Research Article

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Effect of varied waste concrete ratios on the mechanical properties of polymer concrete

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Abstract: Polymer concrete (PC) was developed at the end of the 1950s and gained popularity in the 1970s for precast parts, flimsy floor coverings, and repairs. Due to its superior performance over traditional Portland cement concrete, which offers many benefits, including mechanical properties, quick hardening, and durability. In this article, polymeric concrete was made using a mixture of sand and epoxy, and different proportions of sand were replaced with crushed concrete waste. This study found that the ideal ratio between resin and fine aggregate was 23% resin to 77% fine aggregate in terms of the total weight of the combination to get the best dispersion of fine aggregate. Waste concrete replaced 5, 10, 15, and 20% of aggregate in PC, respectively. It was further demonstrated that increased waste concrete aggregate content in PC increased the 28-day compressive strength by 7.7, 13.44, 16.8, and 18.97%, respectively; flexural strength increased by 16.68, 25.32, 37.16, and 47.71% at 28 days' age; and direct tensile strength was higher than the reference mixture by values of 3.41, 17.21, 23.54, and 30.38% at 28 days age. The findings recommended using recycled fine aggregate on PC and suggested a 20% replacement ratio as an optimum percentage.

Keywords: polymer concrete, epoxy resin, waste concrete, fine recycled aggregate

1 Introduction

Concrete is the most important building material, which cannot be dispensed with during construction. It is the second element consumed after water on the planet due to its efficiency and high quality of endurance. Hydraulic cement, water, fine and coarse aggregates, air, and occasionally additives are often used proportionately to make it. Polymer concrete (PC), made of polyester, is a composite material of aggregates joined by resins [1]. According to reports, PC has been employed for building cladding and other uses. Later on, it was often employed as a repair medium because of its high strength, perfect binding to cement concrete and steel reinforcement, fast drying time, and endurance [2]. Polymer-modified cement concrete has gained popularity and demonstrated superior deformability, cohesiveness, durability, wear resistance, and impermeability to regular concrete. However, when utilized for specialty pavements, it is constrained by expensive polymer pricing, a convoluted production process, and low mechanical indices in areas like bending-tensile strength, polymer toughness, and impact resistance [3]. Unsaturated polyester resin, epoxy resin, methyl methacrylate, polyurethane resin, furan resin, and urea-formaldehyde resin are the most often utilized resins for PC. The aggregates and fillers in PC usually are more than 75% and often exceed 80%. These aggregates are often considered to be harmless specks throughout the polymer matrix. The aggregates used are often separated into two categories based on their particle size: coarse aggregates (having a 5 mm diameter or bigger) and fine aggregates (having a 5 mm diameter or less) [4,5]. Today, epoxy resins – a group of low-molecular-weight prepolymers – are among the most widely used thermosetting reactive resins. They can interact with one another or with other hardening substances. Depending on the hardener's chemical composition and curing circumstances, it may acquire desirable characteristics such as excellent chemical and mechanical toughness, extreme flexibility, high adhesive strength, and high thermal and electrical resistance. It has been claimed that epoxy resins have superior mechanical properties to polyester and vinyl [6,7]. However, because using a polymer costs more than using Portland cement, polymers should only be used when the higher cost is justified by better performance [8].

Waste material reduction, reuse, and recycling have received much attention. Typically, recycling technologies

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are divided into four categories. The most common strategies involve returning something to its original form. Processing an old product into a new one with a different level of physical and/or chemical qualities is known as secondary recycling. Tertiary recycling entails pyrolysis and hydrolysis, transforming trash into fundamental chemicals or fuels. Quaternary recycling is the process of burning garbage to produce energy [9,10]. According to Silva et al. [11], RCAs (recycled concrete aggregates) and mixed recycled aggregates are the two primary types of RAs that can be recovered from CDW. The first, which is more frequently generated and is very heterogeneous, is hardly ever suitable for use in structural concrete [12–14].

