USE OF LOCALLY AVAILABLE MATERIAL TO DEVELOP A TREATMENT TECHNIQUE TO REDUCE THE WATER ABSORPTION CAPACITY OF RECYCLED AGGREGATES

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ABSTRACT

This study was to find a treatment technique to reduce the water absorption of Recycled Aggregates (RA) which involved preparing a coating to reduce the water penetration. The materials considered for the preparation of coating was Termite Mound Soil (TMS) and ordinary Portland cement. The objective was to find their optimum proportions and the slurry thickness for a coating that gives the lowest absorption. TMS was tested for pozzolanic properties. Chemical composition was tested using Atomic Absorption Spectroscopy and other analytical techniques. Mainly water absorption, particle size distribution, AIV, LAAV of RA was tested to ensure the suitability for construction purposes. Slurry was prepared using cement replacement levels of 0, 20, 40, 60 and 80% of TMS. Three sets of coatings were prepared with water to solid ratios of 1, 1.25 and 1.5. Slurries were prepared in a concrete mixture in which the aggregates were coated for 10 minutes at a speed of 30rpm. After air drying, coated aggregates were tested for the absorption after 14 days. The absorption of treated aggregates was compared with those of natural and untreated recycled aggregates. From the successful aggregate batches three concrete test cubes were prepared from each and tested for the 28 day compressive strength after curing for 28 days. Strength values were compared with those prepared with natural aggregates. Aggregates Coated using 50% cement and 50% TMS showed a significant reduction in the water absorption up to 38.44%. The strength of concrete made from aggregates treated with 50% TMS replacement along with the water solid ratio 1 was 37.15N/mm^2 whereas the value obtained from natural aggregates was 37.3N/mm^2

Keywords: *Coating; Recycled aggregates; Termite mound soil; Water Absorption.*

1. INTRODUCTION

With the increasing growth of global construction industry, concrete has become an indispensable material which has made high rise buildings, roads, dams and many other constructions possible. Concrete is a mixture of several major constituents, namely cement, water, fine and coarse aggregates and in some cases, special additives each playing a different part in giving concrete its many desirable characteristics as a construction material. These constituents necessarily, could be manipulated to form different varieties of concretes with different performance levels.

Out of these constituents, fine and coarse aggregates play a major role in concrete by providing a comparatively less expensive filler material, by providing strength to withstand applied loads, abrasion, effect of weather etc, and by helping to reduce the volume changes happening during the concrete setting and hardening process as well as from change of moisture in the cement paste (Parek and Modhera, 2011). Natural rocks, sands or gravel are used as coarse and fine aggregates which take up about 70%-80% of concrete volume (Parek and Modhera, 2011).

However, there is a considerable environmental impact associated in the production of aggregates. Natural sands and gravel are getting scarce by the day making it harder to meet the increasing demand for the aggregates, which according to the recent studies has exceeded 26 billion tonnes by year 2011 (Otoko,

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2014). Further, construction and demolition waste from concrete has become a major source of industrial wastes in the past years (Fucale *et al.*, 2009).

In the light of this situation, more focus is given for finding eco-friendly alternatives or substitutes for natural aggregates. One such option is the recycling of demolished concrete waste and utilizing the same for the preparation of new concrete. Many studies have proved that concrete made with this type of coarse aggregates can have mechanical properties similar to those of conventional concretes and demolition waste has been proved to be an excellent source of aggregates with some modifications (Rahal 2007; Limbachiya *et al.*, 2004; Malešev *et al.*, 2010).

However, there are several drawbacks in recycled aggregates which reduce the utilization as a substitution for natural aggregates. Higher water absorption of recycled aggregates compared to natural aggregates can be considered as the most significant drawback which can directly affect the water to solid ratio of the concrete mix which in turn may reduce the strength of concrete. (Pelufo *et al.*, 2009) This can further change the workability and uniformity of concrete mixtures (Pelufo *et al.*, 2009). Investigations have revealed such high absorption is due to excessive attached mortar and micro cracks generated in the process (Zaharieva, 2003).

