NIPES

Journal of Energy Technology and Environment

Journal homepage: www.nipesjournals.org.ng

Pre-treatment of Recycled Concrete Aggregates with Sulphuric Acid and Water: Effect on Strength and Water Absorption

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Article information

Article History
Received 5 May 2022
Revised 28 May 2022
Accepted 31 May 2022
Available online 13 June 2022

Keywords:
Construction waste, Demolition waste, Recycled concrete, Natural aggregates, Compressive strength, Water absorption

https://doi.org/10.37933/nipes.e/4.2.2022.10

https://nipesjournals.org.ng

Abstract

The use of recycled aggregates obtained from construction and demolition waste can generally result in the conservation of natural aggregates and a decrease in the need for landfills. However, one major issue surrounding the use of recycled aggregates is the cement paste that is attached to the surface of the aggregates, which will need to be removed. In this paper, two methods were adopted for the removal of the adhered cement paste on the surface of the recycled aggregates – one involving the use of water and the other involving the use of dilute sulphuric acid. Five concrete mixes were prepared – four using the treated recycled concrete aggregates and a control mix prepared with natural aggregates. Compressive strength and water absorption tests were conducted on the hardened concrete samples. The results obtained showed that concretes made from recycled concrete aggregates have inferior strength and water absorption properties to those made from natural aggregates. Comparing the two methods of treatment, it was observed that higher strengths were obtained for the concrete samples containing water treated recycled aggregates, while lower water absorption values were obtained for the concrete samples containing acid treated recycled aggregates. Based on the findings of the study, it was seen that there is potential in the use of recycled concrete aggregates in the production of concrete for structural applications

1. Introduction

Concrete is the second most consumed material in the world after water. It is estimated that the current consumption of concrete is about 25 billion tonnes every year in the world [1]. In terms of usage in construction works, it has been reported that concrete is used as much as twice the total of the other construction materials such as steel, wood, plastic and aluminum [1]. As other materials, the use of concrete results in the generation of waste. It is estimated that more than 900 million tons of construction and demolition waste (C&DW) is being generated yearly in Europe, USA and Japan [2].

Most developed nations of the world like USA, China, Spain, etc. are already adopting C&DW in the production of concrete [2,3]. Likewise, recent studies seem to suggest that construction and demolition waste are also being utilised in various construction activities in some of the developing countries. For example, Olaoye et al. [4] observed in their study on the viability of recycled concrete waste as construction material for a sustainable environment that concrete produced with recycled concrete waste aggregate, though exhibiting lower compressive strength could be used for walkways and kerbs production in road construction. In another study, Mudashiru et al. [5] investigated the reuse of construction and demolition waste in some selected areas in Ilorin metropolis in North central Nigeria. They observed that there were specific construction and demolition wastes that were being reused and that most of the construction and demolition wastes were either given away or sold at low prices to prevent storage and transportation of the wastes.

Generally, a concrete produced with the inclusion of construction and demolition wastes is known as recycled aggregate concrete (RAC). Despite the numerous studies that have been conducted on the viability of using recycled aggregates in the production of concrete, many persons still prefer to use the natural aggregates in the production of concrete. The reason for this is not far-fetched. It is due to the cement paste or mortar that is attached or adhered to the surface of the recycled aggregate. This adhered mortar or paste has a negative impact on the absorption ratio and specific gravity of the recycled concrete aggregates [6]. Thus, the main challenge associated with the use of recycled aggregates in concrete production is the removal of the adhered mortar on the surface of the recycled aggregates.

Over the past two decades, several researches have been carried out with the objective being to determine the most effective method of removing the adhered cement mortar from the surface of the recycled aggregate. Amongst these methods are the mechanical methods in which the adhered cement mortar/paste is removed by physically crushing and grinding the waste concrete, and the advanced methods using heat or acid [7]. While the crushing method can result in a substantial reduction of the cement mortar/paste content, there are concerns of increased costs and an overall decrease in the production volume of the recycled coarse aggregates as it involves the crushing of relatively weak coarse aggregates into fine aggregates [8,9]. One way to solve these issues is to use acid to remove the cement paste adhered to the surface of the aggregates. This is possible because the cement paste is alkaline, and can thus be removed via a neutralization reaction between the alkaline cement paste and the acid. It has been reported that the use of sulfuric and hydrochloric acids results in a high rate of cement paste removal [7,10,11]. However, despite the high success rate of removal of the adhered cement paste by acids as reported in the literature, there are other negative impacts the use of acids are bound to have on the properties of the concrete produced from acid treated recycled aggregates. Knowledge of these effects is important as it will help in the proper utilisation and incorporation of recycled concrete aggregates in concrete production. This paper considered two methods of removing this adhered mortar/paste – water and acid, and compares the effectiveness of these methods using strength and water absorption.