On the other hand, due to their lower heterogeneity and improved mechanical properties, RCAs are anticipated to be utilized to manufacture structural concrete, as they contain a minimum recycled concrete percentage of at least 90% [15]. Although the RCAs can be considered similar materials because they are made of original aggregate and mortar, they generally have distinct qualities because they rely on the original concrete's characteristics. It must be emphasized that concrete prepared with RCAs has lower density and workability in its fresh condition and lower mechanical qualities and durability performance [16,17]. Using waste as a replacement for aggregate revealed that sawdust- and PET-chopped concrete behaved better when compressed. The PC's compressive strength with waste replacement was greater than that of the control mix when sawdust and chopped PET were incorporated at 25, 50, and 75%, respectively. When failing, both varieties of waste-replacement PC showed a steady emergence of fissures until destruction [18,19]. Environmental and financial advantages abound when using RCA (recycled concrete aggregate) instead of NA (natural aggregate). The environment and the energy/fuel used for hauling can be preserved by lowering the consumption of NAs and the requirement to create new mining regions. However, using RCA reduces building trash that often ends up in landfills [20]. The study mainly aimed to examine the mechanical characteristics of epoxy resin concrete prepared without and with waste concrete as an aggregate.

2 Materials

2.1 Epoxy resins

A typical epoxy will have epoxy resin and hardener. The research herein used Nitofill EPLV, a low-viscosity epoxy injectable resin. Table 1 lists its physical properties. They must be combined with a hardener to cure this problem.

Table 1: Physical properties of epoxy resin

Property	Evaluation
Pot life	90 min @ 20°C
	40 min @ 35°C
Specific gravity	1.04
Viscosity	1.0 poise @ 35°C

Material's datasheet.

2.2 Sand

4.75 mm maximum grain size of Al-Ukhaider sand was used. Before being added to the mixture, the sand was dried for 24 h at 100°C in a furnace oven. The fine aggregate's gradation and characteristics are according to ASTM C33/C33M-18 [21] standards, as displayed in Table 2.

2.3 Waste concrete

The waste concretes utilized in this investigation were thoroughly washed, dried, and then pulverized with a hand-hammer crusher until they were the consistency of sand. Figure 1 shows the crushed recycled waste concrete. The recycled waste concrete's gradation is also according to ASTM C33/C33M-18 [21] standards, as displayed in Table 3.

2.4 Mix proportions

Five mixtures were produced in the lab. Four different mixtures were produced to test the impact of waste concrete on specific mechanical characteristics of PC; the first mixture acts as a control. Samples were chosen based on the weight ratios of regular sand, resin, and debris. According to the optimal PC1 sample, the proportions of sand, epoxy

Table 2: Sand's grading and some characteristics

Sieve size (mm)	Cumulative passing (%)	Limits following ASTM C33/C33M-13
4.75	100	95–100
2.36	88.84	80–100
1.18	73.59	50–85
600	55.34	25–60
300	21.94	5–30
150	4.83	0–10
Specific gravity = 2.58		
Fineness modulus = 2.49		
Absorption = 1.72%		
Sulfate content = 0.21		

Figure 1: Recycled waste concrete.

Table 3: Recycled waste concrete grading

Sieve size (mm)	Cumulative passing (%)	Limits following ASTM C33/C33M-18
4.75	100	95–100
2.36	83.32	80–100
1.18	78.06	50–85
600	49.86	25–60
300	24.98	5–30
150	6.34	0–10

resin, and scrap concrete were 72, 22, and 5%. The mixing proportions for all mixtures are shown in Table 4.

2.5 Casting, compaction, and curing

All mixtures were blended following the requirements of ASTM C305-14 [22]. A normal rod condensed the concrete, applying 25 blows per layer across three layers producing 40 × 40 × 160 mm^3 prisms and 50 × 50 × 50 mm^3 cubes. The samples were molded after 24 h of casting. Then, they were dried at 23°C, the typical room temperature. Figure 2 illustrates the demolding and curing process of PC specimens.

3 Results and discussion

Table 5 presents the PC testing results

3.1 Flow test

The workability was determined using samples of reference mixes and specimens comprising varying percentages of waste concrete. Figure 3 shows the flow table testing process. The ASTM C 1437-01 [23] flow table test evaluated

Table 4: PC's mixing ratios

Mix ID	Sand (g)	Resin (g)	The weight percentage of the sand replacement ratio (%)	Waste concrete (g)
Control	798	237	0	0
PC1	758	237	5	40
PC2	718	237	10	80
PC3	678	237	15	120
PC4	638	237	20	160

Figure 2: De-molding and curing of polymer mortar specimens.