To overcome these problematic characteristics of recycled aggregates, several treatment methods are implemented by several researchers. One attempt is to increase the performance of RA by heating and rubbing of aggregates, using eccentric - shaft rotor method and straight forward mechanical grinding method to remove adhered motar (Parekh and Modhera, 2011). Moreover, researchers have come up with several surface treatment techniques such as treating the aggregates with mineral oil (Tsujino and Noguchi, 2006), treating the recycled aggregates with several different types of pozzolanic materials such as sodium silicate, colloidal silica and silica fume by surface adsorption (Kim and Youn, 2005) and Treatment of recycled aggregates with Nano silica which has been comprehensively investigated (Scrivener and Crumbie, 2004).

Through this research, it was expected to find a suitable and locally available, cheap material and a technique to treat recycled aggregates. To this end, termite soil along with Standard Portland cement was used. Termite soil, a pozzolanic material, had been used in plaster and bricks by the ancient Sri Lankans to built gigantic Buddhist pagodas (Ranaweera and Abeyruwan 2004). A pozzolanic material can be defined as a siliceous or siliceous and aluminous material having very law cementation value, though finely divided and in the presence of moisture would chemically react to form compounds having cementacious properties and Termite soil is analytically proven to have pozzolanic properties (Ikponmwosa *et al.*, 2009).

Several studies have proved that addition of TMS to concrete can improve the properties of concrete (Ikponmwosa *et al.* 2009; Orie and Anyata, 2012). Cement Partially Replaced by Termite Mound Clay in the preparation of concrete beams has proven to increase the flexural strength (Ikponmwosa *et al.*, 2009). Addition of 15% mound soil by weight of cement has proven to increase the compressive strength and workability by 21.83% and 36.92% respectively. Same investigation concludes that TMS can be used as an additive in structural concrete for high compressive strength and workability (Orie and Anyata 2012).

Termite clay is obtained from termite mound, while mound is a pile of earth made by termites resembling a small hill. It is made of clay whose properties have further been improved by the excrement and saliva from the termite while being used in building the mound (Mijinyewa *et al.*, 2007). In Sri Lanka, Termite mounds are abundant in the dry zone, especially in North Western province and Eastern province of the island. Some mounds extend up to several meters in height and covers a considerable area.

This study aims on finding the optimum combination of cement and termite mound clay, and the most effective water to solid ratio for preparing a durable coating in order to reducing the water absorption of recycled aggregate by filling the micro cracks within the aggregates and reducing the porosity of attached motar.

2. MATERIALS AND METHODOLOGY

A bulk sample of Recycled concrete aggregate was collected from the COWAM centre recycling site in Galle which was started after the tsunami disaster in year 2004, and used as the materials for testing. Standard Portland cement was used and a sufficient amount of Termite mound soil was collected from a termite mound in Kottawa area, Colombo.

Methodology comprised of several steps. Initially recycled aggregates from the recycling center were tested for the physical properties to identify and analyze the major drawbacks. Physical and chemical properties of Termite Mound Soil were studied to ensure the suitability for the preparation of strong, durable, abrasive resistant coating along with cement. Then the aggregates were treated using several mix proportions under several water to cement ratios. Water absorption was tested after the surface treatment. Concrete test cubes were casted from successful batches of treated recycled aggregates and 28 day compressive strength was obtained and the values were compared with those prepared from natural aggregates under same conditions and mix design.

2.1. INITIAL PHYSICAL AND CHEMICAL TESTS

Physical and chemical properties of Termite Mound Soil were tested to ensure the desirable properties of Termite mound soil as a pozzolanic agent. Chemical analysis of TMS was conducted in accordance with BS: 4550: part 2: 1978: testing cement. Atomic Absorption Spectrophotometric method and titrametric procedures were followed. Physical properties were tested accordance with ASTM D 845.

