carried out and an effective removal method feasible for use on field is proposed.

Keywords: *Recycled aggregates, adhered mortar, concrete, water absorption, simple dry rolling, proposed method*

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INTRODUCTION

Recycled aggregates are exhaustively used as a base course in highway and other areas of construction for low grade applications. But taking into account the present demand of aggregates as they occupy 70-80% volume in concrete [1] and on the other hand the huge deficit that would be faced in the near future, it would be essential to adopt a strategy to conserve, save and judiciously use the available resources. This objective to a substantial extent may be achieved by making efficient use of the resource by employing recycled aggregates in making new concrete. However since original cement mortar remains attached on the aggregates, the porosity of the same influences the properties of aggregates. For example the attached cement mortar reduces strength, absorbs higher water content, lowers density, and creates a weaker interfacial zone between new cement mortar and aggregates thereby weakening the strength and mechanical performance of concrete [2]. Evidently it becomes necessary to improve the quality of recycled aggregates which requires adopting some techniques either to minimize the cement mortar portions adhering to recycled aggregates or separate aggregates from the cement paste attached to it. The spirit underlying this paper is to present a comparison of various procedures to remove the traces of adhered mortar left behind on recycled aggregates and further suggest a feasible and economical solution for removing the same without influencing the ultimate behavior of recycled aggregate concrete.

ROLE OF ADHERED MORTAR

The major difference between recycled aggregate and ordinary aggregate is the amount of cement mortar attached on the aggregates.

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When old concrete is crushed, a certain amount of mortar from the original cement mortar remains attached to the recycled aggregates that may affect characteristics of aggregates like density, abrasion and water absorption capacity and also in turn the compressive strength and durability of concrete. Therefore evaluation of these crucial properties of recycled aggregates as discussed below is essential in promoting them in making new concrete.

Water Absorption

Etxeberria et al. [4] concluded that more than 50% of recycled aggregates have adhered mortar paste. In almost all the cases this paste is identified to be of poorer quality than the new paste. On account of this poor quality consequent to its highly porous mortar, the recycled aggregates invariably emerge of inferior quality. Sanchez et al. [5] quantified the percentage of adhered mortar depending on the size of aggregates. The adhered mortar content for aggregate in the size range of 4 to 8mm varies between 33- 55% which for the range 8 to 16mm is 23-44%. These findings are in conformity with the literature [6, 7] suggesting a range of variations of 25-65% depending upon the method adopted to evaluate the mortar content. This adhered mortar contributes to a large amount of water absorption in recycled aggregates and may vary from 2 to 12%, depending upon the size of aggregates and in turn affect the compressive strength and workability of concrete.

Density

Density of concrete is the most important fundamental parameter of aggregates used for judging the quality of aggregate. The bulk density of aggregates directly relates to its close packing in a measure. For a coarser aggregate of a given specific gravity, a higher bulk density indicates that there are fewer voids to be filled by sand and cement. Lower density of recycled aggregate on the other hand is attributed to the existence of porous and less dense residual mortar lumps or particles adhering to the surface of the original aggregate. Measured aggregate density constitutes a pivotal parameter for accurate batching and concrete mix design, which is highly influenced by variations in the composition of the recycled materials. Tam et al. [3] have reported that aggregates with density lower than 1,000 kg/m^3 should not normally be used as aggregates in concrete since they may affect the final strength of concrete.

Size of Aggregates

Larger size recycled aggregates can replace normal aggregates without appreciable reduction in compressive strength. Incorporations of fines 10mm in size in concrete has great impact on strength, as studied by Padmini et al. [9] who reported a strength deterioration by 20-35% despite the parent concrete being of high strength i.e. around 50-58Mpa. As pointed out above, decline in compressive strength has a direct bearing on refinement in size of aggregates: 10mm leads to the reduction in strength around 30% : however,

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with 20mm and 40 mm size aggregates a comparable compressive strength is obtained with reference to parent concrete.