Table 5: PC characteristics

Mix ID	Flow (%)	Compressive strength (MPa)			Flexural strength (MPa)			Direct tensile strength (MPa)		
		Days								
		7	14	28	7	14	28	7	14	28
Control	68	47.4	49.3	50.6	9.5	9.88	10.9	5.52	6.86	7.9
PC1	67	48.1	51.2	54.5	10.3	11.4	12.5	5.53	7.63	8.17
PC2	66.5	50.3	54.1	57.4	11.5	12.6	13.6	6.1	7.95	9.26
PC3	63	52.8	56.3	59.1	12.7	13.7	14.9	7.38	8.39	9.76
PC4	62.5	54.6	57.3	60.2	13.8	14.8	16.1	8.66	9.95	10.3

Figure 3: Flow-table testing process.

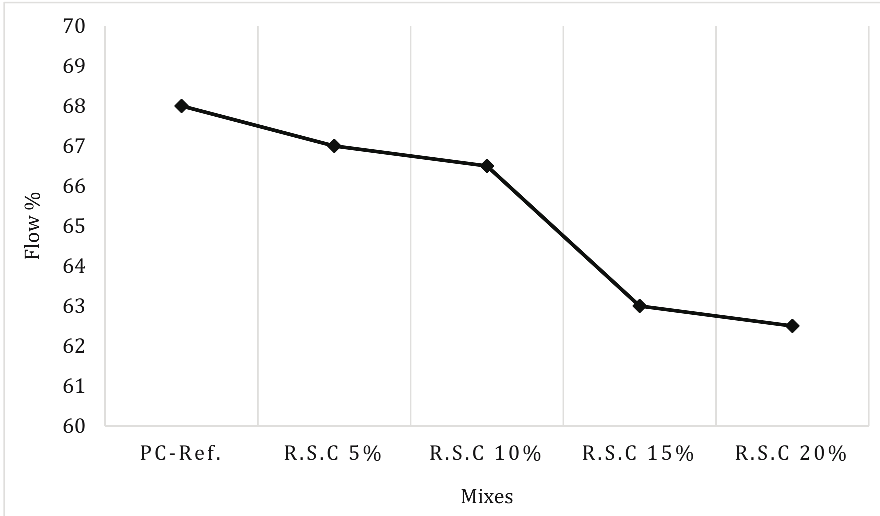

Figure 4: Influence of waste concrete as a partial replacement of sand on the flow table percentage.

the mortar's workability. Figure 4 shows the results of using waste aggregate instead of regular concrete. The flow ratio was slightly lowered due to the use of waste concrete. The flow ratio decreases as the proportion of waste concrete rises. This reduced flow ratio results from waste concrete's greater water absorption capabilities than natural sand [24]. Therefore, increasing the concrete waste ratio in the mixture will decrease its flow ability, making it more difficult to mold. However, in general, the specimens with the used percentages of concrete waste exhibit acceptable workability in handling, placement, and finishing.

3.2 Compressive strength

The ASTM C109/C109M-20 standards [25] were followed for the compression strength test. Using cubical molds with dimensions 50 mm × 50 mm × 50 mm and a digital compressive machine manufactured by ELE International with a load rate of 15,000 kN/min (Figure 5), the average of three samples was calculated for each testing age. As anticipated, the replacement of the waste concrete had a favorable impact on the compressive strength due to the waste concrete-aggregate particles still being well-ringed by the polymer matrix and comparatively dispersed. To develop compressive strength in the polymer mix, the waste concrete aggregate may be used to strengthen micro-crack closure [26]. This occurrence may cause all mixes' enhanced compressive strength compared to the control mix. This mechanism may be why all mixes' compressive strengths are higher than they were with the control mix. The compressive strength will improve slightly at 7 days with an increase of 1.48% when using 5% waste concrete, as indicated in Table 4 and Figure 6, while it will grow more significantly after 28 days with a value of 7.7%. The percentage of compressive strength at 7 days of age was equivalent to 6.12% when 10% of waste concrete was utilized. However, a 13.44% rise was seen at the 28-day curing age. As the replacement rate increased, so did the material's compressive strength. The age-related compressive strength at 7 days was equivalent to 11.39% and grew to 16.8% at 28 days when 15% of waste concrete was used. Most notably, with a 20% glass waste replacement rate, the compressive strength increased by 15.19% after 7 days and 18.97% after 28 days.

