Reusing Concrete from Construction and Demolition for Sustainable Structures

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Abstract

This study experimentally demonstrated that recycling concrete is an effective method for sustainably managing construction and demolition waste. Consequently, 48 standard concrete cube specimens were produced, cured, and subsequently crushed. Of these, 24 cubes were made from recycled aggregates, while the remaining 24 were created using virgin aggregates. The findings indicated that at elevated water/cement ratios, the compressive strength of recycled concrete is comparable to that of virgin concrete; however, at reduced water/cement ratios, the compressive strength of recycled concrete is significantly lower than that of virgin concrete. Specifically, at water/cement ratios of 0.5 and 0.6, the compressive strength ratio of recycled concrete to virgin concrete was 0.89 and 0.985, respectively, at a crushing age of 28 days, and 0.5 and 0.95, respectively, at a crushing age of 7 days. Furthermore, the slump and compacting factor tests indicated that the workability of the virgin concrete mix surpasses that of the recycled concrete.

Keywords: Recycled, Virgin Aggregate, Construction and Demolition, Waste, Strength

1. Introduction

The performance of materials in engineering is no longer evaluated solely based on technological specifications; it is now also assessed in terms of its environmental impact. Sustainable building, often referred to as green construction, involves the creation of structures and the implementation of processes that are environmentally responsible and resource-efficient throughout the entire life-cycle of a building: from site selection to design, construction, operation, maintenance, renovation, and deconstruction [1]. Therefore, sustainable construction is a facet of sustainable development, which is defined as development that fulfills the needs of the present without jeopardizing the ability of future generations to satisfy their own needs [2]. Consequently, sustainable construction should utilize resources efficiently while minimizing negative effects on the environment [3]. The recycling and reuse of construction and demolition (C & D) debris is one element of sustainable or green building practices. The EPA characterizes C & D debris as "waste material generated during the construction, renovation, or demolition of structures. These structures encompass all types of buildings (both residential and non-residential) as well as roads and bridges. Typical components of C & D debris include concrete, asphalt, wood, metals, gypsum wallboard, and roofing" [3]. Historically, when concrete structures were demolished or renovated, the resulting concrete debris was commonly transported to landfills for disposal. However, in today's era of heightened environmental awareness, increased environmental regulations, and the need to lower construction costs, recycling has emerged as a more appealing method for managing the debris.

Effective waste management through the reduction of construction waste or demolition debris that is sent to landfills is an essential aspect of sustainable building practices [4]. Globally, concrete recycling has been recognized as a key element in the responsible management of construction and demolition (C & D) materials. This is due to the numerous advantages it provides, such as preventing concrete debris from occupying landfill space, thus conserving that space, decreasing the need for mined concrete aggregate which in turn saves energy and resources, lowering overall project expenses by reducing the costs associated with concrete rubble disposal, and lessening the environmental impact caused by transporting materials over long distances [5]. In various countries, including the United States, Japan, the Netherlands, the United Kingdom, former Soviet Union nations, Germany, and Denmark, there are already established codes, standards, and testing methods for recycled aggregate concrete, or they are currently under consideration [6]. In Nigeria, the government's renewed commitment to urban areas (particularly cities like Akure in the southwest, designated as a millennium city) to adhere to the original development master plan has resulted in significant demolition and reconstruction activities that generate large amounts of C & D debris. Figure 1 illustrates a demolition project taking place on Arakale Street, Akure, to facilitate road dualization. The solution to the responsible management of this debris is found in recycling.

Figure 1: Panorama of Arakale Street Undergoing Building Demolition

Numerous research studies support the notion that coarse aggregates, along with a limited quantity of fines derived from construction and demolition (C & D) concrete debris, can be repurposed for the manufacture of concrete intended for new construction without a significant decline in quality [7 – 12]. Nevertheless, despite this evidence, the adoption of recycled aggregates in fresh concrete has not yet achieved the desired level of acceptance within the local building construction industry in Nigeria. This is primarily due to the insufficient experimental data regarding the performance characteristics of recycled local aggregates utilized in new concrete applications. Consequently, this research aims to contribute such data. This objective will be accomplished by evaluating the workability and strength of recycled concrete in comparison to that of conventional (virgin) concrete through laboratory experiments.

