Investigation of the Effect of Acrylic Polymer Concrete Adhesive on the Mechanical Properties of Recycled Aggregate Concrete

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Abstract

This study investigated the simultaneous use of recycled aggregates, including recycled fine and coarse aggregates obtained from the crushing of waste concrete, and the potential for improving concrete performance through the incorporation of an acrylic polymer. First, concrete mixtures containing 12.5, 25, 50, and 100% recycled fine or coarse aggregates were separately investigated. Subsequently, concrete mixtures containing both fine and coarse recycled aggregates were evaluated. The effect of polymer incorporation was then examined at contents of 0.25, 0.5, 1, 2, 4, and 8% by weight of cement. Finally, the combined effect of the polymer and recycled aggregates on the compressive strength of concrete was investigated under the selected optimum conditions. Compressive strength was measured at 7, 14, and 28 days for each mixture. The results showed that the use of recycled fine and coarse aggregates reduced compressive strength by approximately 37 and 28%, respectively, while the combined use of both types of recycled aggregate resulted in a further reduction in strength. Polymer incorporation produced a substantial improvement in compressive strength, with 4% identified as the optimum content. At this dosage, the compressive strength of the control concrete increased by approximately 114%. Moreover, incorporating only 0.25% polymer into concrete containing recycled aggregates largely compensated for the strength reduction caused by the recycled aggregates. At 4% polymer, the compressive strengths of concretes containing recycled coarse aggregate, recycled fine aggregate, and a combination of recycled coarse and fine aggregates increased by approximately 109, 107, and 100%, respectively, compared with the control concrete. The findings demonstrate the potential of acrylic polymer modification for improving the mechanical performance of concrete containing recycled aggregates.

KEYWORDS:

Green concrete, Recycled fine aggregate, Recycled coarse aggregate, Polymer, Compressive strength

Introduction

The construction industry is one of the largest consumers of natural resources and producers of waste worldwide. Increasing population, urbanization, and infrastructure development have intensified the demand for concrete and, consequently, the consumption of natural aggregates and generation of construction and demolition waste. In this context, the use of recycled aggregates derived from waste concrete as partial replacements for natural aggregates represents an important approach toward developing green concrete and reducing natural resource extraction and waste disposal [1]. However, the presence of adhered old cement paste, high porosity and water absorption, and microcracks in recycled aggregates can adversely affect both the fresh and hardened properties of concrete, particularly its mechanical strength. These effects become more pronounced as the replacement level of recycled aggregates increases, and

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various studies have reported reductions in compressive, tensile, and flexural strengths, as well as increases in water absorption and shrinkage of recycled aggregate concrete. Therefore, developing effective approaches to mitigate these performance losses is essential for promoting the structural and non-structural applications of recycled concrete.

Polymers have been recognized as an effective method for modifying concrete properties and can improve its microstructure and strength by forming films within pores, reducing porosity, enhancing the interfacial transition zone between aggregates and cement paste, and creating an interconnected polymer–cement network [2] **.** Previous studies have also demonstrated that polymers can improve the mechanical performance and durability of concrete; however, their effectiveness depends strongly on the polymer type and dosage, while excessive polymer contents may reduce strength because of the formation of thick polymer films and a reduction in the effective cement content [3, 4]. In addition, the higher cost of polymers, complexity of production and application, and limited long-term performance data remain important challenges to their widespread use. Although numerous studies have investigated recycled aggregate concrete and polymer-modified concrete [3], studies systematically examining the combined effects of these two approaches remain limited. In particular, a comprehensive comparison of recycled coarse and fine aggregates used separately and in combination in the presence of polymer, together with the determination of optimum replacement levels and effective polymer dosage, is still lacking. Therefore, the present study investigates the effects of recycled coarse and fine aggregates at different replacement levels, both separately and in combination, on the compressive strength of concrete and determines their optimum combination. In addition, the optimum polymer content and its simultaneous and interactive effects with different types of recycled aggregates are evaluated to determine whether the strength reduction associated with recycled materials can be mitigated and a green concrete with satisfactory mechanical performance can be achieved. In this study, compressive strength is considered the primary indicator of mechanical performance, while other durability and indirect strength tests are beyond the scope of the research.

Methodology

In this study, cement, water, natural aggregates including coarse and fine aggregates, recycled aggregates including recycled coarse and fine aggregates, and SA12 polymeric concrete bonding agent were used to investigate the combined effects of recycled aggregates and polymer on the mechanical performance of concrete. Representative samples of the materials used in the study, together with the procedure adopted for producing the recycled aggregates from waste concrete, are presented in **Figure 1, 2**.

(a) (b) (c) (d) (e) (f)

Figure 1. Materials used in the present study: (a) Type II cement, (b) natural coarse aggregate, (c) recycled coarse aggregate, (d) natural fine aggregate, (e) recycled fine aggregate, and (f) polymer.