Aggregates properties were tested in accordance with BS 812: part 2 and IS 2386. Testing was carried out for both natural and recycled coarse aggregates to identify the major drawbacks of recycle aggregates, to ensure the competency of Recycled aggregates for the utilization of construction purposes and to compare them with natural aggregates.

2.2. TESTING OF TERMITE SOIL

Following tests were carried out to test the Pozzolanic property of termite mound soil

- Total Silica analysis
- Chemical analysis for Al_2O_3, Fe_2O_3, MgO and CaO.
- Specific gravity

2.3. TESTING OF RECYCLED COARSE AGGREGATES

Followings tests were carried out to test the properties of recycled coarse aggregates and natural coarse aggregates

- Sieve Analysis test
- Water Absorption test
- AIV test
- LAAV test

2.4. PREPARATION OF MATERIALS FOR THE COATING PROCESS

Termite mound soil lumps were air dried for 7 days before they crushed into smaller particles manually using a hammer. Then the smaller soil lumps were introduced to the ball mill and milled for 20 minutes. Further crushed soil lumps were taken out of the mill and sieved manually using the 0.4mm IS sieve and the fine portion was obtained for the process.

Aggregates were air dried for 7 days and contaminants (polythene, plastic, wooden and glass pieces) were removed manually and sieved using 10mm sieve to remove smaller parti.

2.5. COATING THE AGGREGATES

Table 1: Mix Proportions for all 3 Water Solid Ratios (1, 1.25, and 1.5)

Scenario number	Cement %	Soil%	Cement (g)	Soil (g)	Water(g) (1)	Water(g) (1.25)	Water(g) (1.5)
1	20	80	160	640	800	1000	1200
2	40	60	320	480	800	1000	1200
3	50	50	400	400	800	1000	1200
4	60	40	480	320	800	1000	1200
5	80	20	640	160	800	1000	1200
6	100	0	800	0	800	1000	1200

Six scenarios were developed and all of them were prepared under water /solid ratios namely 1, 1.25 and 1.5. Table 1 summarizes the material mix proportions along with the water content for each slurry mixture. Material from each was placed in the concrete mixture with respective amount of water and was mixed well with a trowel. Then consistent slurry was formed by mixing the materials and water for 10 minutes inside the mixture. Then the Recycled Aggregates were introduced to the mixture containing the prepared slurry and the mixing was carried out for another 10 minutes for each mix proportion at a speed of 30 rotations per minute. Then the coated aggregates were removed from the mixture.

2.6. DRYING, CURING AND TESTING FOR WATER ABSORPTION

Treated aggregates were then allowed to air dry for 2 days on a steel mesh outside the laboratory and aggregates were sprinkled with water for 2 days and kept 14 days inside the laboratory for curing. After 14 days aggregates were kept in water for one day and water absorption was tested according to IS: 2386 (Part III) – 1963.

2.7. COATING THE AGGREGATES

Treated aggregate batches with lowest water absorption were used to cast concrete cubes. A standard mix design for grade 30 concrete was used to cast cubes of size 150mm x 150mm x150mm. Batching was carried out by weight and the cubes were removed from the moulds after 24 hours. The samples were then transferred into the curing tank which was maintained at room temperature. The cubes were tested for compressive strength on removal from the curing tank at the age of 28 days, using compression machine to the requirements of BS 1881: Part 116. Concrete cubes from natural aggregates were prepared and tested under same conditions to compare the results.

