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Influence of Mechanically Treating Recycled Aggregates on Concrete Strength

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تأثير المعالجة الميكانيكية للركام المعاد تدويره على مقاومة الخرسانة

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Abstract
Several studies have highlighted the potential of using recycled concrete aggregates (RCA) as a substitute for natural aggregates in concrete production due to their economic and environmental benefits. However, RCA generally exhibits lower engineering performance than natural aggregates, primarily because of its high water absorption. To address this limitation, researchers have explored various pretreatment methods, including thermal, mechanical, and chemical techniques. This study focused on investigating the impact of mechanical treatment of RCA on the compressive strength, indirect tensile strength, and workability of concrete, where natural coarse aggregates (10-20 mm) were partially replaced with RCA at proportions of 0%, 20%, 30%, 40%, 50%, and 60% by weight. The results showed that incorporating RCA tends to reduce both compressive and tensile strengths of concrete mixes, but this negative effect can be mitigated through mechanical treatment of the aggregates. Overall, mechanical pretreatment proves to be an effective approach to enhance the performance of RCA-based concrete, supporting its broader use as a sustainable alternative in construction.

Keywords: Recycled aggregate, Replacement level, Mechanical treatment, Compressive strength, Splitting tensile strength.

الملخص
أبرزت العديد من الدراسات إمكانية استخدام الركام الخرساني المعاد تدويره (RCA) كبديل للركام الطبيعي في إنتاج الخرسانة نظرًا لفوائده الاقتصادية والبيئية. ومع ذلك، يُظهر الركام الخرساني المعاد تدويره عمومًا أداءً هندسيًا أقل من الركام الطبيعي، ويرجع ذلك أساسًا إلى امتصاصه العالي للماء. ولمعالجة هذا القيد، استكشف الباحثون طرقًا مختلفة للمعالجة المسبقة، بما في ذلك التقنيات الحرارية والميكانيكية والكيميائية. ركزت هذه الدراسة على دراسة تأثير المعالجة الميكانيكية للركام الخرساني المعاد تدويره على قوة الضغط وقوة الشد غير المباشر وقابلية تشغيل الخرسانة، حيث تم استبدال الركام الخشن الطبيعي (10-20 مم) جزئيًا بالركام الخشن المعاد بنسب 0٪ و20٪ و30٪ و40٪ و50٪ و60٪ من حيث الوزن. أظهرت النتائج أن دمج الركام الخرساني المعاد تدويره يميل إلى تقليل كل من قوة الضغط والشد للخرسانة، ولكن يمكن التخفيف من هذا التأثير السلبي من خلال المعالجة الميكانيكية للركام. بشكل عام، ثبت أن المعالجة الميكانيكية المسبقة هي نهج فعال لتعزيز أداء خرسانة الركام المعاد، ودعم استخدامها على نطاق أوسع كبديل مستدام في البناء.

الكلمات المفتاحية: ركام معاد، مستوى استبدال، معالجة ميكانيكية، مقاومة ضغط، مقاومة شد انشطاري.

