



Mechanical Properties of Concrete Utilizing Metakaolin - Cement Coated Recycled Aggregates

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Abstract

The Research supports using recycled concrete aggregates (RCA) as an economical and eco-friendly substitute for natural aggregates (NA) in concrete. However, RCA's higher water absorption reduces its engineering performance compared to NA. To address this, pretreatment methods like thermal, mechanical, and chemical processes have been proposed. This study specifically tested the effect of metakaolin - cement coated recycled aggregates on the compressive and tensile strength of concrete where RCA replaced 10-20 mm natural coarse aggregate at levels of 0, 20, 30, 40, 50, and 100% (by weight). Results showed that while RCA addition generally reduces concrete strength, coating the aggregates mitigates this effect. Notably, concrete with 100% coated RCA showed compressive and tensile strength improvements of approximately 7.5% and 7.7%, respectively, compared to concrete with 100% untreated RCA.

Keywords: Recycled aggregates, Replacement level, Coating, Compressive Strength, Splitting Tensile Strength.

1. Introduction

Recycled concrete aggregates (RCAs) are increasingly recognized as a vital sustainable substitute for natural aggregates (NAs), offering a dual benefit of waste reduction and resource conservation. Life cycle assessments indicate that RCAs are more cost-effective and produce lower carbon emissions than their natural counterparts [1, 2]. Despite these advantages, RCAs often possess inferior physical characteristics, such as higher porosity, increased permeability, and lower density [3, 4]. These deficiencies-primarily caused by porous adhered mortar on the aggregate surface-lead to higher water absorption rates and a weakened interfacial transition zone (ITZ) [5]. Consequently, the use of RCAs can compromise the workability of fresh concrete and the mechanical strength of hardened structures [6, 7]. To mitigate these effects, researches have focused on various pretreatment methods designed to strengthen the ITZ and improve overall aggregate quality [8-12]. Research by Zhu et al. [12] demonstrated that treating recycled aggregates with silica fume significantly bolsters the mechanical properties of concrete. This enhancement occurs because silica fume refines the aggregate surface and narrows the interfacial transition zones; specifically, it penetrates and seals capillary cracks



rather than merely coating the exterior like traditional cement. The use of treated aggregates improved the mixture's stagnation and allowed for higher replacement levels. The current experimental study evaluates the impact of metakaolin - cement coated recycled aggregates (MRCA) on the 28-day compressive and tensile strengths of concrete. To assess performance, eleven distinct mixtures were developed, replacing 10-20 mm natural coarse aggregates with varying percentages (0%, 20%, 30%, 40%, 50%, and 100%) of both treated and untreated recycled materials.

2. Material and Methods

2.1 Materials

This study used CEM I 42.5N cement, commercially sourced and conforming to BS EN 197-1:2000; its properties are listed in Table 1. Recycled concrete aggregates (RCA) were obtained from a demolished six-story building in Benghazi. The concrete waste was manually crushed to achieve a combined gradation, then separated into 20 mm, 10 mm, and 5 mm fractions (Figure 1). Aggregate sieve analysis followed BS 812-103.1:1985. Physical properties (specific gravity, water absorption) for both natural aggregates and RCA, determined per BS 812-2:1995, are given in Table 2. Natural sand had an apparent specific gravity of 2.50 and 0.66% water absorption. Sieve analysis results for the recycled aggregates used in concrete mixes are shown in Table 3. Potable tap water from the laboratory supply was used for all mixtures. Kaolinite clay stones sourced from Sebha were crushed to pass 12.5 mm-sieve, then heat-treated at Wadi Al-Shatti University's Faculty of Engineering to produce metakaolin (MK). The samples underwent gradual heating in an oven (Figure 2), taking 1 hour 36 minutes to reach 800°C, followed by a 2-hour hold at that temperature. After slow, moisture-free cooling, the material was ground to pass a 0.075 mm sieve. The resulting MK was bagged, stored dry, and prepared for experimental use. Its chemical composition is presented in Table 4.

Table 1 Physical and chemical analysis of used cement.

Item	Cement
Physical properties	
Specific gravity (g/cm ³)	3.13
Fineness (m ² /kg) (Blaine)	320
Chemical properties (Oxides, % by weight)	
SiO ₂	20.86
Al ₂ O ₃	5.6
CaO	62.39
Fe ₂ O ₃	4
MgO	1
SO ₃	2.93
K ₂ O	-
L.O.I	2.52



Figure 1: Recycled coarse aggregates.