3. RESULTS AND DISCUSSION

3.1. CHEMICAL COMPOSITION OF TERMITE MOUND SOIL

Table 2: Major Chemical Constituents in TMS

Constituent	Percentage (%)
CaO	0.283
SiO_2	49.6
Al_2O_3	25.2
Fe_2O_3	2.76
MgO	1.82

Table 2 summarizes the percentage of major chemical constituents of TMS. The percentage of SiO_2 AL_2O_3 and Fe_2O_3 in Teremite mound soil was 49.6%, 25.2% and 2.76% respectively. The combined percentage of above three components is 77.50%, which satisfies the ASTM requirement for pozzolanic materials of minimum of 70%. MgO composition was found to be 1.82% which is less than 4% maximum limit, while CaO composition is 0.283% within the recommended range of ASTM C6I8-78. Similar results have obtained by several other researchers (Ikponmwosa *et al.*, 2009).

3.2. PHYSICAL PROPERTIES OF TERMITE MOUND SOIL

Specific gravity of TMS was found to be 2.4073 ± 0.01644. It is a significantly low specific gravity compared to that of Cement which is 3.15. From the chemical tests it is proven that Termite mound soil have pozzolanic properties. Low specific gravity is a great advantage for a cementacious material. Thus termite mound soil can be utilized or can be used as an additive in high strength light weight concrete constructions.

3.3. COMPARISON OF PHYSICAL PROPERTIES OF RECYCLED AGGREGATES AND NATURAL AGGREGATES

Table 3: Physical Properties of NA vs RA

Test	Natural aggregate value (%)	Recycled aggregate value (%)
LAAV	27	43.3
AIV	13	27.58
Water absorption	2.5	5.67

According to BS 882:1992, specifications of coarse aggregates for concrete, standard value for abrasion should not exceed 40%. The average value obtained for untreated recycled aggregates was 43.3% and that is slightly more than the limiting value while deviating highly from the value of natural aggregates which is around 27%.

AIV value for aggregates is not expected more than 30% in the standards and the value obtained for natural aggregates was 13% and the value for untreated recycled aggregates was 27%. It is evident that the AIV value lies within the desirable region and can be utilized for construction purposes.

The average water absorption of natural aggregates lies in the range of 2% to 2.5% but for untreated recycled aggregates the value was close to 6%. It is quite oblivious that recycled aggregates have higher water absorption capacity compared to natural aggregates. Approximately recycled aggregates have 55% higher absorption than the natural aggregates which are a quite high value compared to the specified value, 2%. This can be due to the amount of cement motor attached with aggregates and cracks within the aggregates.

According to the requirements of B.S. 882 aggregate grading was within the expected region. The passing percentage from the 20mm sieve was 89.93 which comply with the given range (85-100), passing percentage from 10mm sieve was 18.81 which also lies in the required range. Also the passing percentage from 5mm sieve was 2.78 which are expected to be between 0 and 5. Thus the recycled concrete aggregates from the Cowam recycling center have many desirable characteristics.

3.4. WATER ABSORPTION OF TREATED RECYCLED AGGREGATES

Table 4: Water Solid Ratio 1.0

Cement (%)	Soil (%)	Average Absorption (%)
20	80	4.13
40	60	4.41
50	50	3.49
60	40	4.81
80	20	4.76
100	0	4.49

In the real case the coating was thicker than both 1.25 and 1.5, and a neat finish could be obtained. It can be observed that all the aggregates treated with the water to solid ratio of 1 have water absorption values lower than before treating. The highest absorption was 4.81 which comprises from 40% soil and 60% cement and the lowest was 3.49 which comprises with similar soil and cement amounts. That can be noted as a significant reduction in absorption as this is very low absorption compared to the absorption value of recycled aggregates before treating. A standard T test was carried out for the results and the mean was 4.34833 with a standard deviation of 0.48803 having a calculated T value of -6.63364 which is less than -3.365, the standard T value for 99% confidence.

Table 5: Water Solid Ratio 1.25

Cement (%)	Soil (%)	Average absorption (%)
20	80	4.54
40	60	4.09
50	50	4.08
60	40	4.24
80	20	4.07
100	0	4.50

In this case the absorption values seem bit random with the varying soil amount. Still the absorption tends to become lower in the region where soil and cement present in similar quantities. It can be noted that all the absorption values are below than the absorption values of untreated recycle aggregates being 4.54 the maximum and the 4.07 the minimum. A standard T test was carried out for the results and the mean was 4.25333 with a standard deviation of 0.21612 having a calculated T value of -16.0564 which is less than -3.365, the standard T value for 99% confidence.

