USE OF RECYCLED AGGREGATES IN STRUCTURAL CONCRETE

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ABSTRACT

Properties of the recycled aggregates and the suitability of the same in structural concrete were studied and compared them with natural aggregates. The results showed that the particle size distribution of recycled aggregates is compatible with those of natural aggregates. The recycled aggregates had abrasive and impact values of 48.7% and 27.10%, respectively while those of the natural aggregates were 29.5% and 11.45, respectively. Bulk density of recycled aggregates was 1065 kg/m^3 with compared to 1296 kg/m^3 of Natural aggregates and the water absorption was 2.82% with compared to 1.22 of Natural aggregates. The mix design proposed for concrete was grade 30. Properties of concrete made under three mixing scenarios of natural aggregate to recycle aggregate proportions such as 50% -50%, 25%-75%, and 0%-100% were compared with those of 100% natural aggregates. With increasing percentage of recycled aggregate content, compressive strength, flexural strength, tensile splitting strength and workability were significantly decreased. According to the results, grade 30 concrete properties could be achieved with mix proportions of 50% natural aggregate and 50% recycled aggregate, without significantly affecting the concrete properties, indicating a 50% saving of natural aggregates thus reducing environmental impacts and enhancing sustainability.

Keywords: *Compressive Strength; Flexural Strength; Mix Design; Tensile Splitting Strength; Workability.*

1. INTRODUCTION

The invention of concrete, created an immediate and eventually permanent demand for construction aggregates. The aggregate serves as reinforcement to add strength to the overall composite material in concrete. Aggregates are among the most mined material in the world. The arrival of modern blasting methods enabled the development of quarries, which are now used throughout the world, wherever competent bedrock deposits of aggregate quality exist (Yong, 2009).

The world demand for construction aggregates was 24.9 billion metric tons in the year 2008. It is a known factor that the world today is experiencing a construction boom so the value 24.9 billion metric tons has only increased from the year 2008. The world construction aggregate demand is forecasted to expand at a rate of 2.9% annually. It is also said that if the demand increases at this rate, in the year 2013 the construction aggregate demand will reach a grand total of 28.7 billion metric tons. That is 3.8 billion metric tons of construction aggregates are used in a very short time span of five years.

According the to the Input-Output table for the year 2000 it is said that the construction industry is the largest buyer of the forest sector a total of 77.23% and mining and quarrying sector a total of 76.45%, in Sri Lanka (www.bournemouth.ac.uk/, 2012).

Almost half of the virgin aggregates in the world are used in the construction industry each year (Poon, 2012; William, 2003). The rate of construction in the world is increasing rapidly resulting in the rapid depletion of the natural resources. In Sri Lanka, demolished waste is mostly filled in land-fills.

Recycled aggregates have lighter weight per unit volume, resulting in lower bulk density. Recycled demolished concrete provides superior compaction and constructability (Parekh, 2011). The recycled coarse aggregate received by demolished concrete consist of crushed stone aggregate with old mortar adhering to it. The water absorption capacity of recycled aggregates is higher than natural aggregates

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which mean that more water needs to be added in to the concrete mix when using recycled aggregates, to get an acceptable workability (Nelson, 2004; ACPA, 1993). The abrasion values and toughness of recycled aggregates is much lower than that of natural aggregates due to the separation of the cement mortar from the recycled aggregates (Parekh, 2011). The use of recycled demolished concrete will reduce the material cost, which will reduce the haul-off cost which will reduce the overall project cost. Furthermore, costs associated with land fill disposal can be avoided. This would increase the project efficiency.

According to an investigation conducted in the year 2002, by the Ministry of Land Infrastructure and Transport (MLIT) Japan, the construction and demolition waste generated yearly is 83 million tons while 35 million tons (i.e. 42.2%) of which is concrete waste. The construction and demolition waste has reached such a high value in Japan due to many natural disasters. Recycled coarse aggregate concrete was used in the Biotope Soga symbiosis building which was installed in the Chiba Heating Power area and also in the Yokohama Thermal Power Plant premises (Yasuhiro, 2006).

Although research work conducted in some countries have indicated that recycled aggregates could be used for production of concrete, it is generally perceived by the builders in Sri Lanka, that the recycled aggregates are inferior in quality to natural aggregates. Therefore, the objective of the present study is to investigate the suitability of recycle aggregate as a construction material to produce structural concrete by testing aggregate properties as well as structural properties of concrete made out of recycle aggregates mixed with natural aggregates in three different mix scenarios.

2. MATERIALS AND METHODS

2.1. *PREPARATION OF SAMPLES*

A bulk sample of demolition building waste, crushed according to the SLS standards and collected from the COWAM centre in Galle was used as the materials for testing.

