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Optimal Aggregate Content in Recycled Concrete

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ABSTRACT

The rapid increase in concrete waste has emerged as a significant global environmental challenge. In addition, the depletion of natural resources commonly used in concrete production highlights the necessity of adopting sustainable alternative materials. The incorporation of recycled aggregates in new concrete is considered an effective approach to reducing environmental degradation and preserving natural resources. This study aims to evaluate the influence of replacing natural coarse aggregates with recycled coarse aggregates on the properties of fresh and hardened concrete. For this purpose, three replacement levels—0%, 50%, and 100%—were examined. A slump test was conducted to assess the workability of fresh concrete, while 28-day hardened samples were subjected to compressive strength, direct tensile strength, and indirect tensile (splitting) strength tests. The results indicate that increasing the replacement ratio of recycled aggregates leads to a notable reduction in compressive strength as well as direct and indirect tensile strengths. Furthermore, higher proportions of recycled aggregates significantly decreased the slump value, thereby reducing the workability of fresh concrete. These findings suggest that although the use of recycled aggregates is environmentally advantageous, their incorporation requires careful technical considerations in concrete mix design.

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1. Introduction

Concrete use has been expanding rapidly worldwide in recent years. With this increasing demand, the shortage of natural aggregate sources is becoming a significant concern. In the near future, it is expected that natural aggregate quarries will experience depletion, forcing us to look for suitable alternatives. Due to the limited lifespan of concrete structures and their destruction caused by natural disasters such as earthquakes, floods, and storms, massive volumes of demolished concrete waste are generated. Landfilling this waste creates serious environmental issues. Reusing old demolished concrete as recycled concrete aggregate (RCA) in new concrete production helps conserve natural resources, preserve the environment, reduce energy consumption, and lower construction costs [1,2]. Research on the reuse of demolished concrete for new concrete aggregates dates back to post–World War II reconstruction efforts. Khalaf and his colleagues were among the first to recycle concrete waste obtained from structures destroyed during the war in Germany [3]. Since then, extensive research has been conducted in developed countries regarding the feasibility of using recycled aggregates in new concrete. In Europe, the United States, and Japan, a significant percentage of construction and demolition (C&D) waste comes from demolished concrete

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structures. For example: Nearly 67% of construction waste in the U.S. consists of concrete. Around 50% of C&D waste in Europe is concrete [4]. Japan produces 19% of its total waste from demolished concrete—approximately 70 million tons per year [6]. In Iran, rapid housing development has increased the volume of C&D waste. In Tehran alone, nearly 12 million tons of construction debris are generated annually.

Table 1.
Test Types and Curing Plan

Mix ID	Sample Dimensions	Number of Samples	Curing Method	Test Type
RC0, RC50, RC100	15*15*15 cm cube	3	moist	Compressive strength
RC0, RC50, RC100	15*30 cm cylinder	3	moist	Indirect tensile strength
RC0, RC50, RC100	15*30 cm cylinder	3	moist	Direct Tensile Strength

Test Age:28days

2. Experimental Program

The goal of this study is to use recycled concrete aggregates (RCA) as coarse aggregates at replacement levels of 0%, 50%, and 100% relative to natural aggregates. After mixing, slump tests were performed on fresh concrete, and the mechanical properties of hardened concrete cured under moist conditions were evaluated. A summary of the sample dimensions, number of specimens, test types, and curing periods is presented in Table 1.

3. Materials

Ordinary Portland Pozzolanic Cement (Fars & Khuzestan Cement Co.) was used in all mixes. Fine aggregates (0–6 mm) and natural coarse aggregates (10–19 mm) were used. Recycled coarse aggregates were produced by crushing old concrete specimens using a laboratory crusher. Before crushing, the concrete samples were cleaned to remove contaminants. Drinking water from Rasht was used in concrete production.

4. Concrete Mix Design

Four mix designs with different water–cement ratios (w/c = 0.4 and 0.5) and different maximum aggregate sizes (10 mm and 19 mm) were used.

Table 2 shows the mixing plan for different water to cement ratios. Also, Tables 3 to 6 show the RCA replacement rate at different water to cement ratios.