All pertinent research work makes it evident that adhered mortar on recycled aggregates is responsible for lowering strength, density and compressive strength of concrete. Hence evaluation and reduction of the mortar is crucial if recycled aggregates have to replace normal aggregates in concrete.

Compressive Strength

Sami et al. [8] emphasized that only parent concrete of high strength will produce high quality second generation concrete. Further they observed that to achieve comparable strength, parent concrete should have strength of at least 25 Map. However the higher the parent concrete strength, the more the adhered mortar content as well, which is attributed to enhance bonding between mortar and aggregate which has a detrimental effect on concrete properties. A loss in strength to the tune of 35% with 30MPa concrete and 25% with 50 Map has been observed. This marked reduction in compressive strength is aggravated when finer size aggregates are used.

METHODS TO OBTAIN ADHERED MORTAR CONTENT

As research carried out hitherto emphasizes that strength of concrete made from recycled aggregates degrades depending upon the percentage of adhered mortar content and thus to produce concrete of comparable strength, it would be necessary to calculate the proportion of adhered mortar and also seek a method to reduce the same. Various methods have been suggested for quantifying adhered mortar content. However evaluation and comparison of the methods is still required to devise an economical and effective method to suit especially tropical Indian conditions.

Dry Rolling

Tavakoli et al. [10] suggested removal of adhered mortar using dry rolling, which consists of dry rolling of coarse aggregates for 20 min. in a rotary drum mixer with a capacity of 0.25 to 15 cu-ft. In this method recycled aggregates in saturated surface dry conditions are placed in a drum mixer Figure.1 and rotated at a speed of 1 to 10 rpm for 20 minutes. The aggregates are then sieved in appropriate size sieves and the loss in weight is measured.

Fig. 1 Rotary Drum Mixer

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Treatment With Acid

Sanchez et al. [6] adopted a method of treating recycled aggregates by immersing into a solution of acid for dissolution of attached cement paste. The procedure consists of soaking recycled aggregates in an acidic environment at around 20^0C for twenty four hours and then watering the recycled aggregates with distilled water to remove the acidic solvents. Three acidic solvents hydrochloric acid (*HCl*), sulfuric acid (H_2SO_4) and phosphoric acid (H_3PO_4) each of 0.1 mole concentration were tried to check the removal of adhered mortar. This concentration [2] is chosen in order that the acidic solvents should not react with the aggregates and thus not lower the quality.

Thermal Treatment

Sanchez et al. [6] devised a thermal approach to determine adhered mortar content. This consists of several cycles of soaking in water and heating of the aggregates. The sample is immersed in water for 2 hrs so that attached mortar is completely saturated. Then the sample is dried in a muffle at a temperature of 500^0 C for further 2 Hrs. and then the sample is immersed into cold water. The heating gives rise to water vapor in a saturated mortar and the sudden cooling causes stress and cracks in the mortar, which later on can be easily removed. The loss in weight is calculated and the adhered mortar removed is found out.

Combined Mechanical and Chemical Treatment

Abdelgadir et al. [11] proposed a mix of mechanical and chemical stress that disintegrate the residual mortar and destroy the bond between the mortar and natural aggregate. The mechanical stress is created by subjecting recycled aggregate to freeze and thaw action and the chemical disintegration is achieved through exposure of the recycled aggregate in a chemical solution like sodium sulphate.

The method consists of subjecting 2 kgs sample in 4% sodium sulphate solution for 24 hrs and subjecting to freeze and thaw cycle in the same solution. Freezing is carried out by keeping the sample in a freezer at -9^0C for 16 hrs and thawing is done by subjecting the same sample in oven at 80^0C for 8 hrs. The sample is subjected to 2 cycles of freezing and thawing and the loss in weight is measured after washing with water.

