Recycled aggregate concrete (RAC)- A sustainable approach for construction industry

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Abstract

With the rapid development of the construction industry which requires an excessive consumption of natural resources and may result in the deterioration of the natural environment, the conflicts between the desire to achieve sustainable development of the construction industry and the shortage of resources will become more and more serious, especially in developing countries like India. At the same time, a large amount of concrete waste is produced from both the construction of new buildings and demolition of old buildings every year. Today, the possibility of recycling construction waste, in particular concrete, has become a major issue around the world. The use of recycled aggregate concrete (RAC) is considered to be an effective measure to develop green ecological concrete and achieve sustainable development in the construction industry. As a result, RAC has attracted increasing interest in both academia and industry. A number of studies have been conducted on RAC especially in relation to understanding the mechanical properties of RAC. The objective of this study was to enhance the understanding of the properties that are associated with concrete and different application areas of RAC.

Keywords: Compressive Strength, Concrete, Creep, Recycled Aggregate Concrete (RAC), Shrinkage, Tensile Strength

Introduction

The aggregates that can be produced from the breakup and crushing of existing Portland cement concrete pavement and structural elements is called recycled aggregate. 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 due to long time affect on environment, these can be replaced with recycled 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.

There are many advantages through using the recycled aggregate. The major advantage is based on the environmental gain. According to Commonwealth Scientific and Industrial Research Organization (CSIRO) construction and demolition waste makes up to around 40% of the total waste each year (estimate around 14 million tonnes) going to landfill. Through recycled these material ,it can keep diminishing there sources of urban aggregated. Therefore ,natural aggregate can be used in higher grade applications. The cost of recycled aggregate is cheaper than virgin

aggregate. The transportation cost for the recycled aggregate is reduced due to the weight of recycled aggregate is lighter than virgin aggregate. Besides that, the recycling site may accept these aggregates materials at lower cost than landfill without tax levy and recycled aggregate can be used at a lower prices than primary aggregate in the construction works. recycled aggregates has great potential in concrete. According to Environmental Council of Concrete Organization), recycled concrete aggregate can be used for side walk, curbs, bridge substructures and superstructures, concrete shoulders, residential driveways, general and structural fills. It also mentioned that recycled concrete aggregate can be used in sub-bases and support layers such as unsterilized base and permeable bases Thus, the use of recycled aggregates in concrete provides environmental as well as economics benefits. The present paper reviewed the different studies related to use of recycled aggregate in concrete.

Historical Background

The applications of recycled aggregate in the construction areas are wide and they had been used long time ago. [1] stated that recycled aggregate have been used in the road industry for the last 100years 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. During 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 second world war, there cycling industry had been well established in Europe. The Detroid News stated that in 1980s,the old concrete crushed into a powder was a popular road builder at Michigan, USA.

Properties of recycled aggregate

Physical properties

Recycled aggregate looks like crushed stone (Figure 1). However, the physical properties of crushed concrete differ from those of conventional concrete. In general, crushed concrete particles are more angular have a rougher surface texture than those of natural aggregate. Roughly textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. The lightweight and porous cement mortar attached to the recycled aggregates causes crushed concrete aggregates to have a lower specific gravity and higher water absorption than those of comparatively sized natural aggregates.

Figure 1: Recycled Aggregate

In general, the saturated surface density of recycled aggregates is lower than that of natural aggregates, due to the low density of the mortar that is adhered to the original aggregate. [2] concludes that with the same quantity of mortar, a recycled aggregate that has been obtained from a concrete of higher strength will have a higher density. The saturated surface density of the aggregates depends on their quality. The aggregates with a higher amount of adhered mortar will have a lower density. According to [3] the density changes with the size of the aggregate when concrete is ground with the same grinding machine employing the same amount of energy in the grinding process. Many studies report on intervals of densities (2290 to 2490 kg/m^3) depending on the size of the aggregates. The saturated surface density of recycled aggregate concrete reduces with smaller sizes of aggregates. As mention previously the saturated surface density does not only depend on original concrete strength but also on the kind of crushing or grinding machine employed and the energy used.[3-5] found that the absorption capacity of recycled aggregate increased with a higher amount of adhered mortar. The high amount of adhered mortar in recycled aggregate also produced a decrease in density. In all case it was accepted that absorption capacity was not dependent on the strength of the original concrete.

