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Study on the use of Recycled Aggregate in concrete

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Abstract

Recycling is the act of processing the used material for use in creating new product. The usage of natural aggregate is getting more and more intense with the advanced development in infrastructure area. In order to reduce the usage of natural aggregate, recycled aggregate can be used as the replacement materials. Recycled aggregate are comprised of crushed, graded inorganic particles processed from the materials that have been used in the constructions and demolition debris. These materials are generally from buildings, roads, bridges, and sometimes even from catastrophes, such as wars and earthquakes.Traditionally, the application of recycled aggregate is used as landfill. Nowadays, the applications of recycled aggregate in construction areas are wide. The applications are different from country to country. Recycled aggregate have been used as concrete kerb and gutter mix in Australia. According to Building Innovation & Construction Technology (1999), Stone says that the 10mm recycled aggregate and blended recycled sand are used for concrete kerb and gutter mix in the Lent hall Street project in Sydney. The major advantage is based on the environmental gain.

Introduction

Recycling is the act of processing the used material for use in creating new product. The usage of natural aggregate is getting more and more intense with the advanced development in infrastructure area. In order to reduce the usage of natural aggregate, recycled aggregate can be used as the replacement materials. Recycled aggregate are comprised of crushed, graded inorganic particles processed from the materials that have been used in the constructions and demolition debris. These materials are generally from buildings, roads, bridges, and sometimes even from catastrophes, such as wars and earthquakes.Traditionally, the application of recycled aggregate is used as landfill. Nowadays, the applications of recycled aggregate in construction areas are wide. The applications are different from country to country. Recycled aggregate have been used as concrete kerb and gutter mix in Australia. According to Building Innovation & Construction Technology (1999), Stone says that the 10mm recycled aggregate and blended recycled sand are used for concrete kerb and gutter mix in the Lent hall Street project in Sydney. The major advantage is based on the environmental gain.

Literature Review

The applications of recycled aggregate in the construction areas are wide and they had been used long time ago. Wilmot and Vorobieff (1997) stated that recycled aggregate have been used in the road industry for the last 100 years in Australia. They also stated that the use of recycled aggregate for the construction and rehabilitation of local government roads has a great improve in the last five years. C & D Recycling Industry (n.d.), the fact file stated that from the time of the Romans, the stones from the previous roads were reused when rebuilding their vaunted set of roads. It also stated that since the end of world war two, the recycling industry had been well established in Europe. According to Seecharan (2004), the Detroid News stated that in 1980s, the old concrete crushed into a powder was a popular road builder at Michigan, USA.In 2002, Poon, et al [1] found that the replacement of coarse and fine natural aggregates by recycled aggregates at the levels of 25 and 50% had little effect on the compressive strength of the brick and block specimens, but higher levels of replacement reduced the compressive strength. However, the transverse strength of the specimens increased as the percentage of replacement increased. They also found that the replacement of natural aggregates at the level of up to 100%, concrete paving blocks with a 28-day compressive strength of not less than 49 MPa can be produced without the incorporation of fly ash, while paving blocks for footway uses with a lower compressive strength of 30 MPa and masonry bricks can be produced with the incorporation of fly ash.

In 2002, Jose and Gomez-Soberon [2] found the result of Porosity of recycled concrete with substitution of recycled concrete aggregate. Experimental analysis was done with the samples of recycled concrete (RC) with replacement of natural aggregate (NA) by recycled aggregate originating from concrete (RCA). The results of the tests of mechanical properties of RC were used for comparison with tests of mercury intrusion porosimetry (MIP), in which the distribution of the theoretical pore radius, critical pore ratio, the surface area of the concrete, threshold ratio and average pore radius were studied at ages of 7, 28 and 90 days. Tests of mercury intrusion porosimetry (MIP) in RC show increase in the total volume of pores, especially in larger pores (> 100 nm). It suggests that property is a function of both the age of the concrete and the amount of mortar that the RCA contains [12]. The results showed some variation in the properties of the RC with respect to ordinary concrete. Porosity increases considerably when NA is replaced by RCA. And a reduction in the mechanical properties of the RC is seen compared with ordinary concrete when porosity increases.

