

EVALUATION OF THE PERFORMANCE OF SUSTAINABLE MODIFIED POLYMER CONCRETE MADE FROM VARIOUS WASTE MATERIALS

Zeinab Raad Mahdi, Shatha Sadiq Hasan, Mustafa Naem Hamoodi and Mohammed Yousif Fattah

Department of Civil Engineering, University of Technology, Baghdad, Iraq

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ABSTRACT: Due to its superior performance over traditional materials, polymer concrete has emerged as a new engineering material in the current context. The main focus of this study was the design and manufacture of polyester polymer concrete (PC) from various recycled materials for use in various building applications. Four different types of recycled aggregate from easily accessible crushed building materials were employed: waste glass (WG), crushed mortar (CM), crushed clay bricks (CB), and crushed concrete (CC). Sustainable modified polymer concrete (SMPC) specimens were made using a conventional casting method and various replacements for normal sand, such as crushed concrete, mortar, clay bricks, and waste glass (10, 20, 30, and 40 volume percent). The mechanical properties of SMPC with and without recycled aggregate were tested for compressive, tensile, and flexural strength. The findings showed that adding (10%, 20%, 30%, and 40%) of (CC, CM, CB, and WG) as a partial substitute for natural fine aggregate improves the mechanical properties (compressive strength, direct tensile strength, and flexural strength) of SMPC. In comparison to other waste materials, the results of using crushed concrete were the best and highest. Similar to reference PC and SMPC with recycled fine aggregate, the rate of strength evolution with age is roughly the same. This research also looked into how the curing temperature affected the SMPC's compressive strength characteristics. The 20, 40, and 60 °C curing temperature ranges were taken into consideration. The findings demonstrate that the compressive strength of PC, both with and without recycled fine aggregate, is significantly impacted by a curing temperature above 20 °C.

Keywords: Clay bricks, Crushed concrete, Waste glass, Recycled aggregate

1. INTRODUCTION

Construction materials made of a polymer matrix and natural aggregate are known as polymer concrete (PC) or polymer mortar (PM) [1]. Indeed, its work in civil engineering projects like bridge decks, concrete crack repair, pavement covering, sewage pipelines, and ornamental building components has, in recent times, developed [2]. The building material made of polyester PC has great chemical resistance as well as strong physical characteristics and comparatively little shrinkage [3, 4].

Studies on the utilization of recycled aggregates (RA) are also available. If RA is not used properly after the destruction of old buildings and roadways, it is regarded as waste [5, 6]. The word "recycled aggregate" refers to crushed concrete, mortar, bricks, glass, or asphalt made from leftover construction waste that are utilized again in different construction projects. In order to recover the aggregate, demolished material is crushed to create recycled aggregate [7].

The majority of buildings in Iraq are made of reinforced concrete, and 75% of these structures have aggregate as part of their concrete composition. Because aggregate is not readily renewable in the ecosystem, its exploitation has a detrimental effect on the environment. Recycling and reusing building debris from demolished structures is one alternative

to the excessive usage of aggregates in construction. Recycling demolished building debris is nothing new, since many nations crush debris to create aggregates, even if only for low-level purposes [8]. Reusing construction and demolition waste has become crucial due to the demands of sustainable development and environmental protection. Since aggregate is a nonrenewable resource, its cost is increasing as it approaches depletion. In light of this, developing a strategy for sustainable development is essential, whether from the perspective of environmental protection or production costs. Unfortunately, this building development and demolition trash is disposed of in landfills, burying the enormous potential value in the garbage while also wasting limited land resources and polluting the environment [9].

The basic principles of sustainable construction material are reuse and recycling for sustainability. The use of recycled concrete aggregates, also known as RCA, in mixes of concrete has been the focus of many studies. Utilizing RCA-based concrete as a building material is anticipated to help address the issue of a shortage of raw materials and enable the construction of infrastructure [10]. The environment cannot be sustained unless waste, pollution, resource depletion, and degradation are taken care of. Large volumes of concrete from demolished structures accounted for thirty to forty percent of all waste in the

construction industry [11]. The rapidly expanding global economy and building sector have produced massive volumes of garbage from construction and demolition, including bricks, steel, concrete, glass, plastics, and ceramic materials [12]. Waste clay bricks and waste mortar made up the majority of the garbage generated during construction and demolition as a result of the rapid urbanization in the world, particularly in Iraq (Figure 1).