EXPERIMENTAL WORK

The present work consists of obtaining recycled aggregates from demolished residential and commercial buildings that were 10 to 30 years old. The samples were collected from four different zones in and around Pune, Maharashtra, India and mixed together to obtain a representative sample. This sample was processed i.e. cleaned for impurities and then manually crushed to a size of 40 to 50mm and further crushed to an appropriate size of 10 to 20mm using a laboratory jaw crusher of capacity 250kg/hr as shown in Figure.2. The aggregates were then sieved through the various IS sieves ranging from 20mm to 10mm as per IS

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2386- 1997, which also helped in the removal of adhered mortar traces loosened during the crushing process. This sample was then further subjected to all test methods for removal of adhered mortar as discussed in earlier sections.

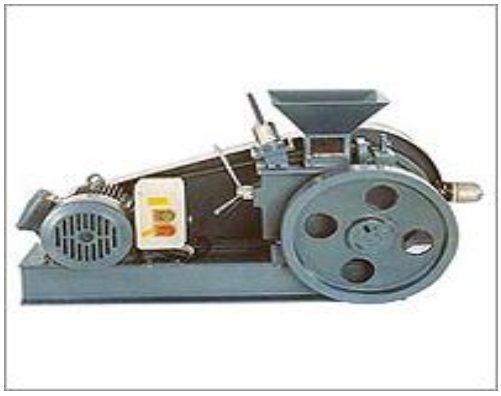

Fig. 2 Laboratory Jaw Crusher

Characteristics of Aggregates

Normal aggregates for the present work selected were from quarries in Pune, Maharashtra in the size range of 10- 20mm.Various properties of recycled aggregates and normal aggregates were evaluated as shown in Table I.

From the above Table I, it is noticed that the properties such as specific gravity & bulk density of recycled aggregates are lower in comparison with those of normal aggregates. It is also seen that the recycled aggregates of 20 mm size have higher water absorption around 6.38 % as compared with that of normal aggregate [1.28 %]. This has also been reported in earlier research work by Juan, [5]. This property of high water absorption is a sufficient indication of comparable amount adhered mortar content present on recycled aggregate. The abrasion resistance of recycled aggregates is also higher in comparison to the normal aggregate which is also an indication of adequate adhered mortar present.

TEST RESULTS

Tests were conducted on the agglomerated sample and three readings were noted by each of test methods for comparison. Figures. 3a, b, c, show the test results as obtained from dry rolling method and those obtained by treatment with acids *HCl*, H_2SO_4 and H_3PO_4 respectively. Figures. 4, 5 depict the percentage reduction by dry rolling with heating and cooling method and combined mechanical and chemical treatment respectively.

TableI: Characteristic of Aggregates used in Present Work

Aggregate Type	Size mm	Sp. Gravity	Bulk Density kg/m3	Water Absorption %	Moisture Content %	Los Angeles Abrasion %
Normal aggregate	20	2.90	1510	1.28	0.5%	16
	10	2.82	1500	1.48	0.5%	18
Recycled aggregate	20	1.76	1320	6.38	3%	36.65
	10	1.825	1260	8	4%	43.40

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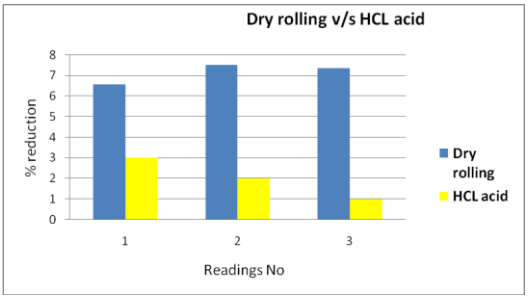