Figure 2. Production process of recycled aggregates used in the present study.

The experimental program was designed and conducted in a stepwise manner, and five main concrete types were investigated: control concrete, concrete containing recycled fine aggregate, concrete containing recycled coarse aggregate, polymer-modified concrete, and concrete containing recycled aggregates in combination with polymer. In the first stage, control concrete without recycled aggregates or polymer was prepared and tested at the ages of 7, 14, and 28 days as the reference mixture. Subsequently, the independent effects of replacing natural fine and coarse aggregates with their recycled counterparts were investigated over a replacement range of 0–100%, followed by evaluation of a combined recycled fine- and coarse-aggregate mixture using the optimum replacement levels determined in the previous stages. In the second stage, the independent effect of SA12 polymer was evaluated at dosages ranging from 0 to 8% by cement weight to determine the optimum polymer content. Finally, the combined effects of polymer and recycled coarse aggregate, recycled fine aggregate, and their combined use were investigated using the optimum contents obtained from the preceding stages. The different mix designs and details of the experimental program are presented in Table 1.

.Table 1. Mix designs used in the present study

Mixing Concrete	Cement (kg/m^3)	Water (kg/m^3)	W/C	Gravel (kg/m^3)	Sand (kg/m^3)	Polymer (%)	RCA (%)
CC	350	175	0.5	476	1341		
FRCA	350	175	0.5	476	(0-1173.4) *		12.5, 25, 50, 100
CRCA	350	175	0.5	(0-416.5) *	1341		12.5, 25, 50, 100
F-CRCA	350	175	0.5	416.5	1173.4		12.5
PL	(322-349.1) *	175	0.5	476	1341	0.25, 0.5, 1, 2, 4, 8	
Pl-FRCA	336	175	0.5	476	1341	4	12.5
Pl-CRCA	336	175	0.5	476	1341	4	12.5
Pl-F-CRCA	336	175	0.5	476	1341	4	12.5

CC: Control concrete; CRCA: Concrete containing recycled coarse aggregate (recycled gravel); FRCA: Concrete containing recycled fine aggregate (recycled sand); PL: SA12 acrylate polymer.
The amounts of cement, natural coarse aggregate, and natural fine aggregate were determined based on their replacement by polymer, recycled coarse aggregate, and recycled fine aggregate, respectively.

For specimen preparation, the coarse and fine aggregates were initially mixed with one-third of the total mixing water for 1 min. Cement was then added together with another one-third of the mixing water, and mixing continued for 2 min. The remaining water was subsequently added, followed by a further 2 min of mixing. For polymer-modified mixtures, the polymer was first combined with the cement and then introduced into the mixer. After casting, the specimens were kept in the laboratory environment for 24 h and subsequently cured by immersion in water maintained at 23 °C. The unconfined compressive strength of 150 × 150 × 150 mm cubic specimens was determined at 7, 14, and 28 days in accordance with ASTM C39 **[5]**, using a loading rate of 0.2–0.3 MPa/s until failure. For each mix design at the 7- and 28-day ages, three independent specimens were tested, and the average value was reported as the compressive strength. The standard deviation and coefficient of variation were also evaluated to assess the dispersion and repeatability of the experimental results.

Results and Discussion

In this study, the effects of the water-to-cement ratio, replacement percentage of natural coarse and fine aggregates with recycled aggregates, SA12 polymer content, and the combined effects of polymer and recycled aggregates on the compressive strength of concrete were investigated. The experimental program was conducted in a stepwise manner. First, the effect of the water-to-cement ratio on the compressive strength of control concrete was evaluated. Subsequently, the behavior of concrete containing recycled coarse and fine aggregates at different replacement levels was investigated, and the performance of the two types of recycled aggregates was compared. The combined use of recycled coarse and fine aggregates was then examined. After characterizing the effects of recycled aggregates, the independent effect of SA12 polymer at different contents was evaluated to determine its optimum dosage. Finally, the performance of the polymer in concrete containing recycled coarse or fine aggregates and, subsequently, in recycled-aggregate concrete containing both recycled coarse and fine aggregates was assessed. The results of the first stage showed that increasing the water-to-cement ratio from 0.40 to 0.50 and 0.55 reduced the compressive strength by approximately 8% and 15%, respectively, demonstrating the important role of the water-to-cement ratio in controlling concrete density and strength. In the recycled aggregate stage, increasing the replacement level progressively reduced compressive strength; however, the reduction was substantially greater for recycled fine aggregate than for recycled coarse aggregate. At replacement levels of 12.5%, 25%, 50%, and 100%, the reductions in strength were approximately 4%, 9%, 19%, and 37% for recycled fine aggregate and 3%, 6%, 14%, and 20% for recycled coarse aggregate, respectively, compared with the control concrete. This difference was mainly attributed to the higher specific surface area and water absorption and the greater amount of adhered old cement mortar associated with recycled fine aggregate. The combined use of recycled coarse and fine aggregates also exhibited better performance than the exclusive use of recycled fine aggregate, indicating the role of particle-size distribution in controlling strength loss. In the polymer stage, increasing the SA12 content up to 4% increased the compressive strength, whereas further increasing the polymer content to 8% resulted in a reduction; therefore, 4% was identified as the optimum polymer content. Subsequently, the addition of polymer to concrete containing recycled aggregates substantially compensated for the strength loss caused by aggregate replacement; notably, even 0.25% polymer almost eliminated the strength reduction associated with 12.5% recycled aggregate. **The final and most important effect of combining polymer and recycled aggregates is presented in Figure 3.**