Introduction

Recycled concrete aggregates (RCAs) are increasingly recognized as a sustainable replacement for natural aggregates in construction. With the growing emphasis on eco-friendly construction practices, the reuse of demolition waste in the form of RCAs offers an effective means of conserving natural resources and reducing construction debris. Life cycle assessments have shown that RCAs emit less CO_2 compared to natural aggregates (Huang et al., 2019; Rampit et al., 2020) and present a more economical option (Rampit et al., 2020). Despite these advantages, RCAs typically exhibit lower quality than natural aggregates due to residual mortar and impurities, which negatively affect concrete performance (Junior et al., 2025). Incorporating RCAs instead of natural aggregates increases porosity (Gomez-Soberon, 2002), permeability (Dhir et al., 2011), and decreases density and specific gravity (Ho et al., 2013). In addition, RCA particles generally have rough, irregular, and heterogeneous surfaces (Ouyang, 2021; Ho et al., 2013). These characteristics reduce the workability of fresh concrete (Ismail et al., 2020) and compromise hardened concrete properties such as compressive strength, elasticity, and shear resistance (Rahal, 2007). The main drawback of RCAs stems from the adhered mortar, which is highly porous. This leads to elevated water absorption (Malesev et al., 2014) and a weaker interfacial transition zone. The water absorption tendency varies depending on aggregate size (Guerzou et al., 2018), recycling practices, and the strength of the original concrete (Silva et al., 2014). To enhance RCA performance, strengthening of the interfacial transition zone is essential (Liu & Peng, 2018), often through pretreatment techniques (Kazmi et al., 2019; Wang et al., 2020; Pan et al., 2017). In particular, mechanical treatments (Martínez-Echevarría et al., 2020; Savva et al., 2021; Oikonomopoulou et al., 2022) have been employed to remove or refine the adhered mortar, thereby enhancing the physical and chemical properties of aggregates and significantly improving the overall performance of RCA based concrete. The impact of mechanically treating recycled concrete aggregates on the concrete's compressive and tensile strengths after 28 days of curing is being investigated in this experimental study. Eleven distinct concrete mixture types were created by substituting treated and non-treated recycled aggregates for natural coarse aggregates in varying weight percentages (0, 20, 30, 40, 50, and 60%). Additionally, the slump of treated and non-treated recycled aggregate concrete mixes was examined.

Experimental Program

Materials

In this research, a commercial CEMI 42.5N cement was utilized. This cement complies with the standards outlined in BS EN 197-1:2000. The physical and chemical properties of the cement are presented in Table 1. The recycled concrete aggregates (RCA) required for the experimentation were collected from demolished concrete waste of 6 story building in Benghazi (Figure 1). The concrete blocks were crushed manually into combined various sizes and later on separated into 20 mm, 10 mm and 5 mm size aggregates. The sieve analysis (Table 2) of 10 - 20 mm size aggregates was carried out in accordance with guidelines of BS 882:1992. The density and water absorption of aggregate were obtained in accordance with BS 812 Part 2:1995 (see Table 2). The impact strength test of aggregate was carried out according to BS 812 Part 3:1975. Natural sand with a specific gravity of 2.5 and absorption of 0.66% was used. The sieve analysis results of the coarse and fine aggregates used in the concrete mixtures are given in Table 3. Potable tap water available at the laboratory used in concrete mixtures in this research.

Table 1: Physical and chemical analysis of used cement.

Item	Cement
Physical properties	
Specific gravity (g/cm^2)	3.13
Fineness (m^2/kg) (Blaine)	320
Chemical properties (Oxides, % by weight)	
SiO_2	20.86
Al_2O_3	5.6
CaO	62.39
Fe_2O_3	4
MgO	1
SO_3	2.93
K_2O	-
L.O.I	2.52

Figure 1: Demolished building.

Table 2 : Properties of natural aggregates (NA) & recycled coarse aggregates (RCA).

Type of aggregate	NA	RCA
Specific gravity	2.54	2.4
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

Mechanical treatment method

The recycled concrete aggregates (RCA) with size of 10-20 mm are placed into Los Angles abrasion machine (Figure 2) in which the drum is rotated for duration of 5 minutes. Impacting the aggregates against each other results in the gradual removal of the adhered slurry from the surface of the aggregate. Figure 3 shows RCA before and after treatment.

Figure 2: Used Los Angeles machine.

(a) (b)

Figure 3: RCA before (a) and after (b) treatment.

Proportions and mixing procedure

Concrete mix design, proportioned by weight according to the Building Research Establishment (BRE) (Table 4), was batched and mixed in a 0.06 m³ laboratory pan mixer. Ingredients were loaded in the sequence: coarse aggregate, cement, and fine aggregate. After 30 seconds of dry mixing, water was added gradually over 15 seconds, followed by 2.5 minutes of wet mixing, resulting in a total mixing time of 3 minutes per batch. The fresh concrete was then placed into molds, compacted on a vibrating table, and finished by troweling the top surface level. It should be noted that the coarse aggregates were soaked in water for 24 hours to achieve full saturation before being used in the mixture.

