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# Construction waste recycling in sustainable engineering infrastructural development

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## Abstract

Nigeria is a developing Country with a large population and land area. In recent years there has been an increase in the number of construction industries and concrete is the main construction material for most of the structures that are being built. This paper considers the option of recycling construction wastes. This approach is environmental friendly and will reduce cost of construction. To improve the quality of recycled aggregate, the water cement ratio should be decreased or alternatively, fly-ash could be used as an additional cementitious material.

***Keywords:*** Recycled Aggregate, Recycled Aggregate Concrete, Sustainability, Demolition Wastes



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## 1. Introduction

Concrete, mixture of cement, sand and water is the major construction material for all civil engineering works. Today, the rate at which concrete is used is much higher than it was 40 years ago (Mehta and Monteiro, 2006). This assertion is also evident in the rate of infrastructural development in different parts of the world. It has been estimated that approximately 50 million tons of concrete are currently demolished each year in the European Economic Communities (Hansen, 1986). Very little demolished concrete is currently recycled or reused anywhere in the world. The small quantity which is recovered is mainly reused as unstabilized base or sub-base in highway construction. The rest is dumped or disposed of as fill.

Concrete is made by mixing Portland cement with sand, crushed rock, and water. Traditionally, aggregates have been readily available at economic prices and qualities to suit construction purposes. The increase in prices of building materials, human development and knowledge, especially in the industrial age, the concept of recycling old or used materials and reusing them has become both a necessity and a challenge.

Recycled aggregate concrete is the concrete produced from old crushed concretes, as a total or partial replacement of natural aggregates (mainly coarse aggregates). Aggregates produced by crushing of the old concrete could also be referred to as recycled aggregates. Such aggregates can be coarse or fine. Recycled aggregate has been used as a replacement for known natural aggregates for a number of years. The future benefits and drawbacks of using recycled aggregate in concrete have been extensively studied by many researchers, (Collins, 1994; Hansen, 1996; Limbachiya et al., 2000; RILEM, 2000; Buyle-Bodin and Hadjieva-Zaharieva, 2002; Ridzuan et al., 2001; Sagoe-Crentsil et al., 2001; Kou et al., 2004; Poon et al., 2004; Akinkurolere and Franklin, 2005).

Recycled concrete is a viable source of aggregate and has been adequately used in granular sub-bases, soil-cement, and in new concrete. Aggregate processing consists of crushing, screening, and washing of the aggregate to obtain proper cleanliness and gradation. If necessary, a benefaction process such as jigging or heavy media separation can be used to upgrade the quality. The evaluation of numerous experiments has shown that, in most cases, pure demolished concrete as well as demolished masonry can basically be used as aggregates in the production of new concrete. Therefore, based upon these backdrops, cost of dumping either residue of fresh or rejected units in the pre-cast concrete plants is expected to keep rising.

However, the increase in industrial age and human developments has led to researching into possibilities of using recycled concrete materials as a new source of aggregates in the construction industry. The process of the reservation of natural resources, prevention of environmental pollutions and cost reduction consideration in construction project have prompted the re-use of the recycled concrete aggregate for making different construction materials (Poon et al., 2002), producing high-strength/high-performance concrete (Hansen, 1996), or serving as the base or sub-base material in road construction (Collins, 1994). Before this demolished debris can be ready for reuse, crushing and screening are required to produce aggregate within the limits of mixing gradation for either Portland cement concrete or bituminous concrete. As a result of crushing, micro-cracks will remain in recycled concrete aggregate so much that particular attention (for example, high amount of water requirement, smaller specific gravity, and possible reduction in quality and durability, etc.), needs to be paid in advance in order for the product to meet the specific required performance.

## 2. Minimization of construction waste through recycling

The processes of renovation and demolition in the maintenance and modernization of buildings and roads generate large amounts of solid wastes and rubbles, adding to the already vast and continuously increasing solid waste stream. At present, there are shortages of good natural aggregate in many urban areas, and distances between deposits of natural material and sites of new construction have grown larger, while transportation costs have become increasingly higher making recycling an unavoidable option. Also, as mentioned earlier most states in Nigeria are not left out of these infrastructural developments, Figure 1 shows a demolished building in state hospital area of Ekiti State, southwest Nigeria.

Recycling waste concrete as source for the production of new concrete can help control environmental pollution and the problem of depleted natural aggregates. Also, recycling of waste concrete is beneficial and necessary from the viewpoint of environmental preservation and effective utilization of resources. For effective utilization of waste concrete, it is necessary to use waste concrete as recycled aggregates for new concrete (Jianzhuang et al., 2005).

From economic point of view, Recycling concrete is an attractive option for governmental agencies and contractors alike. With recycled aggregates, there is potential for cost savings in hauling.