2. Methodology

2.1 Materials

Cement:

The cement used for this study was Portland cement, which was obtained from a local vendor in Benin City in Edo State, Nigeria. The physical and chemical properties of the cement are shown in Tables 1 and 2 respectively.

Table 1: Physical properties of the cement

Property	Value
Color	Grey
Specific gravity	3.15
Specific surface area (cm^2/g)	3540

Table 2: Chemical properties of the cement

Property	Portland cement
Lime (CaO), %	62.8
Alumina (Al_2O_3), %	5.4
Soluble silica (SiO_2), %	20.3
Iron oxide (Fe_2O_3), %	3.9
Magnesia (MgO), %	2.7
Sodium oxide (Na_2O), %	0.14

Aggregates:

The fine aggregate used in the study was obtained from a quarry site in Edo State, Nigeria. The impurities were removed so it conforms to the requirements of BS 882:1992 [12]. Sieve analysis conducted on it placed it at Zone II, with a maximum particle size of 4.75 mm and a specific gravity of 2.57. The coarse aggregate used was crushed granite, with a nominal maximum particle size of 20 mm, and a specific gravity of 2.71. The properties of the fine and coarse aggregates used for the study are shown in Table 3.

Table 3: Properties of aggregates

Property	Fine aggregate	Coarse aggregate
Specific gravity	2.57	2.71
Density	1.52	1.61
Zone	II	N/A
Maximum size of aggregate	5mm	20mm

Recycled aggregates:

The recycled aggregates were extracted from concrete cubes left in the structural section of the Civil and Structural Engineering Laboratory in the University of Benin, Benin City, Edo State (see Plate 1). In preparing the recycled aggregates, the concrete cubes were first crushed manually using sledge hammers. Afterwards, the aggregates were manually removed from the rubble and placed in two separate buckets. Water and 0.1M sulphuric acid were placed in each of the buckets, and the aggregates were soaked for 7 days and thereafter dried under air for 3 days.

(a) (b)

Plate 1: (a) Recycled concrete dumpsite (b) Extracted aggregates from the recycled concrete

Water:

Potable water as obtained from the University's main water supply was used for mixing the concrete. The water was free from all forms of impurities and organic matter. It conforms to BS EN 1008:2002 [13] requirements.

Sulphuric acid:

The sulphuric acid used for the study was purchased from a local chemical vendor in Benin City, Edo State. The acid was diluted to 0.1M and this was used to pre-treat the recycled concrete aggregates (RCA). To make the 0.1M sulphuric acid, 0.04cm^3 of concentrated sulphuric acid was mixed with 9.96 litres of water. Distilled water was used to prepare the 0.1M sulphuric acid.

2.2. Concrete mix

Five different concrete mixes were adopted for the study, each with 28 day target strength of 30 MPa. The first mix designated as NCA, is the control mix and does not contain recycled aggregate. The remaining four mixes contain either water treated recycled aggregates (WTA) or acid treated recycled aggregates (ACT), at proportions of 15% and 30% by weight of the natural coarse aggregates (as shown in Table 4). For each of the mixes, the various constituents (binder, water and aggregates) were weighed separately and placed in the concrete mixer. After mixing, the concrete was placed into 100 mm cube moulds. The moulds were covered with thin polythene sheets and left to cure in the laboratory for at least 24 hrs, after which the cubes were demoulded and placed in the curing tub to cure under water for 28 days.