Table 4: Proportions for concrete mixes.

Mix	Replacement Level (%)	Kg/m^3						
		Cement	Water	Sand	Coarse aggregate			
					NA 5-10 mm	NA 10-20 mm	RCA 10-20 mm	TRCA 10-20 mm
C	0	350	175	630	380	880	-	-
R-20	20	350	175	630	380	704	176	-
R-30	30	350	175	630	380	616	264	-
R-40	40	350	175	630	380	528	352	-
R-50	50	350	175	630	380	440	440	-
R-60	60	350	175	630	380	352	528	-
TR-20	20	350	175	630	380	704	-	176
TR-30	30	350	175	630	380	616	-	264
TR-40	40	350	175	630	380	528	-	352
TR-50	50	350	175	630	380	440	-	440
TR-60	60	350	175	630	380	352	-	528

NA: Natural aggregate; **RCA**: Recycled concrete aggregate; **TRCA**: Treated recycled concrete aggregate

Curing of specimens

After casting, the concrete specimens were covered with thin polythene sheets and left to cure under laboratory conditions for a period of 24 hours. Thereafter, the specimens were demoulded and stored in curing water at approximately 20°C until the test age.

Testing of specimens

The standard cylinder of 100 mm diameter × 200 mm height was used for indirect tensile strength and tested according to BS 1881: Part 117:1983 and compressive strength was performed on 100 mm cube according to BS1881: Part 116:1983. The workability of freshly mixed concrete was measured by using the slump test according to BS1881: Part102: 1983.

Results and Discussion

Properties of Aggregates

Table 5 presents the properties of natural and recycled aggregate before and after treatment. It can be seen from results that both natural and recycled aggregates have the specific gravity of 2.54 and 2.40, respectively. Natural aggregates (NA) have a lower water absorption (2.53%) compared to recycled aggregates (6.35%). This higher absorption in recycled aggregates (RCA) suggests they may retain more moisture, potentially affecting their performance in concrete mixes. The impact value for natural aggregates is 18, while for recycled aggregates it is significantly higher at 29.7. A higher impact value indicates that recycled aggregates may be less durable and more susceptible to damage under impact loads. Compared to recycled aggregates (RCA), treated recycled aggregates (TRCA) exhibit higher specific gravity (2.42%) and lower impact value (24.0), indicating treatment effectiveness. Water absorption also decreased by about 18.7%. However, TRCA properties remain less favorable than natural aggregates.

Table 5: Properties of natural aggregates & recycled coarse aggregates.

Type of aggregate	NA	RCA	TRCA
Specific gravity	2.54	2.40	2.42
Water absorption (%)	2.53	6.35	5.16
Impact Value (%)	18	29.7	24.0

Slump of concrete mixes

The results of slump tests of all concrete mixes are shown in Figure 4. Both the C and R-mixes exhibit identical slump values of 4cm, indicating comparable workability. In contrast, the TC-mix demonstrates a marginally higher slump (5cm), suggesting greater fluidity and workability compared to the other two mixes. This enhanced flow-ability may be attributed to the rounded morphology of the treated aggregate (see Figure 3).