Fig.1 Buildings in Iraq after demolition. a. demolition of an old building. b. grinding of crushed concrete.

In Iraq, there is a huge need for concrete. A significant amount of trash from building construction and demolition is produced annually as a result of infrastructure upgrades or the extension of building lifespans.

Many studies have been conducted globally to convert building waste materials into "green" materials. One of these studies revealed that recycled concrete has a lower compressive strength than conventional concrete, which limits its application to infrastructure reconstruction, roads, walkways, and flooring [13]. Additionally, recycled concrete, which comes from a variety of building waste materials, of which thirty to forty percent are old concrete, can be utilized to make concrete while using less energy and natural resources [14]. The mechanical properties and characteristics of concrete made using recycled aggregates have both been examined in earlier publications. The majority of researchers have come to the same conclusion: recycled concrete performs less as the replacement ratio rises [15]. Although there are other opinions that recycled concrete performs better. The compressive strength of recycled concrete is slightly higher than that of control concrete or exceeds the target strength [16, 17]. Also, the results demonstrate that even though the performance of RA is low, the impact on the performance of RC is minimal when the replacement ratio is less than 30% to 50%. Additionally, by secondary processing recycled aggregates, altering the mixing method, and enhancing the curing environment, many researchers have attempted to offset the negative effects of recycled aggregates on the qualities of recycled concrete [16, 18].

The study of creative and novel applications for waste materials is always progressing. The goal of these studies is to meet society's need for an affordable and safe way to dispose of trash. Using

recycled aggregates preserves the environment by reducing the need for new disposal sites and natural resources. The focus of the current study is on waste materials that can be used in PC mixes instead of traditional components like sand. Specifically, these elements include broken clay bricks, glass trash, demolished concrete, and building construction waste [19].

Recycled aggregates can be obtained through the demolition of a variety of structures, including buildings, airport runways, bridge supports, and concrete roadbeds [20]. These aggregates can then be utilized to make concrete that is referred to as recycled aggregate concrete. The characteristics of the recycled aggregate concrete influence the original concrete's strength, size distribution, and water absorption [21]. Reusing concrete refuse from demolitions can reduce pollution and the depletion of natural resources. But before recycling such garbage for making concrete, several analyses need to be carried out to determine its properties [20].

The use of crushed bricks as aggregates is particularly interesting since it can help preserve natural aggregate supplies while also significantly reducing the issue of waste storage. Nevertheless, there are several barriers to using crushed brick aggregates in concrete, including regulatory restrictions on water absorption and impurities as well as a lack of understanding regarding the behavior of concrete composed of crushed bricks. The first concrete products were made in Germany in 1860 using crushed brick and Portland cement, but the Second World War's reconstruction efforts are credited with the first notable application of crushed brick as aggregates in fresh concrete [22].

Several European and American nations have reported on the results of recent, fruitful experiments on the use of broken bricks as aggregates in concrete. Only a small number of them discuss concrete created with the fine fraction or coarse and fine particles; the majority of them, however, are focused on experiences using broken bricks as coarse aggregates [23].

Recent years have seen the preparation of various particle sizes of recycled bricks as alternative aggregate, including recycled coarse aggregate RCA (with particles > 5 mm in diameter), recycled fine aggregate RFA (with particles < 5 mm in diameter), and supplemental cementitious material (with particles < 0.125 mm in diameter). Glass is the perfect recyclable material. Utilizing recycled glass contributes to energy conservation. Reusing discarded glass to produce recycled aggregate concrete is one of its major contributions to the construction industry [24].

Due to the chemical similarities between glass and ordinary sand, the utilization of glass waste and glass powder waste in PC has been the subject of several studies [3, 17].

2. RESEARCH SIGNIFICANCE

Waste materials that are easily accessible and inexpensive are increasingly finding usage in construction engineering. This research centered on creating SMPC from building demolition that can be used in an array of building projects. The recycling of fine aggregate from building and demolition waste is not common practice in the creation of PC in Iraq. As a result, the article's key innovation is the preparation of sustainable PC modified with recycled fine aggregate in a replacement ratio of 0 to 40% for regular fine aggregate. The main objective of this work is to evaluate SMPC properties by replacing ordinary fine aggregate (OFA) with four different types of RFA from building and demolition waste and different replacement percentages. Also, the findings of this study add to previously published works and have the potential to boost recycling rates for construction and demolition debris, which would lessen the demand for natural resources in the building industry.