2.2. *TESTING OF AGGREGATES*

Following tests were carried out for testing the aggregates properties of recycled aggregates as well as natural aggregates.

- Sieve Analysis test - (BS-812-103.1, 1985)
- Specific Gravity and Water Absorption test -(BS 812: Part II: 1975)
- Bulk Density test - (BS 812: Part II: 1975)
- Los Angeles Abrasion Value (LAAV) test for crushing and impact value of aggregates- (ASTM C131)
- Aggregate Impact Value AIV test for impact value of aggregates - (IS: 2386 part IV)

2.3. *TESTING OF CONCRETE*

The recycled aggregates were mixed with natural aggregates under three different scenarios to evaluate the properties of concrete made using different proportions of recycled aggregates.

Table 1: Respective Percentage of Aggregates Mixed For Production of Concrete

Scenario No :	% of Recycled Aggregates	% of Natural Aggregates
1	50	50
2	75	25
3	100	0
4	0	100

The concrete cubes, beams and cylinders made were tested for 7 days, 14 days and 28 days. Three samples were made for each testing date under every scenario. The properties of concrete made according to the table 1, were compared with the concrete made with 100% natural aggregates.

The selection of the materials used to prepare the concrete and the required proportions of them was calculated according to grade 30 mix design (BRE mix design method). The workability of the each mix was tested prior to the making of concrete specimens. Curing and the testing of the specimens were done according to the BS standards.

Table 2: Initial Data Taken For The Mix Design

Target strength (MPa)	30
Water / Cement ratio	0.56
Weight of cement per bag (Kg)	50kg

Following were used for testing concrete specimens;

- Determination of compressive strength of test cubes - (BS 1881-part 116 : 1983)
- Determination of flexural strength – (BS 1881- part 118 : 1983)
- Determination of tensile splitting strength- (BS 1881- part 117 : 1983)

3. RESULTS AND DISCUSSION

3.1. PROPERTIES OF RECYCLED AGGREGATES

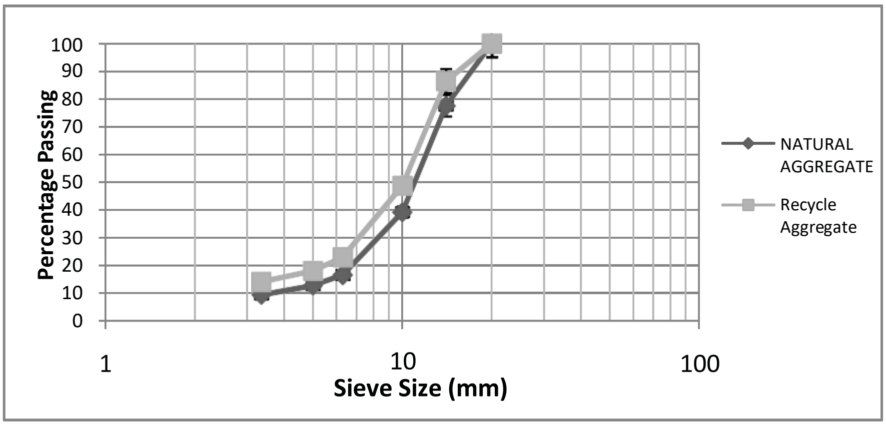

Figure 1: Gradating Curves for Natural Aggregate vs. Recycled Aggregate

Figure 1 shows the comparison of grading curves for natural and recycle aggregates. The coefficient of curvature (gradation) of recycled aggregates and natural aggregates gradation curves are 2.6255 and 2.1228, respectively showing a difference of 19.1%. The uniformity coefficient of recycled aggregates and natural aggregates gradation curves are 5.5000 and 3.5625 respectively, indicating a difference of 35.2%. Gradation affects many properties such as bulk density, physical stability, permeability etc. According to the results, it shows a dense gradation such that approximately of equal amounts of various sizes of aggregates. It is favourable for engineering applications as the bulk density is relatively high, the physical stability is satisfactory, and the permeability is relatively low, due to the well packing of particles and hence the increasing of the unit weight.

The specific gravity of an aggregate is considered to be a measure of strength or quality of the material in it. The specific gravity values obtained for recycled aggregates and natural aggregates was 1.749 and 1.571, respectively, showing a 10% reduction from natural aggregates to recycle aggregates, hence the strength is reduced. This is probably because the recycle aggregates contain some amounts of mortar attached to its surface.

The water absorption of recycled aggregates and natural aggregates are 2.815 and 1.219 respectively. The water absorption reduces around 50% from recycled aggregates to natural aggregates, probably due to the presence of abundant amount of voids in the attached mortar, concrete etc.

Aggregate density has an important influence on concrete density since aggregates occupy up to 75%-80% of the volume of concrete. So the reduction of the bulk density from NA to RA tends to decrease the relevant concrete density and this has a direct implication on the amount of self weight that the structure must carry.