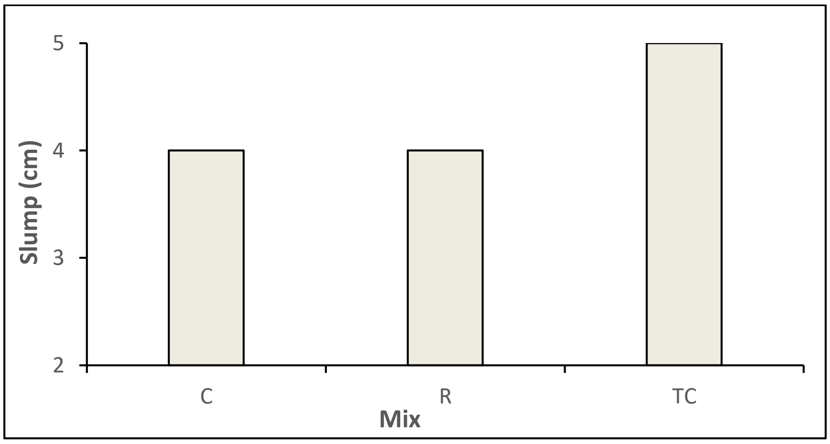

Figure 4: Slump results for concrete mixes.

Compressive strength

The influence of treated (TC) and non-treated (R) recycled coarse aggregate on compressive strength of concrete mixes at different replacement levels is shown in Figure 5. As can be shown in the graph, the control mix (C) with no recycled aggregates has the highest compressive strength at 44.8 MPa. This serves as the benchmark for evaluating the performance of mixes with R and TR aggregates .As the percentage of recycled coarse aggregates increases from 20% (R-20) to 60% (R-60), there is a noticeable decrease in compressive strength .The R-20 mix achieves 43.7 MPa, but by the time we reach R-60, the compressive strength drops to 38.3 MPa. This trend suggests that higher recycled coarse aggregates content leads to a reduction in the quality of the concrete .The drop in compressive strength with increasing recycled coarse aggregates can be attributed to several factors, including the inherent properties of recycled aggregates, which may have higher porosity and lower density than natural aggregates (see Table 3). Additionally, the bonding between the cement paste and recycled coarse aggregates is often weaker .

The TR mixes (Figure 5) demonstrate a different trend compared to the R mixes .The compressive strength of the TR-20 mix (44.7 MPa) is very close to that of the control mix (C), indicating that mechanical treatment may help maintain strength even with a 20% replacement .As the percentage of TR increases, the strength remains relatively stable, with TR-40 at 44 MPa, TR-50 at 43.5 MPa, and TR-60 at 43 MPa .This suggests that mechanical treatment can mitigate some of the negative effects of using higher amounts of recycled aggregates.

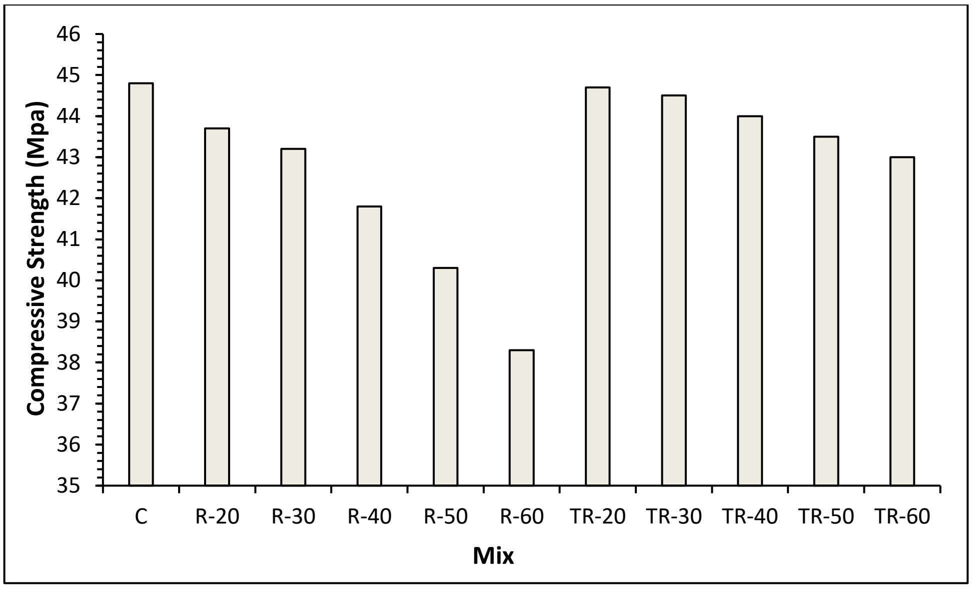

Figure 5: Compressive strength results for concrete specimens.