3. MATERIALS AND METHODS

3.1 Unsaturated Polyester Resins (UPR)

The most popular resin systems for PC are unsaturated polyester and epoxy resins due to their affordability, accessibility, and superior mechanical performance. The most often used thermosetting matrix is UPR because of its chemical resistance, thermal stability, mechanical characteristics, availability, and inexpensive cost [1]. In this study, a commercial UPR was used. The resin was combined with a liquid hardener that had an amine base for curing. For PC, the range of resin dosage described by various authors is typically between 10% and 25% by weight [16, 21]. The UPR's basic characteristics are listed in Table 1.

Table 1 Some properties of used unsaturated polyester resin.

Specific gravity @ 25 0 C	1.12
Viscosity @ 25 0, C	300 mPa.s
% of Styrene	40%
Curing time	28 - 53 min
Gel time	20

3.2 Fine Aggregate (FA)

Between 60% and 95% of a mix's weight is typically utilized as aggregate, which can have a variety of particle sizes and natural compositions, such as silicate, limestone, quartz, and granite [1, 3]. The aggregates can be distributed throughout the polymer matrix and are typically inert in nature.

Aggregates can be classified as coarse aggregates (materials with a size greater than 5 mm) or fine aggregates (materials with a size less than 5 mm), depending on their dimensions. In this study, ordinary and recycled FA with a maximum size of 4.75 mm was used in all PM. The FA was dried in a furnace oven at (100°C) for one day prior to being used in the PM mixes.

3.2.1 Ordinary Fine Aggregate (OFA)

Natural silica sand with a fineness modulus, specific gravity, and absorption of 2.49, 2.63, and 2.5%, respectively, and passed through sieve No. 4 (4.75 mm), was used as OFA. Al-Ukhaider OFA from the Karbala region of Iraq used in this study conformed to Iraqi specifications (ASTM C33/C33M-13) [25].

3.2.2 Recycled Fine Aggregate (RFA)

Four different RFA types made from building and demolition waste are utilized in this study. The four RFA listed below, each graded in accordance with Iraqi standards (ASTM C33/C33M-13) [27], have a maximum size of 4.75 mm: Crushed concrete (CC) is obtained from the slab of the old building (Figure1); the age of the destroyed home is approximately 30 years. Crushed mortar (CM) is obtained from the flooring mortar of the same old building. Crushed clay bricks (CB) are obtained from the destroyed wall of the same old house. and, finally, waste glass is produced from the crushed windows of the same destroyed building.

The repurposed building was first crushed. The steel and iron fragments were then eliminated. Thirdly, well-graded aggregates were created by treating the resulting granular materials. The treated recycled aggregate (CC, CM, CB, and WG) was then crushed once more to provide the appropriate particle-size distribution.

4. DESIGN DETAILS FOR THE PPC MIXTURES

4.1 PPC Trial Mixtures

The (base/ hardener) resin ratio was established by many trial mixes, and in order to get the ideal ratio, the ratio is constrained by its original product. To find the reference PC with high compressive strength after seven days and good flow, seven experimental mixes of regular fine aggregate and polymer resin are created as shown in Table 2. The optimum mix that considered reference mix was mix D with (23) % polymer resin and (77) % OFA. This work's mixtures were all completed in accordance with ASTM C 305-20 [26].

Table 2 PC trial mixes

Mixes	A	B	C	D	E	F	G
Normal sand (%)	74	75	76	77	78	79	80
PR (%)	26	25	24	23	22	21	20
Flow table %	81	79	76	73	67	59	55
Compressive strength at 7 days	31.1	32.7	36.3	39.8	38.2	35.4	32.3

*In this study, Mix D (189 gm polymer: 662 gm normal sand), flow (68%) was employed as the reference mixture.

4.2 Mix Proportions

The mixes were separated into four series, each with four mixes, to accomplish the goal of this study, as indicated in Table 3. As part of the experimental program for the investigation of SMPC properties, seventeen PPC combinations were produced. Fig. 2 represents the shape of SMPC samples used in this study.