The LAAV values of recycled aggregates and natural aggregates are 48.70 and 29.50 respectively. The AIV values of recycled aggregates and natural aggregates are 27.10 and 11.45 respectively. When considering the LAAV and AIV values, there was a significant reduction in abrasion and impact resistance; this is mainly due to the attached mortar being removed during the process of testing and therefore increasing the percentage of fines. Care should be taken when using recycled aggregates for pavement applications and should be verified with other properties such as surface texture, strength and elasticity, aggregate voids, hardness and particle shape as well.

3.2. PROPERTY VARIATION OF CONCRETE MADE BY USING RECYCLED AGGREGATES

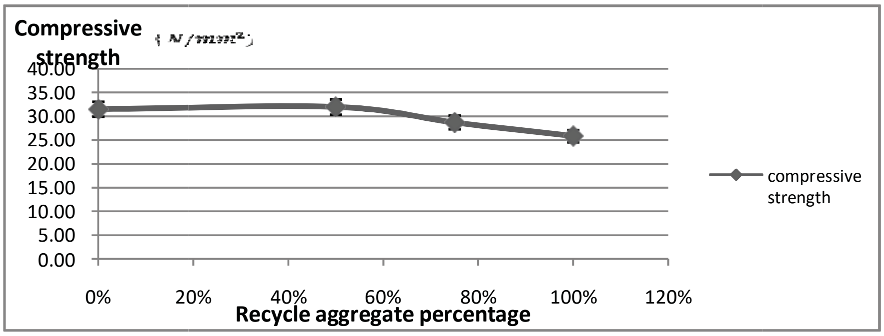

Figure 2: Compressive Strength of Concrete after 28 Days

According to Figure 2 the average compressive strength of test specimens after 28 days at the recycled aggregate content of 0%, 50%, 75%, 100% are 31.54 N/mm^2, 32.01 N/mm^2, 28.25 N/mm^2, 25.90 N/mm^2 respectively. Figure 2 shows that the concrete made with 50% recycled aggregates could achieve strength of grade 30, similar to the concrete made by using 100% natural aggregates. This indicates a 50% saving of virgin aggregate without affecting the properties of the concrete. And also the concrete made by using 100% recycled aggregates has achieved a rade 25 which is also satisfactory for various structural purposes.

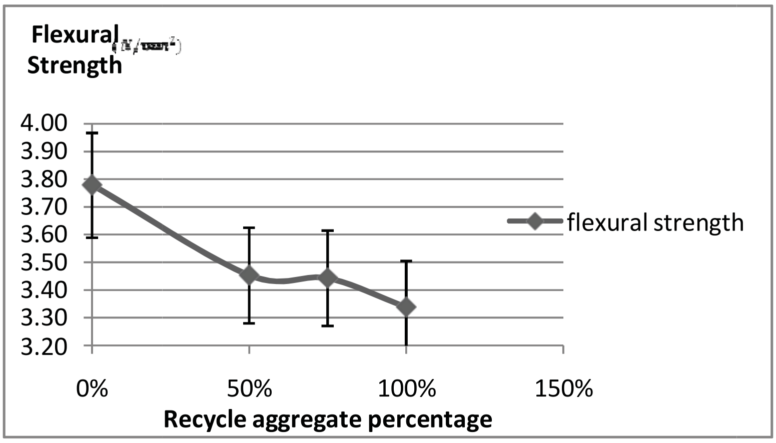

Figure 3: Flexural Strength of Concrete after 28 Days

The average tensile strength of test specimens after 28 days with respect to the recycled aggregate content of 0%, 50%, 75%, 100% are 3.78N/mm^2, 3.45 N/mm^2, 3.44 N/mm^2, 3.34 N/mm^2 respectively. According to Figure 3 there is a considerable difference in the flexural strength values of the concrete made by using 100% virgin aggregates and 50% recycled aggregates, and it should be noted that the difference is around 9%. The difference of the flexural strength values when using 100% virgin aggregates and 100% recycled aggregates is around 12%.