Splitting tensile strength

Figure 6 shows the results of splitting strengths for concrete specimens with various percentages of treated (TR) and non-treated (R) recycled aggregate at the 28 days. It can be seen from the graph that the control mix (C) achieved the highest splitting tensile strength of 3.03 MPa. This serves as the baseline for comparison, as it contains no recycled aggregate .As the percentage of recycled aggregate replacement increases from 20% to 60%, the splitting tensile strength gradually decreases .For R-20 mix, the strength drops to 2.55 MPa, representing a 15.8% reduction compared to the control mix .For R-60 mix, the strength further decreases to 2.07 MPa, a 31.7% reduction .Recycled aggregates typically have higher porosity, lower strength, and contain residual mortar, which leads to weaker interfacial transition zones in the concrete.

The mechanical treatment of recycled aggregates improves the splitting tensile strength compared to the untreated R mixes .For TR-20 mix, the strength is 2.71 MPa, which is higher than R-20 mix (2.55 MPa) and closer to the control mix .Even at higher replacement levels (e.g., TR-60 mix), the strength only drops to 2.5 MPa, which is higher than the corresponding value for R-60 mix (2.07 MPa) .Mechanical treatment of recycled aggregates removes weak residual mortar and enhances the aggregate properties. This improves the bond between the aggregate and the cement paste, resulting in better tensile strength performance than untreated recycled aggregates.

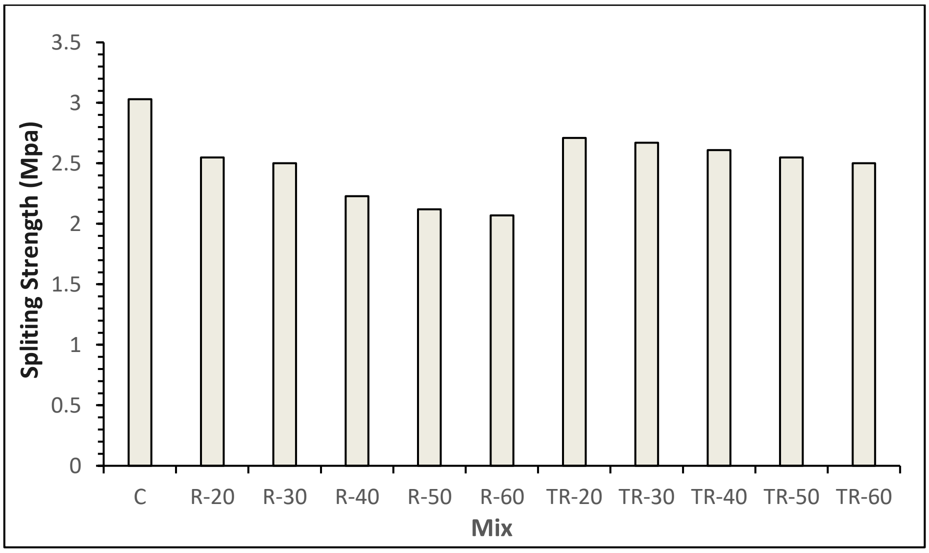

Figure 6: Splitting strength results for concrete specimens.

Conclusions

According to the test results, the following main findings can be drawn from this investigation:

- Compared with natural aggregates, the recycled concrete aggregates have a higher water absorption, a smaller apparent density, and a larger impact value.
- Mechanical treatment of recycled concrete aggregates improves the aggregates properties. This treatment improves the surface texture and reduces the porosity of the aggregates, leading to better bonding with the cement matrix.
- Concrete workability increases as the replacement of mechanically treated recycled aggregates in concrete mixes increases.
- The replacement of natural aggregates with recycled concrete aggregates leads to reduction in the compressive and splitting tensile strengths of concrete. However, the mechanical treatment of recycled aggregates effectively enhances their performance.

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