In 2002, Ajdukiewicz, and Kliszczewicz [3] studied on the influence of properties of original concrete on mechanical properties of recycled aggregate concrete. It was found that it is possible to obtain recycled concrete with higher compressive strength than the original one. They proposed that mix design of recycled concrete is very similar to the procedure for concrete with natural (new) aggregate; with necessary corrections in water content to obtain proper workability, but the changes in water/cement ratio need be relatively small.

In 2003 Lin et.al [4] assessed both slump and compressive strength of concrete made with recycled aggregates. They indicates that the optimal alphanumeric series of designation of experiment is water/cement ratio of 0.5, volume ratio of coarse aggregate of 42.0%, 100% natural river sand, 0% crushed brick, and as-is recycled aggregate without water-washed aggregate. The resulting concrete has slump of 180 mm and a compressive strength of 30.17 MPa at 28 days, which is applicable for most concrete structures.

An observation made by Levy and Helene in 2004 [5] reveals that Concrete made with recycled aggregates (20%, 50%, and100% replacement) from old masonry or from old concrete can have the same fresh workability and can achieve the same compressive strength of concrete made by natural aggregates in the range of 20–40 MPa at 28 days. It was also noticed that when the natural aggregate is replaced by 20% of the recycled aggregates from old concrete or old masonry, the resulting recycled concrete will likely present same, and sometimes better, behaviour than the reference concrete made with natural aggregates in terms of the properties like workability, water absorption, compacting factor.

In 2004, an observation made by Seung et.al [6] reveals that porous concrete based on the content of recycled aggregate has the target void ratio and the measured void ratio less than 1.7%. They found that the compressive strength reduced rapidly when the target void ratio and the content of the recycled aggregate exceeded 25% and 50%, respectively. Three recycled coarse aggregate (RCA) replacement percentages (i.e., 0%, 50% and 100%) and two types of steel rebar (i.e., plain and deformed) were considered. Based on the test results, the influences of both RCA replacement percentages and the rebar surface on the bond strength between the RAC and steel rebars were investigated. It was found that under the equivalent mix proportion (i.e., the mix proportions are the same, except for different RCA replacement percentages), the bond strength between the RAC and the plain rebar decreases with an increase of the RCA replacement percentage, whereas the bond strength between the RAC and the deformed rebar has no obvious relation with the RCA replacement percentage. The aim of this work was to investigate the bond behaviour between recycled aggregate concrete and steel rebars and to establish a bond stress versus slip relationship between recycled aggregate concrete and steel rebars.

In 2006, an observation made by Vivian et.al [8] reveals that the porous nature of recycled aggregate reduces the mechanical properties of the recycled aggregate concrete. Around 25–40% of recycled aggregate substitution is found to be most favourable in using TSMA. Further, around 50–70% of recycled aggregate replacement can also give some improvement although the enhancements are less significant when compared with that of 25–40%.

Etxeberria et.al [9] observed in 2007 that the absorption capacity and the humidity level of recycled aggregates must be considered for concrete production. The humidity content in recycled coarse aggregates must be high. With respect to the mechanical properties it was found that concrete made with 100% of recycled coarse aggregates has 20–25% less compression strength than conventional concrete at 28 days, with the same effective w/c ratio (w/c=0.50) and cement quantity (325 kg of cement/m3). In 2008, Sami et.al [10] found that the toughness and soundness test results on the recycled coarse aggregate showed higher percentage loss than natural aggregate, but remained within the acceptable limits. In 2009, an observation made by Domingo-Cabo et.al [11] showed that the evolution of deformation by shrinkage and creep of recycled concrete was similar to a conventional concrete, although the results after a period of 180 days showed the influence of the substitution percentage in the recycled aggregates present in the mixture. The current study shows that much of the work using RCA in concrete has been done worldwide however few efforts has been taken in our country for using construction and demolition wastes in concrete. Hence, this work is aimed at the investigation of mechanical and physical properties of RCA and the strength, workability characteristics of recycled aggregate concrete.