Table 6: Water Solid Ratio 1.5

Cement(%)	Soil(%)	Absorption average (%)
20	80	4.42
40	60	4.25
50	50	3.83
60	40	4.59
80	20	4.71
100	0	5.40

In this water solid ratio it is quite evident that the lowest absorption can be obtained when cement and soil present in similar amounts. The lowest absorption 3.83 is observed in the 50% soil and 50% cement stage while the highest absorption is reported when the cement percentage is 100% and without soil. So it proves that the soil has a considerable role in reducing the water absorption. It also evident that 80% soil is always got a higher absorption proving that too much of soil or soil alone cannot reduce the absorption in a significant level. A standard T test was carried out for the results and the mean was 4.5333 with a standard deviation of 0.52409 having a calculated T value of -5.3127 which is less than -3.365, the standard T value for 99% confidence.

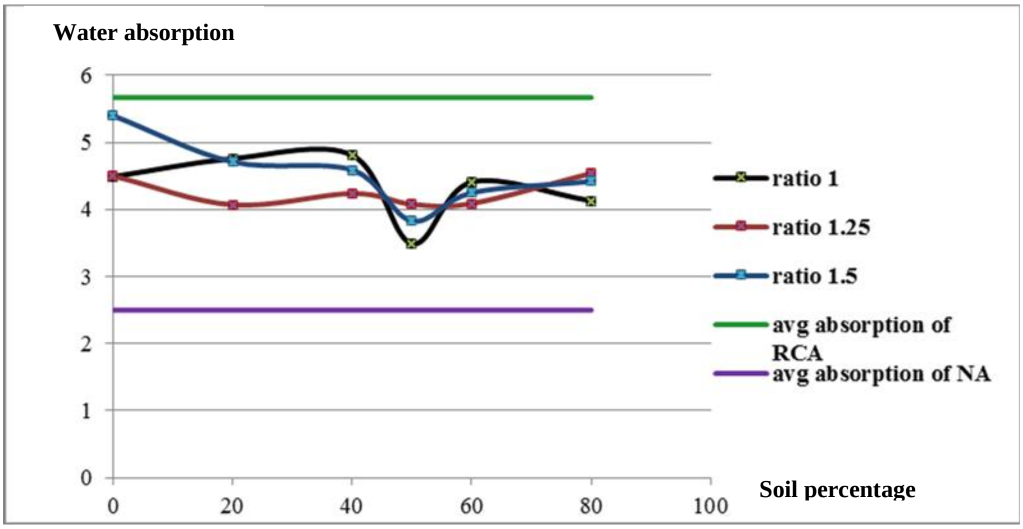

Figure 1: Variation of Water Absorption with the Soil Amount and Water Content

Based on the standard t test results all 3 sets of coatings have reduced the water absorption of recycled aggregates with a 99% level of significance compared to the water absorption value of recycled aggregates before treating. Further a significant reduction in absorption could be noticed in the 50% cement and 50% TMS stage in all 3 water solid ratios compared to other mix proportions and the least absorption was achieved in water solid ratio 1 as reflected in Figure 1.