Table 4: Mix proportions of the starting materials

Mix designation	Natural coarse aggregates	Water treated coarse aggregates	Acid treated coarse aggregates
NCA	100%	0%	0%
WTA15	85%	15%	0%
ACT15	85%	0%	15%
WTA30	70%	30%	0%
ACT30	70%	0%	30%

2.3. Test methods

Compressive strength:

Compressive strength was determined on triplicate samples of the mixes in Table 4, at specific ages of 3, 7, 14 and 28 days. At the test age, the concrete cubes were brought out from their respective curing environment, surface dried (as applicable), and weighed before testing. The compressive strength (in MPa) was taken as the average failure load (in kN) divided by the cross sectional area of the concrete cube (in mm^2), as shown in the expression below:

$$P = \frac{F}{A} \quad (1)$$

Water absorption test:

Water ingress tests were carried out according to BS1881-122:2011 [14]. After 28 days of curing, the concrete samples were immersed completely in water for 24 hrs. The mass of the samples were recorded before and after immersion in the water, and the water absorbed (W_a) as a percentage was obtained using the expression below.

$$W_a = \frac{(M_t - M_d)}{M_d} \times 100 \quad (2)$$

3. Results and Discussion

3.1. Compressive strength

The compressive strength of the concrete cubes obtained at 3, 7, 14 and 28 days, are shown in Figure 1. From the figure, it can be seen that the compressive strength of the concrete samples prepared with the natural coarse aggregates (NCA), were generally higher than those prepared with recycled concrete aggregates (RCA). This agrees with previous studies by [15–17] and can be attributed to the presence of the old mortar, which will always remain attached to the recycled aggregate particles [18]. It can also be seen that as the proportion of the recycled aggregates increased, the compressive strength decreased accordingly. For instance, at 7 days, the strength of the concrete mix containing 15% of water treated recycled aggregates was about 10% lower than that of the concrete mix without recycled aggregates. Comparing the methods of pre-treatment, it can be seen that the concrete samples containing the recycled aggregates treated with water had overall superior strength than those containing recycled aggregates treated with sulphuric acid. However, irrespective of the method of pre-treatment employed for the recycled concrete aggregates, the 28-day strength of all the concrete samples was greater than 30MPa, which was the target strength.

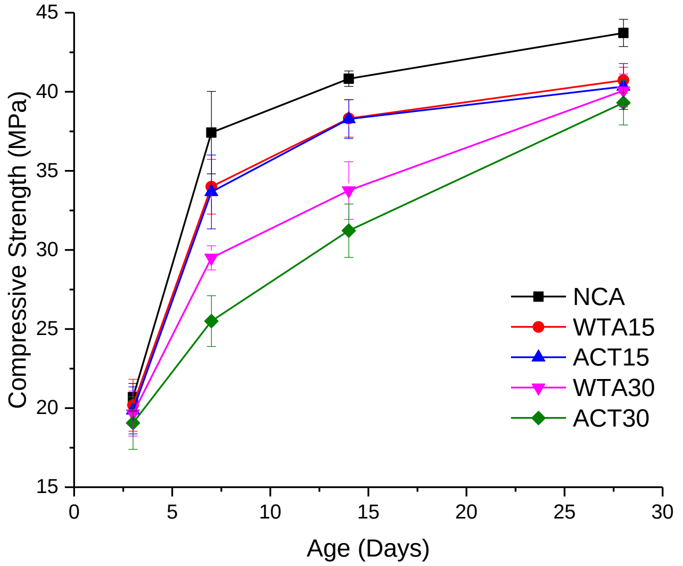

Figure 1: Compressive strength development for the various mixes

Strength deterioration ratios (SDR) were computed for the concretes containing the recycled aggregates. SDR is defined as the ratio of the strength loss of the concrete samples containing recycled aggregates relative to the strength of those without recycled aggregates [19]. The computed SDRs for 7 and 28 days strength are shown in Table 5. From the table, the SDR can be seen to increase with the proportion of the recycled aggregates in the mix. It can also be seen that the concrete samples containing the acid treated recycled aggregates had higher strength deterioration ratios as compared with those that were containing water treated recycled aggregates. The lower strength of the acid treated aggregates may have been caused by the reaction of the sulphuric acid with calcium hydroxide, which will result in the formation of gypsum that can be easily washed away [20]. Similar findings were also reported by [10,11].