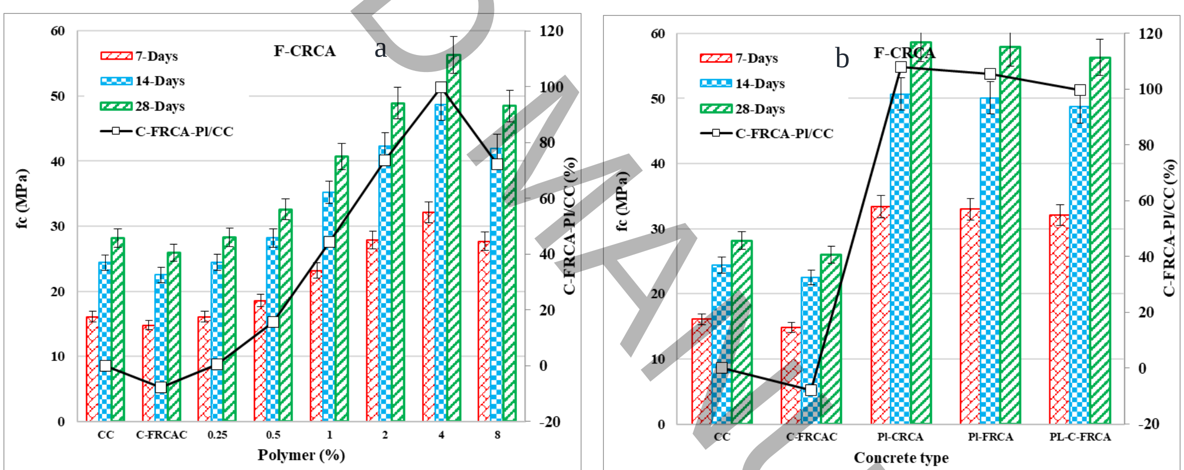

Figure 3. Effect of polymer on recycled-aggregate concrete containing recycled coarse and fine aggregates: (a) different polymer contents; (b) types of recycled-aggregate concrete.

Concrete containing 12.5% recycled coarse aggregate and 12.5% recycled fine aggregate simultaneously exhibited an approximately 8% reduction in compressive strength compared with the control concrete without polymer; however, the addition of 0.25% polymer almost completely compensated for this reduction. Increasing the polymer content to 4% and 8% subsequently increased the compressive strength of the recycled-aggregate concrete by approximately 114% and 85%, respectively, relative to the control concrete. Moreover, at the optimum polymer content of 4%, the incorporation of recycled coarse aggregate, recycled fine aggregate, and their combined use resulted in approximately 105%, 107%, and 100% increases in compressive strength, respectively, compared with the control concrete. These results demonstrate that SA12 polymer, particularly at the optimum content of 4%, can substantially compensate for the strength loss associated with recycled aggregates and facilitate the production of recycled-aggregate concrete with improved mechanical performance.

Conclusion

With the aim of reducing the consumption of natural aggregates and promoting more environmentally sustainable concrete production, this study used recycled aggregates obtained from demolished concrete as coarse and fine aggregates in concrete mixtures. The results showed that replacing natural aggregates with recycled aggregates, particularly recycled fine aggregate, reduced the compressive strength of concrete. As a strategy to compensate for this reduction, SA12 polymer was incorporated into the concrete mixtures. The results demonstrated that even 0.25% polymer could compensate for a substantial portion of the strength loss caused by recycled aggregates, while increasing the polymer content to the optimum level of 4% not only eliminated the strength reduction but also resulted in a significant increase in compressive strength compared with the control concrete. Therefore, the appropriate combination of recycled aggregates and polymer can facilitate the production of recycled-aggregate concrete with improved mechanical performance while reducing the consumption of natural aggregates and, consequently, contributing to the mitigation of the environmental impacts associated with the construction industry.

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