3.5. COMPARISON OF PHYSICAL PROPERTIES OF RECYCLED AGGREGATES AND NATURAL AGGREGATES

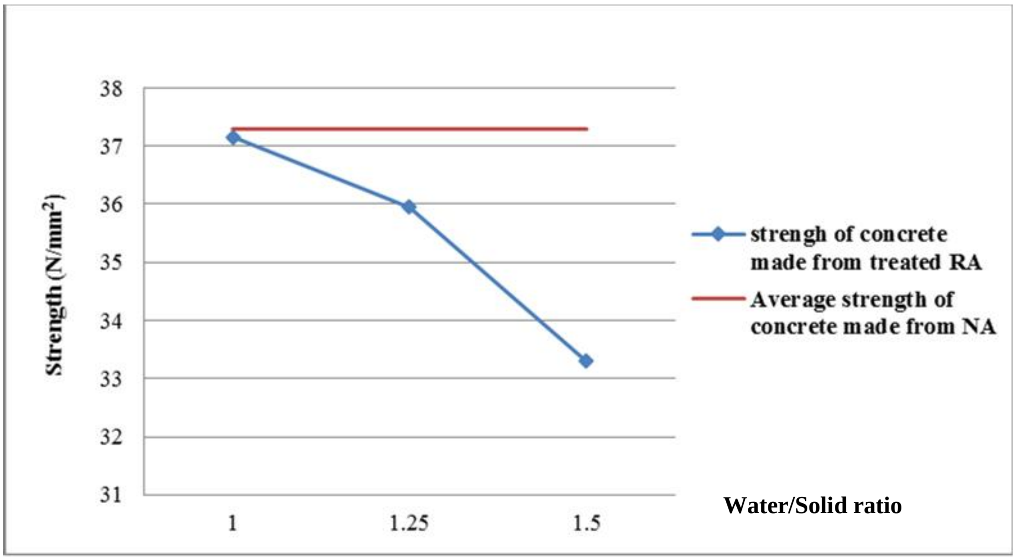

Figure 2: Variation of 28 Day Strength of Concrete with Water Solid Ratio of The Coating

The concrete was made under grade 30 mix design using 50% soil and 50% cement coating from all three water to solid ratios. The 28 day strength values are summarized in figure 2. The average strength value for concrete made from natural aggregates was 37.3N/mm^2 and the average strength values obtained for water solid ratios 1, 1.25 and 1.5 were 37.15 N/mm^2, 35.95 N/mm^2 and 33.3 N/mm^2 successively. It is evident that higher the slurry thickness higher the strength achieved.

4. CONCLUSIONS

From the results analysis and discussion it is evident that coatings made using mixtures of 50% cement with 50% Termite mound soil, at water/cement ratios of 1 and 1.5 can be used as a treatment method to reduce the water absorption of recycled aggregates up to 38.44%. Considering the 28 day strength of concrete made from successful aggregate batches it can be concluded that the aggregates treated with 50% and 50% soil under the water to solid ratio 1 is the optimum coating to reduce the water absorption while maintaining the design strength similar to those concrete made from natural aggregates.

From the research findings it is quite oblivious that termite mound clay can be used along with cement for treating recycled aggregates to reduce the water absorption of recycled aggregates. Termites are considered as pests and due to their activities wooden structures are degraded quickly. These mounds make no any economical value and are destroyed to control Termites. Thus Termite soil can be obtained freely or at a very low cost. Compared to the cost of natural aggregates this method is economical and can save the environment while at the same time giving a solution for managing construction waste.

5. RECOMMENDATIONS

1. Recycled aggregates have competitive properties similar to natural aggregates except water absorption and can be utilized for construction after treating.
2. Construction wastes must be properly sorted before processing as it could be noticed that in the recycled aggregates we used we could find lot of impurities such as tile pieces, Calicut tile pieces, glass and wooden pieces. It is recommended that a proper selection is required before crushing the demolished wastes to manufacture high quality recycled aggregates to meet the technical specifications.
3. From the research findings it can be recommended that termite mound clay can be used along with cement for treating recycled aggregates to reduce the water absorption of recycled aggregates.
4. Further researches are recommended to identify the variation of concrete strength with the addition of TMS. Also we could notice that higher the slurry thickness higher the strength leading to a question that addition of termite mound soil can increase the strength of concrete. Several studies have done on this matter and this makes it interesting for further investigation and research as the carbon foot print for cement production is very high.

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