Strength of recycled aggregate

According to the Los Angeles Abrasion test recycled aggregates obtained by grinding a 40 MPa strength concrete have lower abrasion than aggregates obtained by 16 MPa strength concrete is shown in Table 1. The crushing machine and the power employed in the crushing used by each researcher is unknown, so it must be careful in comparing the results. Los Angeles abrasion is higher when the strength of original concrete is lower due to the lower strength of adhered mortar. According to ASTM C-33 standard "Standard Specification for Concrete Aggregates", the aggregates will be valid to use in concrete production if the loss determined by the "Los Angeles Abrasion test" is less than 50%.

Table 1: Los angle abrasion loss percentage of recycled aggregates obtained by grinding 40 MPa [3]

	Recycled aggregates in abrasion according to several investigators				
Size fraction	4-8 mm	8-16 mm	16-32 mm	5-25 mm	5-13 mm
Los angles abrasion loss percentage	30.1	26.7	22.4	23.0	20.1

Chemical properties

One of the main issues surrounding the use of recycled concrete aggregate in concrete production is the potential for reaction between the recycled aggregates and alkaline water. Alkali-silica reaction results in volumetric expansion, in which there is a high probability of internal fracturing and premature deterioration of the concrete. Where alkali-silica reactivity is of concern, the potential for deterioration should be evaluated (Recycled materials Resource Center, 2004 URL: http://www.rmrc.unh.edu/). Chloride ions from marine exposure can also be present in recycled aggregates. Because of the use of deicing salts as a mechanism to control development of ice on pavement, there is a strong possibility that chloride ions will be present in recycled concrete aggregate. The presence of chloride ions in Portland cement concrete can adversely impact the reinforcing steel within concrete. Reinforcing steel in the presence of chloride ions will react to form iron oxide or rust. If the formation of iron oxide persists, there is a high probability of

delamination of the concrete structure. Since total elimination of all deleterious contaminants is not practical, experimentation is required to determine acceptable levels and to eliminate unnecessary processing cost while providing a quality product. These issues are currently under investigation. These chemical-related cautions apply largely only to use of recycled aggregates in new concrete mixes or asphalt concrete. Many, perhaps most, of the uses for recycled aggregate (such as a road-base or erosion control) are not subject to these limitations.

Effect of recycled aggregate on compressive strength of concrete

Though researchers have reported a reduction in strength in recycled aggregate, it should be noted that the extent of reduction is related to the parameters such as the type of concrete used for making the recycle aggregate (high, medium or low strength), replacement ratio, water/cement ratio and the moisture condition of the recycled aggregate. For example, Katz found that at a high w/c ratio (between 0.6 and 0.75), the strength of recycled aggregate is comparable to that of reference concrete even at a replacement level of 75% [6]. Rao found the strength of recycled aggregate and reference concrete to be comparable even at 100% replacement, provided that the water-cement ratio was higher than 0.55 [7]. However, as the water-cement ratio is reduced to 0.40, the strength of RAC was only about 75% of the reference mix. [8] used concrete from back-fill or road sub-base materials in pavements as recycled aggregates. The maximum coarse aggregate was 16 mm. He compared reinforced concrete with natural aggregates and with recycled aggregates. His results showed that compressive strength of concrete with natural aggregates was 35% higher than compressive strength of concrete with recycled aggregates. In a study by [9] in Japan, it was found that construction industry produced 83 million tons construction waste per year of which, 35 million tons was related to concrete waste. He replaced 30% and 50% of recycled coarse aggregates from building with 30 years age. He obtained 32.6-35.8 MPa compressive strength after 28 days with standard curing condition. [10] focused on characterizing two RAC sources in Ontario and producing novel concrete utilizing recycled aggregate as coarse aggregate in RAC. Three aggregate types were investigated, one control virgin aggregate source and two recycled aggregates produced from the crushing of hardened concrete.