Recycling Process

Recycling plant normally located in the suburbs of cities due to the noise pollution that make by the equipments that used during recycling process. According to Aggregate and Quarry (n.d.), all the machinery used have to fit with the effective mufflers to reduce the noise from the processing activity.

The main reason that choosing the structural building as the source for recycled aggregate is because there is a huge amount of crushed demolition Portland cement concrete can be produced.

The equipments that used during recycling process are various from the site conditions and also country to country. There are few different types of equipment had been used effectively to break up the Portland cement pavement and structural building.

Recycling of Portland Cement Concrete (n.d) mentioned that there are few different types of equipment had been used for crushing the Portland cement pavement. The equipments are as below: (a) Diesel pile – driving hammer. It is mounting on a motor grader that sticks in the Portland cement pavement on around 30cm grid pattern. (b) Rhino – horn – tooth – ripper – equipped hydraulic excavator. It is used to remove all the steel reinforcement that remaining in the Portland cement pavement.

Crushing is the initial process of producing the construction and demolition debris into recycled aggregate. The concrete debris is crushed into pieces in this process. Aggregate and Quarry (2001) stated that generally the equipments used for crushing process are either jaw or impacted mill crushers. It also stated that all the recycling crushers have a special protection for conveyor belts to prevent damage by the reinforcement steel that in the concrete debris. They are fitted with the magnetic conveyors to remove all the scrap metal. According to Recycling of Portland Cement Concrete (n.d.), the equipments used to crush and size the existing concrete have to include the jaw and cone crushers. The concrete debris will break down to around 3 inches by the primary jaw crusher. It also mentioned that the secondary cone crushers will breaks the materials to the maximumsize required which vary between ¾ and 2 inches.

Screening is the process that separates the various sizes of recycled aggregate. The screening plant is made of a series of large sieves separates the materials into the size required. Recycling of Portland Cement Concrete (n.d.) stated that the size of screen that used to separate the coarse recycled concrete aggregate and fine recycled aggregate is 3/8 inch. The size of screen used to separate the coarse recycled aggregate can be under or over ¾ inches. It also stated that one more screen should be used to separate those particles that more than the specified size. All the recycled aggregate are stored according to the different size of aggregate. According to Recycling of Portland Cement Concrete (n.d.), the stockpile has to prevent from the contamination of foreign materials. It also mentioned that the vehicles used for stockpiling have to be kept clean of foreign materials.

Comparison of Recycled Aggregate and Natural Aggregate

Recycled aggregate has the rough – textured, angular and elongated particles where natural aggregate is smooth and rounded compact aggregate.

According to Portland Cement Association, the properties of the freshly mixed concrete will be affected by the particle shape and surface texture of the aggregate. The rough – texture, angular and elongated particles require much water than the smooth and rounded compact aggregate when producing the workable concrete. The void content will increase with the angular aggregate where the larger sizes of well and improved grading aggregate will decrease the void content.

The quality is different between recycled aggregate and recycled aggregate. According to Sagoe and Brown (1998), the quality of natural aggregate is based on the physical and chemical properties of sources sites, where recycled aggregate is depended on contamination of debris sources. It also stated that natural resources are suitable for multiple product and higher product have larger marketing area, but recycled aggregate have limited product mixes and the lower product mixes may restrain the market.The density of the recycled concrete aggregate is lower than natural aggregate. Sagoe and Brown (1998) stated that when compare with natural aggregate, recycled concrete aggregate have lower density because of the porous and less dense residual mortar lumps that is adhering to the surfaces. When the particle size is increased, the volume percentage of residual mortar will increase too.