Fig. 3a: Test Results of Dry Rolling & Soaking in HCL Acid

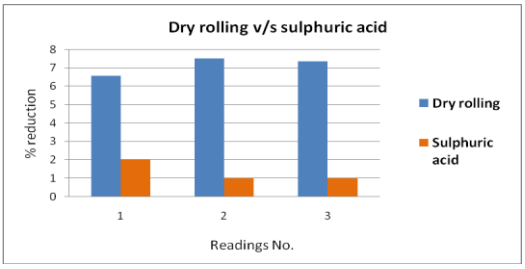

Fig. 3b: Test Results of Dry Rolling & Soaking in Sulphuric Acid

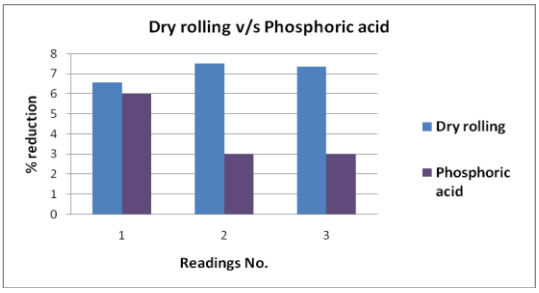

Fig. 3c: Test Results of Dry Rolling & Soaking in Phosphoric Acid

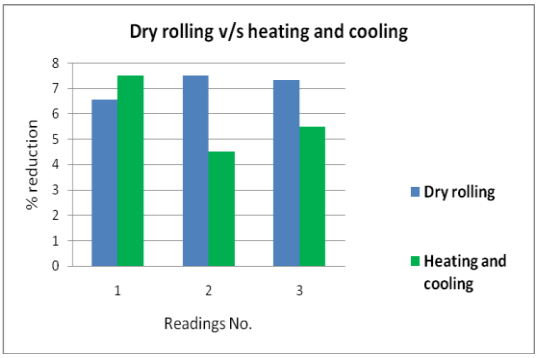

Fig. 4: Test Results of Dry Rolling & Heating and Cooling

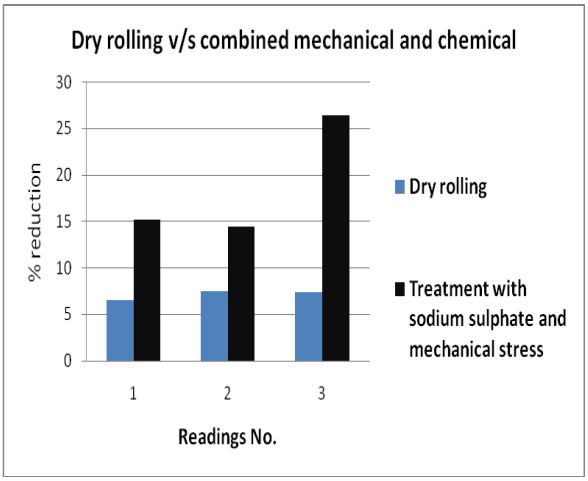

Fig. 5: Test Results of Dry Rolling & Combined Mechanical and Chemical Treatment

Comparison of Test Results

Dry rolling happens to be the most economical, simple method for removal of adhered mortar which can also be used to treat construction waste in huge quantity. Hence considering the simplicity and practicability of handling the aggregates it was decided to compare all the other three methods with dry rolling method.

From Figures. 3.a, b, c it is evident that percentage reduction in adhered mortar is higher by dry rolling method than any of the acid treatments. Similarly heating and cooling method also indicates lesser values as compared with dry rolling Figure. 4. On the other hand the combined mechanical and chemical treatment is better than dry rolling, for removal of adhered mortar as seen from Figure.5. However considering the difficulty of operation and the use of chemicals, which is again tedious and unsafe, the method cannot be used as an effective solution to treat tons of waste in the construction industry. The method also requires

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electronic instruments which again make it an impractical solution on field, though this method has been able to reduce mortar content to the extent 16 to 26% which is even more than the dry rolling method.

PROPOSED METHOD

From the comparison of all four methods it is seen that though combined chemical and mechanical method results in reduction of adhered mortar to a great extent, this method is not advisable to use in the field on site. Dry rolling is certainly a simpler method; workable to treat huge quantity of construction waste however the method has been able to reduce adhered mortar content to an extent of 7.5% only. Thus an attempt has been made in this work to find out whether dry rolling method itself can be supported by other process which could not only improve percent reduction of adhered mortar but also could be used in practice. In view of this the sample of recycled aggregates before dry rolling was subjected to environmental changes, i.e. wetting and drying cycles by subjecting the aggregates to natural sunlight and exposing them to rain for around two months period. The results of simple dry rolling have been compared with those obtained from environmental stress cycles followed by dry rolling method which are depicted in Figure.6.