Effect of recycled aggregate on tensile strength of concrete

Research has shown that the tensile strength in concrete depends on micro cracks in the cement paste and on the interfacial transition zone between the cement paste and the aggregates with grain size larger than 4 mm [11]. There are also other factors that play a role for the tensile strength of concrete. But when looking at RAC these two reported effects are crucial. This is because both of these are connected with the water absorption of the concrete, and in RAC the water absorption is much higher than in regular concrete. [12] investigated the tensile splitting strength of RAC. The tensile splitting strength decreases with the amount of recycled aggregate. For 100% recycled aggregate the tensile splitting strength decreased with 20%. The investigation compares the results with previous articles. Those existing articles stated a reduction between 21% and 35%. Both the splitting and the flexural tensile strength were tested in the article by [13]. A replacement of 20 % gave a decrease of 10 % compared with natural aggregate concrete. When recycling the RAC again and adding 80% natural aggregate the decrease was only 5% compared with normal aggregate concrete. The article explains this with a reduction of residual mortar in the second time the concrete is recycled.

Effect of recycled aggregate on modulus of elasticity of concrete

Because of the high residual mortar content in conventional RAC mixes, the modulus of elasticity always seems to be lower [14]. It can also be established that the recycled aggregate amount has a more important influence on the elasticity modulus, than on the compressive strength [12]. But not only has the amount of recycled aggregate had an effect on the modulus of elasticity, the water cement ration played an important role as well. It can be seen in figure 3 that the modulus of elasticity decreases with the increasing of the water/cement ratio. We can also see the big difference between the RAC with 100% replacement and the normal aggregate concrete. Another study also found a reduction on the elasticity modulus [13]. With a 100% replacement of natural aggregates with recycled concrete the loss of the E-modulus was about 16%. This is in fact about the same as in figure 3. Both these articles used conventional proportion methods and did not take into account the residual mortar in the recycled aggregate. [12] finally identifies the process in establishing the modulus of elasticity using the Equivalent Mortar Volume (EMV) method. With only a few exceptions the EMV concrete mixes gave a higher modulus than conventional concrete mixes. It is recommend a replacement ratio of 20 % for recycled aggregate and the use of the EMV method. With this amount of replacement it was not any significant differences observed in the value of the modulus of elasticity.

Effect of recycled aggregate on drying shrinkage and creep

Researching literature has reported that the recycled aggregate has a significant effect on the drying shrinkage and creep. Because the old cement paste reduces the specific gravity, increases the porosity, and the water absorption becomes higher. High water absorption and lower specific gravity leads to higher drying shrinkage and creep. Water absorption in coarse aggregates is 6% higher than in natural aggregates. Fine recycled aggregates have an even higher absorption [15]. However, RAC can offer similar creeping and drying shrinkage as in normal aggregate concrete. This was accomplished by a research team from Canada. The purpose of their investigation was to see how the RAC mixed by EMV method performed in shrinkage and creeping tests. At creeping tests the RAC performed even better than normal aggregate concrete. It was believed that the reason for this result was that the total mortar volume was the same in both the RAC and the normal aggregate concrete. But the fresh mortar crept more than the old mortar in the RAC, and in the normal aggregate concrete the amount of fresh mortar were highest [16].

Conclusion

Recycled aggregate concrete was the focus of this study. In this review various properties of recycled aggregates were discussed like density, porosity, water absorption, compressive strength, tensile strength, modulus of elasticity, creep and shrinkage; recycled concrete aggregates showed inferior results as compared to normal aggregates. the use of recycled aggregates in concrete also provides environmental as well as economics benefits. Overall, addition of recycled aggregate have deteriorating effect on concrete but further research and formation of standards considering the various proportions of recycled aggregates with natural aggregates is valuable.

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