Table 2 Properties of natural aggregates & recycled coarse aggregates.

Type of aggregate	NA	RCA
Specific density	2,54	2.40
Water absorption (%)	2.53	6.35
Impact Value (%)	18	29.7

Table 3 Sieve analysis of coarse and fine aggregates.

Sieve (mm)	Passing (%)	
	Coarse	Fine
20	100	-
14	79	-
10	35	-
5	2	100
2.36	0.1	100
1.18	-	98.92
0.6	-	85.86
0.3	-	9.86
0.15	-	0.08

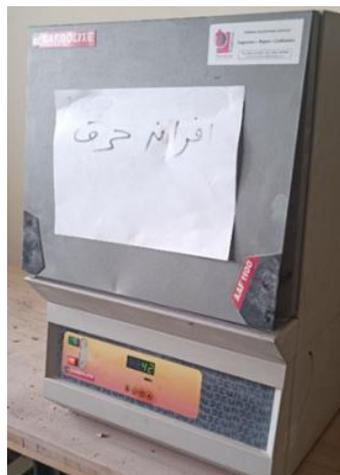


Figure 2: Oven used to heat Kaolinite clay.

Table 4 Chemical composition of metakaolin.

CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	Cl	Na ₂ O	MnO	P ₂ O ₅
6.86	56.14	32.74	2.41	0.16	0.60	0.01	0.07

2.2 Coating Treatment of RCA

The recycled concrete aggregates (RCA) were soaked for 5 minutes in a solution comprised of 4.5% metakaolin (MK), 45.5%, cement and 50% water. Subsequently, the aggregate was dried at room temperature for 3 days, after which it was ready for use.

2.3 Proportions and Mixing Procedure

The proportions of all concrete mixtures are specified in Table 5. Mixing was conducted in a laboratory pan mixer having a capacity of 0.06 m³. The sequence of ingredient addition was coarse aggregate, cement, and fine aggregate. These dry constituents were mixed for 30 seconds. Water was subsequently added gradually over a 15-second period, and mixing continued in the wet state for a further 2.5 minutes, achieving a total mixing duration of 3 minutes per mixture. Following mixing, the concrete was placed into molds, compacted using a vibrating table, and the top surface leveled and finished with a trowel.

Table 5 Proportions for concrete mixes.

Replacement Level (%)	Kg/m ³						
	Cement	Water	Sand	Coarse aggregate			
NA 5-10 mm				NA 10-20 mm	RCA 10-20 mm	MRCA 10-20 mm	
0	350	175	630	380	880	-	-
20	350	175	630	380	704	176	-
30	350	175	630	380	616	264	-
40	350	175	630	380	528	352	-
50	350	175	630	380	440	440	-
100	350	175	630	380	-	880	-
20	350	175	630	380	704	-	176
30	350	175	630	380	616	-	264
40	350	175	630	380	528	-	352
50	350	175	630	380	440	-	440
100	350	175	630	380	-	-	880

NA: Natural aggregates; RCA: Recycled concrete aggregates; MRCA: Surface-coated recycled aggregates

2.4 Curing of Specimens

After casting, the concrete specimens were covered with thin plastic sheeting and cured in the lab for 24 hours. They were then demolded and submerged in curing water until testing.

2.5 Testing of Specimens

A standard cylinder (100 mm diameter × 200 mm height) was tested for indirect tensile strength according to BS 1881-117:1983, while compressive strength was determined using 100 mm cubes per BS 1881-116:1983. Fresh concrete workability was assessed via the slump test following BS 1881-102:1983. For aggregates, water absorption and specific gravity were tested per BS 812-2:195, and the aggregate impact value was determined according to BS 812-3:1975.

3. Results and Discussion

3.1 Properties of Aggregates

Figure 3 presents the specific gravity, water absorption and impact value's results of natural and recycled aggregates before and after treatment. The specific gravity of the NA is 2.54, while that of the RCA is 2.40, making RCA 3.05% lower in density compared to NA. The specific gravity of MRCA is 2.40. It can be also seen from the results that the impact strength of RCA is 65% lower compared to NA. The impact strength of MRCA is 28.5%, representing a 4% improvement compared to the RCA. According to the absorption results shown in the graph, absorbency of NA is 2.53%, while that of RCA is 6.35%. The absorbency of the RCA is approximately 2.5 times higher compared to the NA. The absorption value of the MRCA is 6.04%, representing a 4.88% improvement compared to that of the untreated RCA.