2. Materials and Methods

2.1. Recycled Aggregates

The construction and demolition concrete aggregates designated for recycling were sourced from the debris of a demolished concrete wall located on Arakale Street, Akure. The site is illustrated in Fig.2.

Figure 2: Demolished Wall Source of Recycled Concrete Aggregate

A sledgehammer was employed to drive a chisel into the damaged concrete wall. The chiseled section subsequently fragmented into smaller pieces. An ordinary hammer was then utilized to further dismantle the structure, ensuring that the coarse aggregates were not crushed by the hammer's impact. Sieving was conducted using a 5.0mm sieve size to separate the fines from the coarse aggregates. Both types of aggregates were soaked in water for a duration of 3 days, during which a long stick was intermittently used to stir the mixture, thereby enhancing the separation of the adhered cement paste. After soaking, all particles were dried by spreading them on a concrete floor and exposing them to sunlight. Periodic turning was performed with a shovel to guarantee that all particles were thoroughly dried. The grading of the aggregates was executed in accordance with the standards set forth in BS 812 – 103.1 [13].

2.2. Virgin Aggregates

The virgin aggregates utilized were identical to those found in the demolished structure. Consequently, the coarse aggregate consisted of crushed granite, while the fine aggregate was sharp sand. The results from the sieve analysis of the recycled aggregate were then employed to grade the virgin aggregates size by size.

For each sieve size and the corresponding weight of recycled aggregate retained, an equal weight of virgin aggregate of the same size was separately measured. The various weights of the virgin aggregate were subsequently combined to create a continuously graded aggregate, simulating the recycled aggregate.

2.3. Concrete Mix

A nominal mix ratio of 1:2:4 was utilized to create concrete using both recycled and virgin aggregates. The batching process was conducted by weight, adhering to the method outlined in BS 5328 – 2 [14]. Ordinary Portland cement served as the binding agent. Two distinct mixes were formulated with recycled aggregates, corresponding to water/cement ratios of 0.5 and 0.6. The selection of a water/cement ratio of 0.5 was based on initial trial mixes, which indicated that lower ratios resulted in a concrete mix with zero slump and a very harsh texture, leading to poor workability. Conversely, the upper ratio of 0.6 was chosen because preliminary tests performed at the Civil Engineering Department of the Federal University of Technology, Akure, indicated that the ideal workability and strength characteristics for both recycled and virgin concrete fall within a water/cement ratio range of 0.5 to 0.6. Additionally, two mixes with comparable water/cement ratios were prepared using virgin aggregates. Slump tests and compacting factor tests were conducted for each of the four resulting mixes. The compacting factor test was deemed necessary as the mixes from both recycled and virgin aggregates at a water/cement ratio of 0.5 exhibited zero slump, signifying that they were dry mixes.

2.4. Concrete Cube Crushing

The standard cube dimension of 150mm was utilized for the concrete test cubes. A total of 48 cubes were cast, with 24 cubes each made from recycled aggregates and virgin aggregates. The cubes were prepared and cured following the guidelines of EN 12390 – 2 [15]. The compressive strength of the cubes was evaluated in accordance with the specifications of EN 12390 – 3 [16]. For both recycled and virgin aggregate concrete, 3 cubes were crushed sequentially at maturity ages of 7, 14, 21, and 28 days for water/cement ratios of 0.5 and 0.6 to ascertain their compressive strengths. The compression testing apparatus employed was the Compact – 1500, which has a maximum capacity of 1560kN crushing load. While the relevant strength of concrete for design purposes is typically its strength at 28 days, the strengths at 7, 14, and 21 days were also examined, as is commonly practiced, to observe the variation in strength with age, which can be crucial for concrete applications where specific minimum strength levels must be achieved at early ages.