**Figure 1.** A demolished building around state hospital road in Ado-Ekiti, Ekiti State, Nigeria

## 3. Qualities of recycled aggregate concrete

Currently, there is a widespread move and researches going on aimed at adopting new operational strategies at prevention and minimization of the waste generation. Lots of works have been carried out to determine the suitability and sustainability of recycled aggregate concrete. This paper considers some mechanical properties of recycled aggregate concrete i.e the compressive, tensile and flexural tests.

### 3.1. Rate of strength development and compressive strength

#### *3.1.1. Recycled Aggregate Concrete (RAC) with coarse recycled aggregates and natural sand*

In their works, Limbachiya et al. (2004), the compressive strength test on standard 100mm cubes up to one year after initial curing in water at 20 °C and in air at 20°C/ 55% RH showed that up to 30% recycled coarse aggregates has no effect on the strength of recycled aggregate concrete, but thereafter, a gradual reduction with increasing RCA content occurs. Also, Nixon (1978), based on his review and earlier research concluded that the compressive strength of recycled aggregate concrete is somewhat lower (in some cases up to 20% lower, but usually less) compared with the strength of control mixes of conventional concrete.

Kou et al. (2004) also reported that as the recycled aggregate content increased from 0% to 100%, the compressive strength decreased accordingly. However, the reduction in strength can be either compensated by a decrease in the w/c ratio or with the use of fly ash as an additional cementitious material. They also reported that for example, if a concrete strength of 66 MPa is needed, the concrete could have a water-cement (w/c) ratio of 0.45 without fly ash and a recycled aggregate content of about 6%. Alternatively, the recycled aggregate content could be increased from 6% to 33% by adding fly ash as 25% by weight of cement. If a higher recycled aggregate content is preferred (i.e. 50%), the water-cement ratio could be reduced from 0.45 to 0.4 but no additional fly ash would be required.

Also, according to Ravindrajah et al. (1988), the difference in strength between natural aggregate concrete and recycled-aggregate concrete for a constant w/c ratio is slightly higher at lower values for the water-cement ratio. Frondistou-Yanna (1977) reported that the compressive strength of concrete containing recycled aggregates was within the range of 4-14% lower than that of natural concrete. Wesche and Schulz (1982) compiled earlier results obtained by Buck (1977), Malhotra (1978), and Frondistou-Yannas (1977). An apparent correlation was found between compressive strengths of conventional and recycled aggregate concretes. As it can be seen in Figure 2, recycled concretes consistently had 10% lower compressive strength than control concretes made with conventional aggregate.

Akinkurolere (2008) also reported that at 90 days it appears that replacement with recycled aggregates up to 60% does not have much adverse effect on the compressive strength of recycled aggregate concrete. In addition, at this dose, the rate of increase in strength of recycled aggregate concrete was higher than natural aggregate concrete. This might be due to angular shape and rough texture of recycled aggregates which might have provided better bonding and interlocking between the cement paste and the recycled aggregates themselves compared with those of natural aggregates. Another major reason for this trend might be the absorbent nature of the recycled aggregates which absorbed some of the water during mixing and caused a reduction in the actual water-cement ratio of the recycled aggregate concrete mixes.