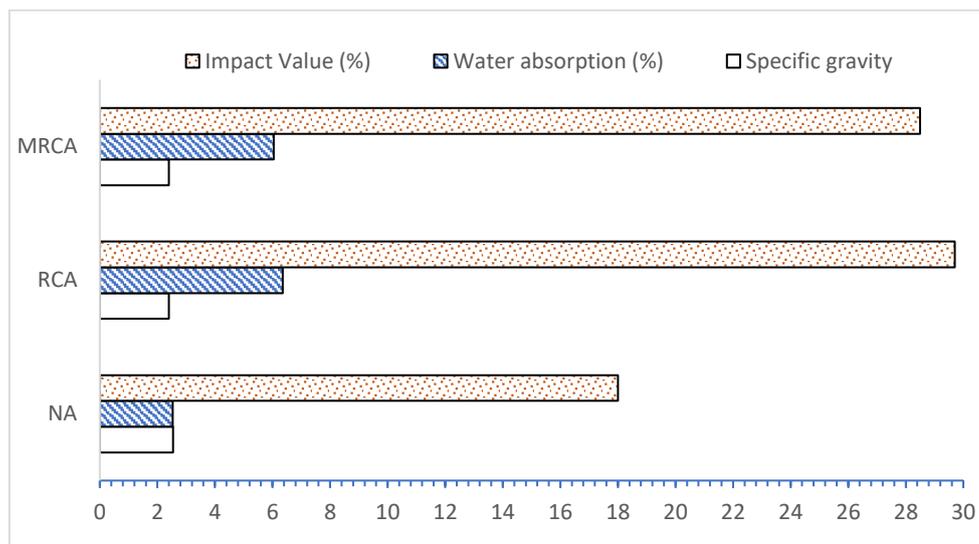


Figure 3: Specific gravity, water absorption and impact values of aggregates.

3.2 Compressive Strength

Figure 4 demonstrates a progressive decline in the compressive strength of concrete mixes as the proportion of recycled concrete aggregate (RCA) increases. The control mix (0% RCA) reached approximately 45 MPa. Strength steadily decreased with higher RCA content, dropping to about 38 MPa at 100% replacement - a significant 14.5% reduction from the control. This trend aligns with Junior et al. [13], who observed RCA-induced strength losses ranging from 2.6% to 43%, and Fellaah et al. [14], who reported reductions of 2.6% and 8.44% at 25% and 75% replacement, respectively. While MRCA mixes also exhibit a consistent strength decrease from 0% to 100% replacement, they consistently outperform RCA mixes at every level. For example, at 50% replacement, MRCA strength (42.3 MPa) is 5% higher than RCA (40.3 MPa). This performance gap widens to 7.5% at full replacement (MRCA: 41.2 MPa vs. RCA: 38.3 MPa). Crucially, the rate of strength loss differs: RCA strength declines sharply, particularly beyond 30% replacement, resulting in a total loss of 14.5% (44.8 MPa to 38.3 MPa). In contrast, MRCA strength degrades more gradually, retaining over 92% of its peak strength (44.8 MPa to 41.2 MPa, an 8% loss). This highlights MRCA's superior resistance to strength reduction at high replacement levels, likely due to the coating process enhancing aggregate quality by reducing porosity.