Figure 5: Compressive strength testing process.

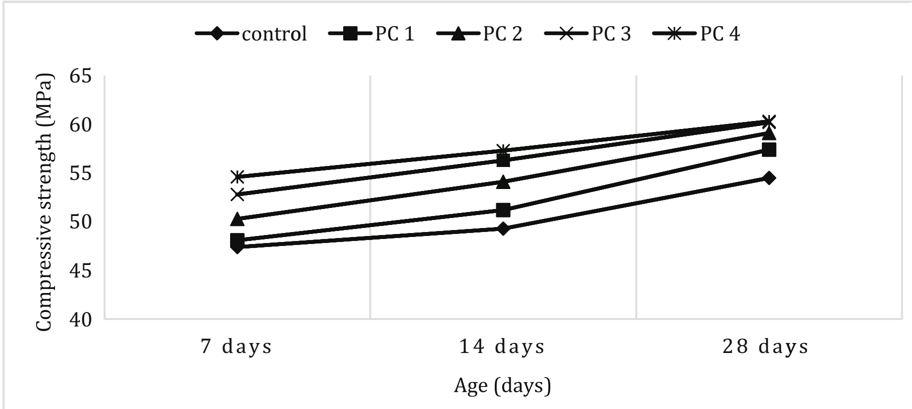

Figure 6: Influence of partial replacement of natural sand with waste concrete on the compressive strength.

Figure 7: Flexural strength testing process.

3.3 Flexural strength

A third-point loading test using 40 × 40 × 160 mm^3 prisms was used to calculate the flexural strength, as specified by ASTM C348-18 [27]. Figure 7 shows the flexural strength testing process. The mean ages of three samples were provided for every testing age. According to the schedule, the concrete waste substitution improved the flexural strength and the proportion of waste concrete utilized in the mix directly correlated with the rise in flexural strength. Figure 8 demonstrates that the flexure strength rose by 5% with waste concrete. The percent increases were 8.42, 15.18, and 16.68% after 7, 14, and 28 curing days, respectively, compared to the reference mix. At 7 days, the flexure strength increases by 21.05%, at 14 days by 27.43%, and at 28 days by 25.32% when the replacement rate is raised to 10% concrete waste. When 15% of the waste concrete was utilized, the flexural strength increased by 33.68% after 7 days, 38.97% after 14 days, and

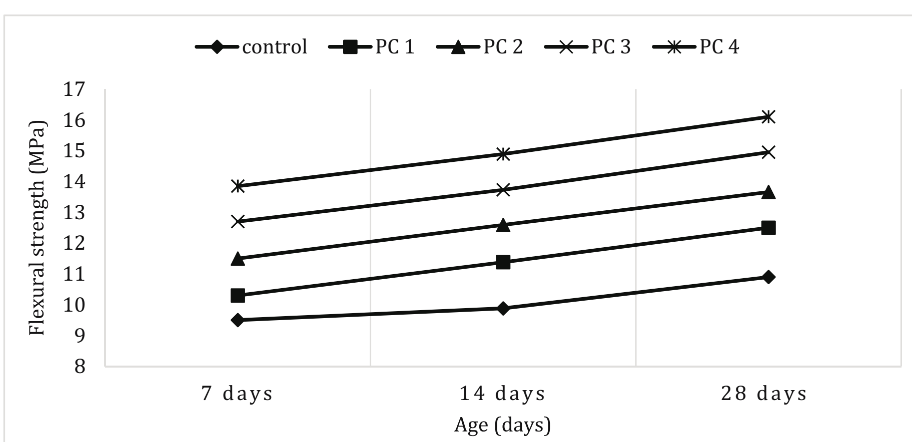

Figure 8: Influence of partial replacement of natural sand with waste concrete on the flexural strength.