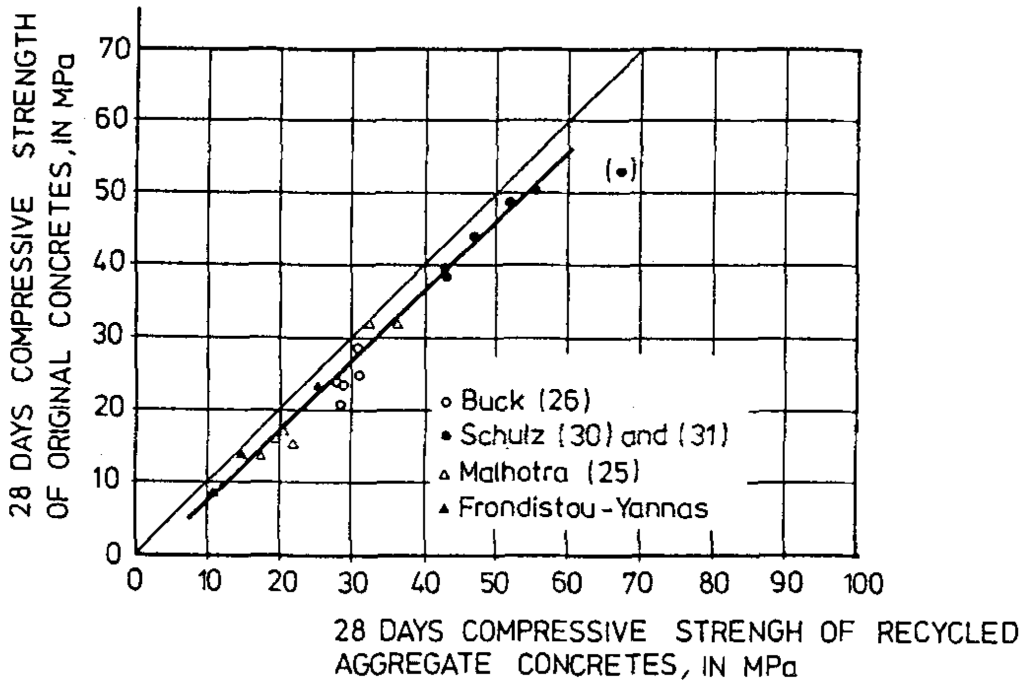


**Figure 2.** Compressive strengths of recycled aggregate concretes as a function of the strengths of original concretes (Wesche and Schulz, 1982)

## 3.2. Tensile and flexural strength

### *3.2.1. Tensile*

BCSJ (1977), Mukai et al. (1978) and Ravindrarajah and Tam (1985) concluded in their works that indirect tensile strength of recycled aggregate concrete made with coarse recycled aggregate and natural sand is not significantly different from that of conventional concrete. However, when both coarse and fine recycled aggregates were used as replacements, the tensile strength of recycled aggregate concretes was up to 20 % lower than that of conventional concrete. Gerardu and Hendriks (1985) reported at most a 10 % lower indirect tensile strength for recycled aggregate concrete made with coarse recycled aggregate and natural sand compared with conventional control concretes made with virgin materials. If the sand is also replaced with crushed concrete fines, the reduction is at most 20 %.

Kou et al. (2004) also reported that similar to the results of the compressive strength, the tensile splitting strength decreased with an increase in the recycled aggregate content. The 90-day tensile strength of concrete prepared with 100% recycled aggregates was 12%, 10% and 9% lower than that of the conventional concrete. Also, when fly ash was incorporated as an additional cementitious material, the splitting tensile strength of the concrete mixtures prepared with 100% recycled aggregates increased by 3%, 6%, and 8%, respectively. The increase in the tensile splitting strength with fly ash could be attributed to the pozzolanic reaction of fly ash and the possible reduction in porosity as a result of the densification effect of the fine fly ash particles.

Akinkurolere (2008) also reported that there is a sharp reduction in rate of tensile strength development. It was noted through the study that at early ages, where there is a higher percentage of recycled aggregates, there was also a higher tensile strength compared to other mixes containing recycled aggregates. Also, for concrete containing high proportions of recycled aggregates the failure of the specimens occurred along the recycled aggregates having been the weakest point.

### *3.2.2. Flexural*

The rate of development of strength at early ages was similar to that of the compressive strength, but greatly reduced at later ages (Akinkurolere, 2008). This increase in strength at early ages and decrease at later ages may be attributed to the rough–textured recycled aggregates. According to Mehta (2006), a stronger physical bond between the rough-textured aggregate and the cement paste is responsible for the increased tensile strength at early ages. However at later ages when chemical interaction between the aggregates and the paste begins to take effect, the effects of the surface texture may not be as important.

BCSJ (1977) found that the flexural strength of recycled aggregate concrete is somewhere between 1/5 and 1/8 of its compressive strength, similar to what is the case for conventional concrete, but no experimental data was presented. Meanwhile, Ravindrarajah and Tam (1985) found no significant difference in flexural strength of conventional concrete and recycled aggregate concrete made with coarse recycled aggregate and natural sand. Lastly, Katz (2003) concluded in his work that the ratio of the flexural and the splitting strengths to the compressive strength is in the range of 16–23% and 9–13%, respectively. These values are about 10–15% lower compared to the recommendations of ACI 363R.

## 4. Conclusion

Numerous laboratory experiments, field tests, and full scale pavement rehabilitation projects have shown that it is possible to recycle concrete to produce aggregate for construction. Recycling of concrete to produce structural grade concrete for other purposes is technically feasible provided certain precautions are taken. Giving contractors the option to recycle will determine the economic feasibility of such operations.

The construction industry must aim at durability and sustainability. The development of technologies for the recycling of concrete and the market for various types of recycled aggregate concrete materials has proved the viability and sustainability of recycling concrete. The truth however, is that there is a long way to go before this level of recycling can be attained in developing countries such as Nigeria, where many other environmental problems must be prioritized. Feasibility of this is based on economics, policies & strategies, certification of recycled materials, planning of demolition projects, and education and information. The successful implementation of recycling in the future should be part of Government's vision in order to save natural resources and protect the environment.

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