Table 2.
Mix Design for Different Water–Cement Ratios

Mix No.	Mix ID	Cement(kg/m3)	Water(kg/m3)	Sand(kg/m3)	Gravel(kg/m3)
1	Mix Design 1:(w/c = 0.4, max aggregate 19mm)	365	128	139	51
2	Mix Design 2:(w/c = 0.4, max aggregate 10mm)	271	128	389	51
3	Mix Design 3:(w/c = 0.5, max aggregate 19mm)	366	128	307	65
4	Mix Design 4:(w/c = 0.5, max aggregate 10mm)	270	128	375	65

Table 3.
w/c = 0.5, Max, Aggregate Size = 19mm

Mix ID	Cement(kg)	Water(kg)	Sand(kg)	Natural Coarse(kg)	RCA(kg)
RC0	366	128	307	366	0
RC50	366	128	307	183	183
RC100	366	128	307	65	366

Table 4.
w/c = 0.5, Max, Aggregate Size = 10mm

Mix ID	Cement(kg)	Water(kg)	Sand(kg)	Natural Coarse(kg)	RCA(kg)
RC0	270	128	375	270	0
RC50	270	128	375	135	135
RC100	270	128	375	0	270

Table 5.
w/c = 0.4, Max, Aggregate Size = 19mm

Mix ID	Cement(kg)	Water(kg)	Sand(kg)	Natural Coarse(kg)	RCA(kg)
RC0	365	128	319	365	0
RC50	365	128	319	183	183
RC100	365	128	319	0	366

Table 6.
w/c = 0.4, Max, Aggregate Size = 10mm

Mix ID	Cement(kg)	Water(kg)	Sand(kg)	Natural Coarse(kg)	RCA(kg)
RC0	271	128	389	271	0
RC50	271	128	389	135	135
RC100	271	128	389	0	270

5. Results

5.1. Compressive Strength Results

Table 7.
Compressive Strength, w/c = 0.4, 19 mm Aggregates

Mix ID	28-Day Compressive Strength (Mpa)
RC0	36.10
RC50	32.70
RC100	24.30

Table 8.
Compressive Strength, w/c = 0.4, 10 mm Aggregates

Mix ID	28-Day Compressive Strength (Mpa)
RC0	36.20
RC50	31.20
RC100	27.20

Table 9.
Compressive Strength, w/c = 0.5, 19 mm Aggregates

Mix ID	28-Day Compressive Strength (Mpa)
RC0	40.10
RC50	35.50
RC100	30.10

Table 10.
Compressive Strength, w/c = 0.5, 10 mm Aggregates

Mix ID	28-Day Compressive Strength (Mpa)
RC0	39.90
RC50	36.20
RC100	28.20

5.2. Indirect Tensile Strength (Brazilian Test)

Table 11.
Brazilian Tensile Strength, w/c = 0.4, 19 mm Aggregates

Mix ID	28-Day Compressive Strength (Mpa)
RC0	2.80
RC50	2.62
RC100	2.15

Table 12.
Brazilian Tensile Strength, w/c = 0.4, 10 mm Aggregates

Mix ID	28-Day Compressive Strength (Mpa)
RC0	2.92
RC50	2.78
RC100	2.29

Table 13.
Brazilian Tensile Strength, w/c = 0.5, 19 mm Aggregates

Mix ID	28-Day Compressive Strength (Mpa)
RC0	3.40
RC50	2.70
RC100	2.30

Table 14.
Brazilian Tensile Strength, w/c = 0.5, 10 mm Aggregates

Mix ID	28-Day Compressive Strength (Mpa)
RC0	3.80
RC50	2.39
RC100	2.03

5.3. Direct Tensile Strength

Table 15.
Direct Tensile Strength, w/c = 0.4, 19mm

Mix ID	28-Day Compressive Strength (Mpa)
RC0	2.24
RC50	2.00
RC100	1.52

Table 16.
Direct Tensile Strength, w/c = 0.4, 10mm

Mix ID	28-Day Compressive Strength (Mpa)
RC0	2.34
RC50	1.95
RC100	1.83

Table 17.
Direct Tensile Strength, w/c = 0.5, 19mm

Mix ID	28-Day Compressive Strength (Mpa)
RC0	2.72
RC50	1.89
RC100	1.61

Table 18.
Direct Tensile Strength, w/c = 0.5, 10mm

Mix ID	28-Day Compressive Strength (Mpa)
RC0	2.90
RC50	1.67
RC100	1.52

6. Conclusion

1-Increasing RCA content reduces compressive strength, direct tensile strength, and indirect tensile strength.

2-Recycled aggregates have lower strength due to the presence of old mortar adhered to their surface.

3-RCA particles tend to break into finer particles during mixing, increasing the fine aggregate content
and reducing slump.

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