Figure 9: Direct tensile strength testing process.

37.16% after 28 days. Finally, as the replacement rate rises, the increase in flexural strength also does so. When 20% concrete waste is utilized, this strength increases by a disproportionately significant amount when compared to the reference combination, with values of 45.58, 40.71, and 47.71% at ages 7, 14, and 28 days, respectively, when compared to the reference mixture.

3.4 Direct tensile strength

BS 6319-7:1985 standards [28] were followed to estimate the direct tensile strength on dog bone-shaped samples 76 mm long, 25 mm thick, and 645 mm^2 in cross-section at the mid-point employing a piece of testing equipment with a 10 kN capacity as illustrated in Figure 9. A mean of three specimens was provided for every testing age. All mixes' tension strength increased to that of the control mix via micro-reinforcement, which was used to adjust the placement of particles vertically aligned with the direction of the destructive force. It has been noted that there are a lot of concrete particles in the matrix. Figure 10 shows that tensile strength increased by 0.18, 11.22, and 3.41% at 7, 14, and 28 days, respectively, when 5% of waste concrete was substituted for the polymer mortar (reference mix). There was a linear relationship between the percentage of replacement and the age increment, with the highest age increment occurring at 7 days (10.51%), followed by a 33.7% rise at 15% and a 56.88% increment at 20% compared with the benchmark mix. It has been observed that the concrete waste particles are numerous, and those stacked vertically on the path of the force of destruction may have served as a type of micro-reinforcement that boosted the tensile strength.

4 Conclusions

The conclusions that may be drawn from this examination on a PC are as follows:

1) The properties of PC may be altered by including waste concrete, although the exact effect is proportional to the amount of waste concrete utilized.
2) PC mixes using crushed waste concrete had greater flexural, compressive, and direct tensile strengths than those with regular sand. Also, increasing the replacement

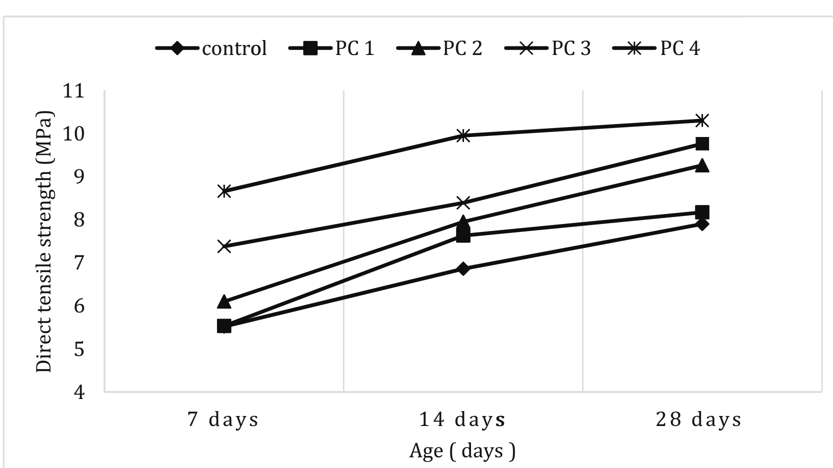

Figure 10: Influence of partial replacement of natural sand with waste concrete on the direct tensile strength.

percentage leads to an enhancement of the mechanical properties.
3) Employing recycled fine aggregate could serve a purpose in PC. It recommended a 20% replacement ratio as the ideal ratio since it shows the best improvement on compressive, flexural, and tensile strength results reaching about 18.97, 47.71 and 30.38%, respectively.
4) The outputs of the different measured mechanical properties increased linearly and gradually in a similar pattern.
5) Using waste concrete as a fine aggregate may improve sustainability and solve environmental problems.
6) The specimens with the incorporated amounts of concrete waste display good workability in handling, positioning, and finishing.
7) Composing waste concrete in place of fine NAs produces a comparable result in many mechanical properties, including compressive, flexural, and direct tensile strength. However, more research is required to examine the impact on durability and other features.

Conflict of interest: The authors state no conflict of interest.

Competing interest: The authors state no competing interest.

Data availability statement: Most datasets generated and analyzed in this study are in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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