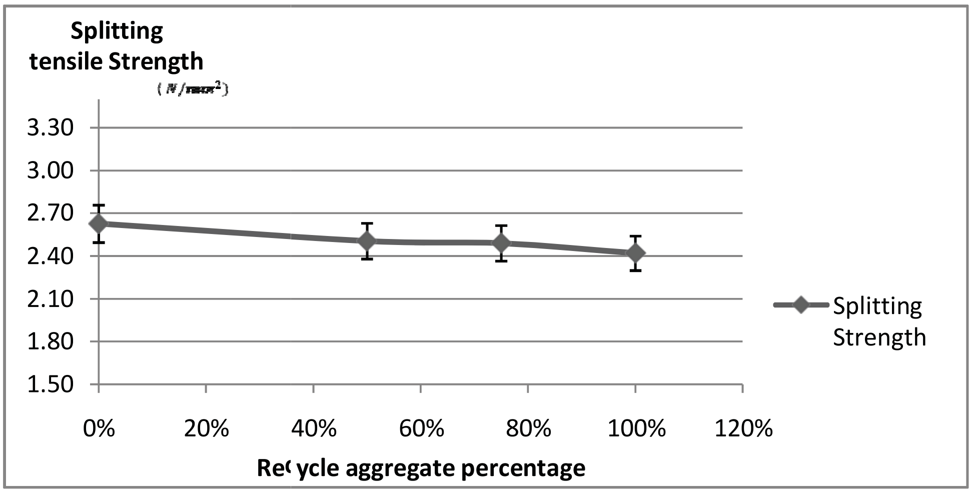

Figure 4: Tensile Splitting Strength of Concrete vs. Recycled Aggregate Content

The average splitting tensile strength of test specimens after 28 days with respect to the recycled aggregate content of 0%, 50%, 75%, 100% are 2.63 N/mm^2, 2.51N/mm^2, 2.49 N/mm^2, 2.42 N/mm^2, respectively. When observing the values which were given from the splitting tensile strength test, according to Figure 4, it can be noted that there is no significant variation in the values when increasing the percentage of recycled aggregates used. This is probably due to the better mechanical interlocking and interfacial bond due to the angular shape and rough texture of the recycled aggregates.

In general it can be noted that the use of recycled aggregates has no adverse effect on flexural strength and splitting tensile strength values.

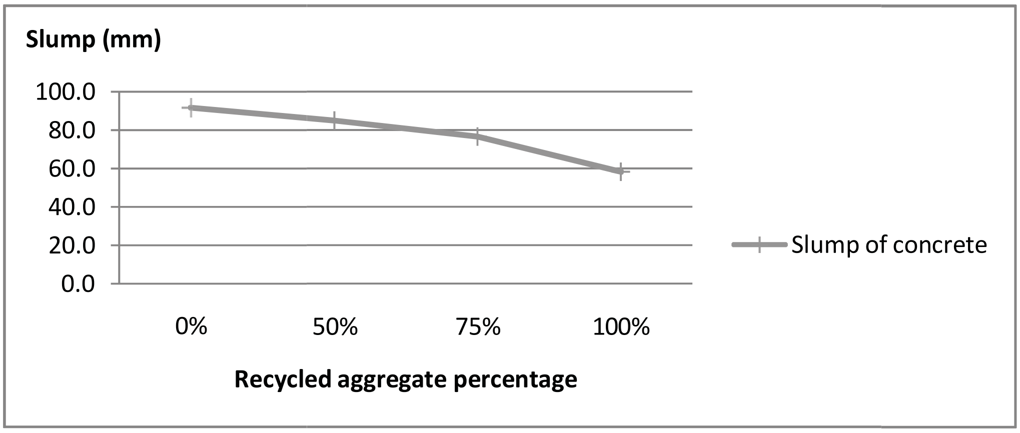

Figure 5: Workability vs. Recycled Aggregate Content

According to Figure 5, the average workability of the concrete made by using 0%, 50%, 75%, 100% recycled aggregates are 91.7 mm, 85 mm, 76.7 mm, 58.3 mm respectively. There is a reduction in the slump with the increment of recycle aggregates used in the concrete. This is mainly due to the physical characteristics of the recycled aggregate particles. The recycled aggregates used were more porous, and much rougher than natural aggregates due to the adhered cement paste. The rough-textured recycled aggregate particles increased the harshness of concrete mix, and thus decreased its workability, particularly at a greater content. The dispersion of aggregates consisting of relatively a high content of coarse particles can be lower due to increased inter-particle collisions. The loss of cement paste into the surface pores of RA also decreased the workability of concrete. Also another reason was that the amount of water added to all scenarios was kept constant and no add mixtures were used. The pore spaces in the attached mortar on the recycled aggregates would have absorbed a fair quantity of water, hence reducing the workability of the concrete (Kosmatka and Panarese, 1994).

4. CONCLUSIONS

Although some negative results were shown when testing the aggregate properties of recycled aggregates, there were no significant adverse impacts in the concrete being made from recycled aggregates. Due to the light weight of concrete and lower bulk density, it can be used with thin sections in high rise building. Though the workability reduced with RA, it should be noted that there are many admixtures in the market to overcome the issue.

Finally, it can be conclude that at least 50% of natural aggregates can be easily replaced with recycled aggregates in concrete, without significantly affecting the concrete properties, indicating a 50% saving of natural aggregates thus reducing environmental impacts and enhancing sustainability.

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