3. Results and Discussion

The outcomes of the slump and compacting factor tests are presented in Table 1, while a summary of the compressive strength values for the two types of concrete is provided in Table 2 and illustrated graphically in Fig.3 for a water/cement ratio (w/c) of 0.5 and in Fig.4 for a w/c of 0.6.

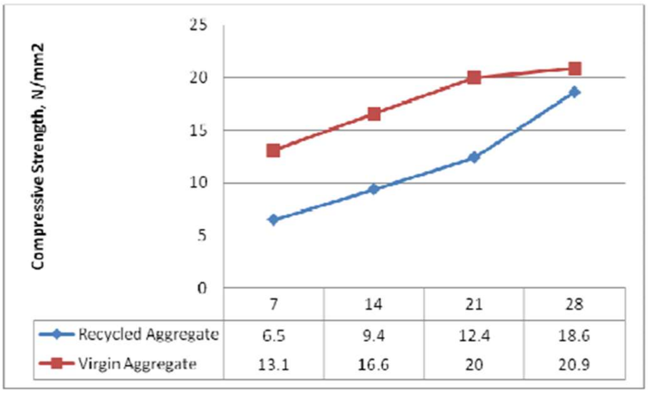
Table 1: Results of Slump and Compacting Factor Tests

Aggregate Type	Water / Cement Ratio	Slump, mm	Compacting Factor
Recycled	0.5	0	0.70
	0.6	5	0.85
Virgin	0.5	0	0.76
	0.6	40	0.93

Table 2: Summary of Compressive Strength Results

Aggregate Type	Water / Cement Ratio	Mean Compressive Strength, N/mm²			
		Age, Days			
		7	14	21	28
Recycled	0.5	6.5	9.4	12.4	18.6
	0.6	11.5	12.0	15.0	19.6
Virgin	0.5	13.1	16.6	20.0	20.9
	0.6	12.1	15.5	18.6	19.9

Figure 3: Compressive Strength of Concrete for w / c = 0.5



The findings from both the slump test and the compacting factor test indicate that the workability of recycled concrete is inferior to that of normal (virgin) concrete when the water/cement ratio is held constant. This implies that a greater amount of water is required for recycled concrete to achieve the same level of workability as virgin concrete. While recent studies have established that virgin concrete typically exhibits superior workability compared to recycled concrete, the current study quantitatively presents the slump values and compacting factor ratios for specific water/cement ratios of 0.5 and 0.6.

The results regarding compressive strength demonstrate that at lower water/cement ratios, the strength of recycled concrete at various maturity ages examined is significantly lower than that of virgin concrete. Conversely, at higher water/cement ratios, the compressive strength of recycled concrete aligns closely with that of virgin concrete.

According to the findings of this study, at the maturity age of 28 days, the compressive strength of recycled concrete was merely 89% of that of virgin concrete at a water/cement ratio of 0.5. However, at a water/cement ratio of 0.6, the compressive strength of recycled concrete reached as high as 98.5% of that of normal concrete. Furthermore, the rate of strength gain prior to the age of 28 days is considerably slower for recycled concrete compared to virgin concrete, particularly at lower water/cement ratios. Consequently, at 7 days, the strength of recycled concrete is approximately 50% of the strength of virgin concrete at a water/cement ratio of 0.5 and around 95% of the strength of virgin concrete at a water/cement ratio of 0.6.

4. Conclusions

The following conclusions can be drawn from this investigation:

a) At equivalent water/cement ratios, the workability of virgin concrete surpasses that of recycled concrete.

b) In contrast to virgin concrete, where the compressive strength diminishes as the water to cement ratio rises, recycled concrete exhibits the opposite behavior; specifically, its strength improves as the water to cement ratio increases.

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