Table 5: Computed strength deterioration ratios for the water and acid treated RCA concrete

Mix ID	**7 day SDR**	**28 day SDR**
WTA 15	9.14%	6.83%
ACT 15	10.02%	7.75%
WTA 30	21.16%	8.33%
ACT 30	31.85%	10.11%

3.2. Water absorption

Figure 2 shows the results of the water absorption for the natural coarse aggregate (NCA) samples and the recycled concrete aggregates. From the figure, it can be seen that the amount of water absorbed by the concrete samples increased with time. In particular, the concrete samples that did not contain recycled aggregates recorded overall lower percentages of water absorbed as compared to the concrete samples containing recycled aggregates. The reason for the increased water absorption of the recycled concrete aggregates is the adhered mortar on the surface of the recycled aggregate [21]. The adhered mortar is a porous material; and therefore, will allow more ingress of water into the concrete [11,22]. It was also observed from the figure that the acid treated recycled aggregate concrete (ACT) had lower percentages of water absorbed than the water treated recycled aggregate concrete (WTA). This implies that the acid treated recycled aggregates had lower mortar adhered to the surface of the aggregates, and tends to suggest that the acid treatment resulted in more removal of the adhered mortar from the surfaces of the recycled concrete aggregates.

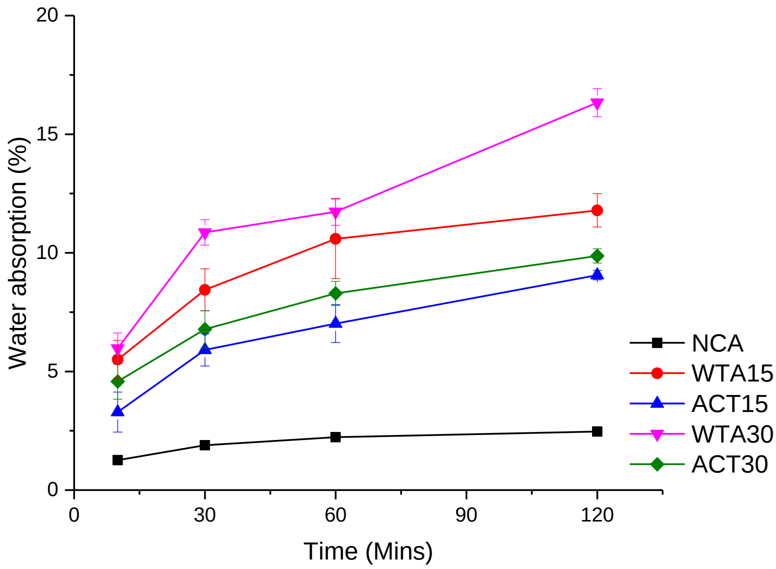

Figure 2: Percentage of water absorbed by the various concrete samples

4. Conclusion

This study focused on studying the effects of the method of pre-treatment of recycled concrete aggregates on the strength and water absorption properties of the concretes made from these treated recycled concrete aggregates. Two different pre-treatment methods were used – one involving the use of water and the other involving the use of diluted sulphuric acid. The results obtained from the study showed that the use of recycled concrete aggregates in concrete will result in a weaker and more porous concrete. The pre-treatment method involving the use of water produced concretes that were slightly better in terms of strength than those that were pre-treated using dilute sulphuric acid. In contrast, the acid-treated samples appeared to have better water resistant properties than the water-treated samples.

Overall, the findings of the study are promising and show that there is potential in the use of recycled concrete aggregates in the production of concrete for structural applications. This is important for construction practices as it can lead to a significant reduction in the cost of construction as against where natural aggregates are used. However, other factors such as the time and cost of the pre-treatment process have to also be considered.

Nomenclature

A	Cross sectional area (mm^2)
ACT	Acid treated recycled aggregate
C&DW	Construction and demolition waste
F	Failure load (kN)
M_d	Mass of dry sample (g)
M_t	Mass of sample after time *t* (g)
NCA	Natural coarse aggregate
P	Compressive strength (MPa)
RAC	Recycled aggregate concrete
RCA	Recycled concrete aggregate
SDR	Strength deterioration ratio
W_a	Percentage of water absorbed
WTA	Water treated recycled aggregate

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