The strength of recycled aggregate is lower than natural aggregate. Sagoe and Brown (1998) stated that this is due to the weight of recycled aggregate is lighter than natural aggregate. This is the general effect that will reduce the strength of reinforcement concrete.

Experimental Test Results

Cement

Specific gravity of cement

Specific gravity is normally defined as the ratio between the mass of a given volume of material and mass of an equal volume of water . One of the methods of determining the specific gravity of cement is by the use of a liquid such as water-free kerosene which does not react with cement .The specimen used in the specific gravity test was specific gravity bottle.

	Mass of saturated surface dry sample, W_2 (Kg)	Mass of (flask+ water+ sample) W_3, (Kg)	$G=W_2/\{W_2-(W_3-W_4)\}$	G avg.
1	0.5	1.79	3.14	
2	0.5	1.846	3.22	3.12
3	0.5	1.805	3.02	

Table 1 Specific Gravity of Cement

Aggregates

Specific Gravity and Water Absorption

Water absorption is defined as the absorption rates of water by aggregate. It is determined by measuring the increase in mass of an oven dried sample when immersed in water for 24 hours. The ratio of the increase in mass to the sample, expressed as a percentage, is termed of absorption (Neville, A. M., 2002). The standard procedure is prescribed in IS :2386(Part III)-1963. The absorption rate not only affects the bond between the aggregate and cement paste but also the specific gravity of the aggregate. When the water absorption of the aggregate is higher, it will decrease the workability of fresh concretes. Past researchers had proved that the absorption rates of recycled aggregate are higher compared to natural aggregate The absorption rate gives the effect to the mix proportions in control water content and to maintain water-cement ratio constant. That means, in concrete design, the higher absorption gives the problems for workabilityand water demand. The specific gravity is cluster under three different conditions namely bulk, apparent and saturated specific gravity. The bulk specific gravity is where the specific gravity of the aggregate is determined under the natural environment. The apparent specific gravity is determined after the aggregate is oven dried for 24 hours. The saturated specific gravity is determined when the aggregate is under the saturated condition. The specific gravity of an aggregate gives valuable information on its quality and properties and it is seen that the higher the specific gravity of an aggregate, the harder and strong it will be (Gambhir, M. L.,2004). The results show that the specific gravity values of RA are almost equal of the NA. This indicates that the qualities of RA are almost the same of the NA and can be used in any concrete mix.

	Mass of saturated surface dry sample, W_2 (Kg)	Mass of (flask+ water+ sample) W_3, (Kg)	$G=W_2/\{W_2-(W_3-W_4)\}$	G avg.
1	0.5	1.88	2.8	
2	0.5	1.874	2.72	2.72
3	0.5	1.868	2.63	

Table 2. Specific Gravity (Natural Coarse Aggregate)

	Mass of saturated surface dry sample, W_2 (Kg)	Mass of (flask+ water+ sample) W_3, (Kg)	$G=W_2/\{W_2-(W_3-W_4)\}$	G avg.
1	0.5	1.84	2.29	
2	0.5	1.856	2.48	2.47
3	0.5	1.846	2.63	

Table 3Specific Gravity (Recycled Coarse Aggregate)

	Mass of saturated surface dry sample, W_2 (Kg)	Mass of (flask+ water+ sample) W_3, (Kg)	$G=W_2/\{W_2-(W_3-W_4)\}$	G avg.
1	0.5	1.79	2.23	
2	0.5	1.846	2.36	2.21
3	0.5	1.805	2.02	

Table 4.Specific Gravity (Fine Aggregate)

Aggregate type	Mass of Aggregate (dry surface sample) W_1 (Kg)	Mass After Heating W_2, (Kg)	$(W_1-W_2)*100/W_2$
Natural Coarse Aggregate	2.0	1.99	0.4%
Recycled Coarse Aggregate	2.0	1.95	2.26%
Fine Aggregate	2.0	1.98	1.2%

Table 5 Water Absorption Test

Concrete

Compression Test

Compressive strength of concrete can be defined as the measured maximum resistance of a concrete to axial loading. Compression test is the most common test used to test the hardened concrete specimens because the testing is easy to make. The strength of the concrete specimens with different percentage of recycled aggregate replacement can be indicating through the compression test. The specimens used in the compression test were cubes of side 150mm. There are three specimens were used in the compression testing in every batches.