It is evident that environmental stress followed by dry rolling has been effective to remove

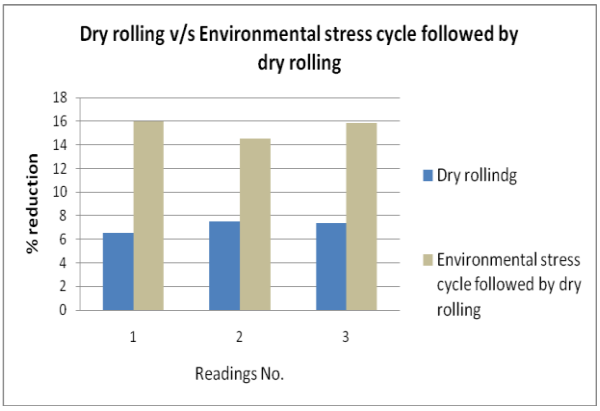

Fig. 6: Test Results of Dry Rolling & Enviornmental Stress Cycles Followed by Dry Rolling

adhered mortar content to the extent of about 16%. However such an environment cannot be achieved throughout the year thus it was decided to standardize the process and simulate this condition in the laboratory to achieve the required environmental stress cycles in terms of wetting and drying. Wetting was carried out by soaking the aggregates for 48 hrs in water and then drying them by exposing them to normal temperature of 27± 2 ^{0}C for 24 hrs. The samples after drying were subjected to dry rolling in a rotary drum mixer for 20 min and 30 min respectively. Research work by Tavakoli et al. [10] has recommended 20 min as the standard time for dry rolling of recycled aggregates. However the time of dry rolling was extended by another 10 min in the proposed work to see whether it could have any additional impact on removal of adhered mortar content. Aggregates after dry rolling for 20 & 30 min. respectively were sieved through standard IS sieves ranging from 20mm to 10mm and the loss in weight and so also change in water absorption was measured.

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This proposed method was then used to test nine more samples obtained from different places in Maharashtra, India to check the percentage reduction in adhered mortar. The initial water absorption for each of the samples was recorded and the percentage reduction of water absorption after the proposed method was measured as presented in Table II.

Table II: Results by Proposed Method

Sample No.	Initial water absorption	% reduction of adhered mortar proposed method		Water absorption after treating by proposed method
		20 min dry rolling	30 min dry rolling	
1	6.38	27.27	34.18	2.66
2	5.48	24.75	32.85	3.73
3	5.48	20.9	30.03	2.66
4	5.26	25.8	33.62	2.88
5	5.26	22.75	35.85	2.76
6	4.82	21.25	32.8	3.08
7	4.82	20.98	35.78	2.66
8	3.842	20.8	35.12	3.0
9	3.09	20.56	32.87	3.02

The results obtained for proposed method have been plotted as shown in Figure.7. The Figure. indicates variation of percentage reduction in adhered mortar with initial water absorption of the samples.