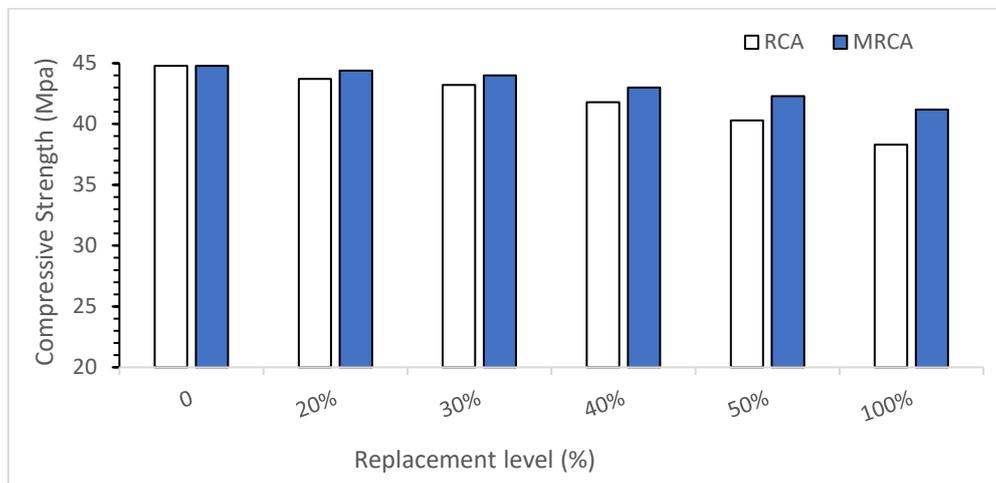


Figure 4: Compressive strength results.

3.3 Splitting Tensile Strength

Figure 5 presents the splitting tensile strength results for the concrete specimens. The graph indicates a steady decline in the strength of recycled aggregate concrete (RCA) with increasing replacement levels, from approximately 3.0 MPa at 0% replacement to about 2.0 MPa at 100% replacement. While tensile strength decreases for both types of recycled aggregate concrete as

replacement levels rise, the decline is less severe in concrete using coated aggregates (MRCA) than in concrete using uncoated aggregates (RCA) (Figure 5). Crucially, MRCA consistently exhibits higher tensile strength than RCA across all replacement percentages. At full (100%) replacement, MRCA mix demonstrates a 7.7% higher splitting tensile strength (2.23 MPa) compared to RCA (2.07 MPa).

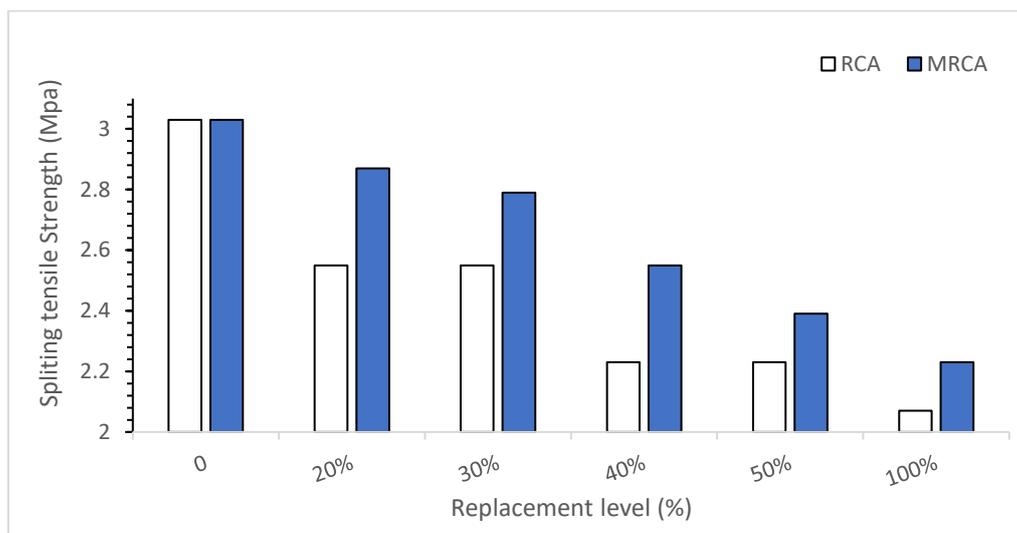


Figure 5: Splitting tensile strength results.

4. Conclusion

Based on the test results, the study yields the following primary conclusions:

- In comparison to natural aggregates, recycled concrete aggregates (RCA) exhibit higher water absorption, lower density, and greater impact values. However, metakaolin - cement coated recycled aggregates has been shown to enhance its physical and mechanical properties.
- Incorporating recycled concrete aggregates (RCA) into concrete mixes can impact both compressive and splitting tensile strengths negatively, but coating RCA with metakaolin - cement can help mitigate this effect.
- The complete substitution of recycled aggregate with metakaolin - cement coated recycled aggregate results in an approximate improvement of 7.5 and 7.7% in compressive and tensile strengths, respectively, relative to concrete produced with 100% untreated recycled aggregate.



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