Differences of the strength among the different percentage of recycled aggregate used in the age of 7 and 28 days also indicated through the compression test.

The height of the test specimen in relation to its lateral dimensions greatly influences the results. The more slender the test specimen, lower will be the crushing strength. The ratio of the minimum dimension of the specimen to maximum size of aggregate should be at least 4:1.

Natural Aggregate (%)	Recycled Coarse Aggregate (%)	Specimen1 (KN)	Specimen2 (KN)	Specime3 (KN)	Average (KN)	Strength (N/mm^2)
100%	0%	400	440	420	420.0	18.7
75%	25%	395	460	430	428.3	19.0
50%	50%	400	410	425	411.7	18.0
25%	75%	410	390	395	398.3	17.7

Table 6 Compressive Strength of Cubes on 7th day of curing

Natural Aggregate (%)	Recycled Coarse Aggregate (%)	Specimen1 (KN)	Specimen2 (KN)	Specime3 (KN)	Average (KN)	Strength (N/mm^2)
100%	0%	650	800	710	720	32.06
75%	25%	835	790	640	755	33.62
50%	50%	675	650	700	675	30.05
25%	75%	650	645	635	643	28.56

Table 7. Compressive Strength of Cubes on 28th day of curing

Slump Test Result and Analysis

Series of test was carried out on the concrete cylinder to obtain the strength characteristics of recycled aggregate for potential application in high strength structural concrete. This chapter discuss on the results that obtained from the testing. The results are such as slump test, compacting factor test, compression test, indirect tensile test and modulus of elasticity.

The slump test indicates a decreasing trend of workability when the percentage of recycled aggregate increased. Table 10 below shows the average slump recorded during the test.

Natural Aggregate (%)	Recycled Coarse Aggregate (%)	Slump value (mm)
100%	0%	120
75%	25%	104
50%	50%	98
25%	75%	75

Table 8 The slump result for each batch of mix concrete Percentage of Recycled Aggregate (%) Slump (mm)

According to the result, the highest slump obtained was 120mm and the lowest slump was 75mm. The average slump for each batch of mix was 82mm. Therefore, target slump had been achieved, where the range is from 50mm to 120mm. The workability was good and can be satisfactorily handle for 0% recycled aggregate to 75% recycled aggregate. The slump from 0% recycled aggregate to 75% recycled aggregate were considered moderate due to the drop in the range of 5mm to 9mm. There was no problem for the placement and compaction of fresh concrete in these two batches. The workability was very low due to the slump was just 64mm. The reason was because of the high absorption capacity of recycled aggregate. From the result obtained, it shows that the workability was getting lower when more recycled aggregate were used.

Conclusion and Recommendations

The conclusion and achievements of these studies are as:

In this study, the review and research of current usage to the use of recycled aggregate in the concrete was discussed into different sectors, such as constructions, industries, applications, recycling process, previous research and investigation. Total of four batches of concrete mixes required by the scope of the study. The concrete mixes consisted of every 25% increment of recycled aggregate replacement from 0% to 100%. The investigation and laboratory testing on recycled aggregate concrete specimens such as compression test, indirect tensile test. This study is to determine the strength characteristics of recycled aggregate for potential application in the structural concrete. Furthermore, with the cheaper price of recycled aggregate compared to natural aggregate, the builders can carry out the construction task with lesser material costs. Although recycled aggregate can be applied in the high strength structure, but one issue must not be neglected as recycled aggregate with reduce water content would have low workability. Whenever recycled aggregate is applied, water content in the concrete mix has to be monitored carefully due to the water absorption capacity of recycled aggregate will vary.

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