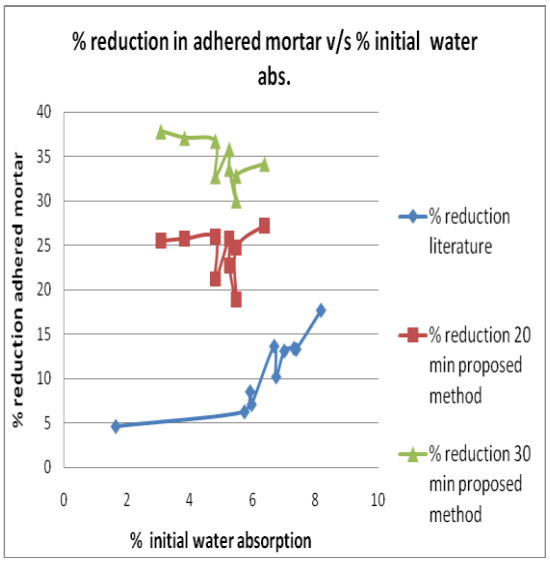

Fig. 7: Comparison of Proposed Method with Literature Results

From the Figure.7 it is evident that the proposed method i.e. standardized wetting and drying cycles followed by dry rolling method results in higher reduction in adhered mortar for both 20 min. and 30 min. dry rolling. These results have been further compared with simple dry rolling method reported in literature [2]. The proposed method has been able to reduce mortar content to the extent of 18– 28% with 20min dry rolling and around 30–38 % for 30 min dry rolling as against 4.5 to 18 % with simple dry rolling.

Although 30 min cycle has resulted in higher removal of adhered mortar it was observed that extended rolling resulted in rounding and reduction in size of the aggregates as seen in Figure.8. As rounded aggregates could yield poor concrete due to lack of bond between the smooth surface of aggregate and cement paste, it was decided to maintain 20 min as the appropriate time for subjecting recycled aggregates to rolling in a rotary drum mixer.

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a) 20 min rolling b) 30min rolling

Fig. 8: Recycled Aggregates after 20min and 30min Dry Rolling Proposed Method

The removal of adhered mortar content has also resulted in reduction of water absorption to the extent of 20–60%. Thus lesser the water absorption of aggregates better will be its performance in concrete. The water absorption of aggregates has direct impact on w/c ratio of concrete and in turn on strength and durability of concrete. Figure.9 portrays percentage reduction in water absorption with initial water absorption of all the samples tested in the present work. It is seen that more the initial water absorption more is the removal of adhered mortar traces present on recycled aggregates.

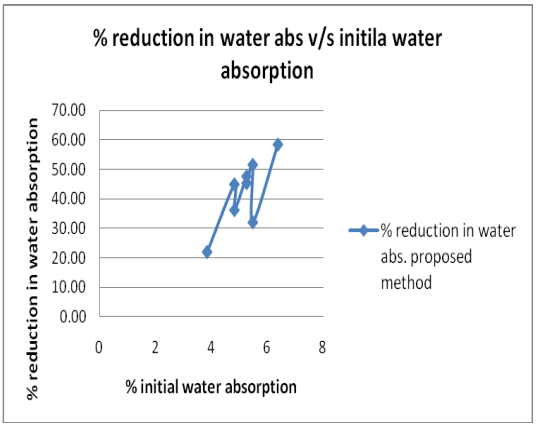

Fig. 9: Percent Water Reduction v/s Intial Water Abs. at 20 min Proposed Method

The removal of adhered mortar in terms of percentage reduction in water absorption forms the basis for effective use of recycled aggregates in concrete to achieve the properties at par with that of normal aggregates. Thus the authors of this paper propose an economical, effective and feasible method for removal of adhered mortar as the wetting and drying cycles followed by dry rolling for 20 minutes.

CONCLUSIONS

1) Dry rolling is practically feasible on site to treat higher quantity of waste more efficiently and thus is a suitable method for removal of adhered mortar from recycled aggregates. However, the proposed method in the present work namely standardized wetting and drying cycles followed by dry rolling for 20 have resulted in reduction of adhered mortar to the extent of 18-28% which is around 0.5 to 3 times higher in comparison to simple dry rolling method.
2) More the initial water absorption more is the reduction of adhered mortar traces present on recycled aggregates.
3) Extended dry rolling is not advisable since it results in rounding and sizing down of aggregates, though percentage reduction is more. However this is not attributed to reduction in mortar content but due to reduction in size of aggregates as evident from Figure.8.

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4) Since adhered mortar on recycled aggregates results in absorption of water and effecting compressive strength, the proposed method is able to reduce water absorption to the extent of 2–60%, thus the most effective method to remove adhered mortar thereby improving the quality of aggregates.

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