(a)



(b)



(c)

Fig.2 SMPC samples. (a) compressive strength samples. (b) tensile strength samples. (c) flexural strength samples

5. RESULTS AND DISCUSSION

5.1 Compressive Strength

The test for compressive strength is a particularly important mechanical test since it provides details on the composition and structure of the mortar. According to ASTM C109/C109M [27], the compressive strength test was conducted. Using an electrical testing machine with a 1500 KN capacity, this test was performed on 50 mm cubes, Fig. 2a. By

Table 3 Composition of conventional PC and SMPC with recycled aggregate.

Group 1	% Replacement of normal sand NS	Mixes title	PR	NS	CC	CM	CB	WG	Flow (%)	Description
Reference	0	PC	189	662					68	Control
Series 1	10	PPC1	189	595.80	66.20				72	Crushed concrete (CC)
	20	PPC2	189	529.60	132.40				78	was used in
	30	PPC3	189	463.40	198.60				81	place of NS.
	40	PPC4	189	37.20	264.80				83	
Series 2	10	PPM1	189	595.80		66.20			71	Crushed mortar (CM) was used
	20	PPM2	189	529.60		132.40			74	in place of NS.
	30	PPM3	189	463.40		198.60			78	
	40	PPM4	189	37.20		264.80			81	
Series 3	10	PPB1	189	595.80			66.20		70	Crushed clay bricks (CB)
	20	PPB2	189	529.60			132.40		73	were used in
	30	PPB3	189	463.40			198.60		76	place of NS
	40	PPB4	189	37.20			264.80		79	
Series 4	10	PPG1	189	595.80				66.20	73	waste glass (WG) was used
	20	PPG2	189	529.60				132.40	79	in place of NS
	30	PPG3	189	463.40				198.60	84	
	40	PPG4	189	37.20				264.80	86	

dividing the greatest force applied to the specimen during the test (to determine the final failure) by the average cross-sectional area of the specimen, the compressive strength of the specimen was determined. Fig. 3 illustrates the variance in compressive strength of four distinct sets of SMPC using various types of recycled aggregates and various curing ages. Each of these four sets of environmentally friendly modified PC includes four percentage replacements of recycled aggregate. Compression tests performed at 7, 14, and 28 days after curing were used to assess the compressive strength of PCs. The outcomes were compared with those of aggregates formed naturally. Table 4 presents the experimental test findings, which indicate that the compressive strengths of sustainable modified PC are incrementally affected by the partial replacement of normal aggregates with recycled aggregate (CC, CM, CB, WG). As shown in Fig. 3, the use of recycled aggregate as a substitute for natural sand has increased the compressive strength of sustainable PC replacements, except for crushed bricks, which replacement increased by up to 30%.

As shown in Fig. 5a, the compressive strength of the SMPC with crushed concrete aggregates gradually increased as the CC content increased. This resulted from the old mortar's strong adhesion to the recycled concrete aggregate, which may have increased the sustainable polymer concrete's compressive strength [10].

For the same reason also the compressive strength of the sustainable PC with crushed mortar gradually increased as the CM concentration done, as shown in Fig. 5b.

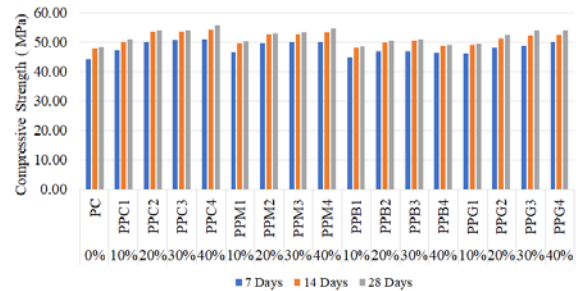


Fig.3 Compressive strength at 7, 14, and 28 days for every blend

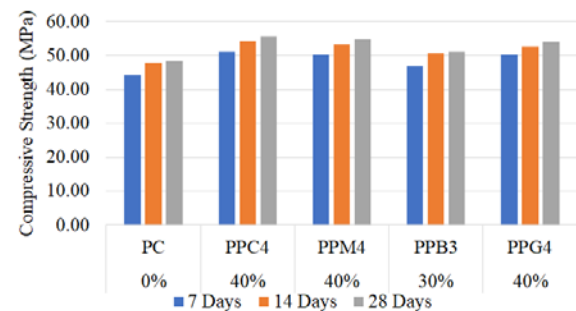


Fig.4 The compressive strength of the reference PC and the highest strength of all series at 7, 14, and 28 days

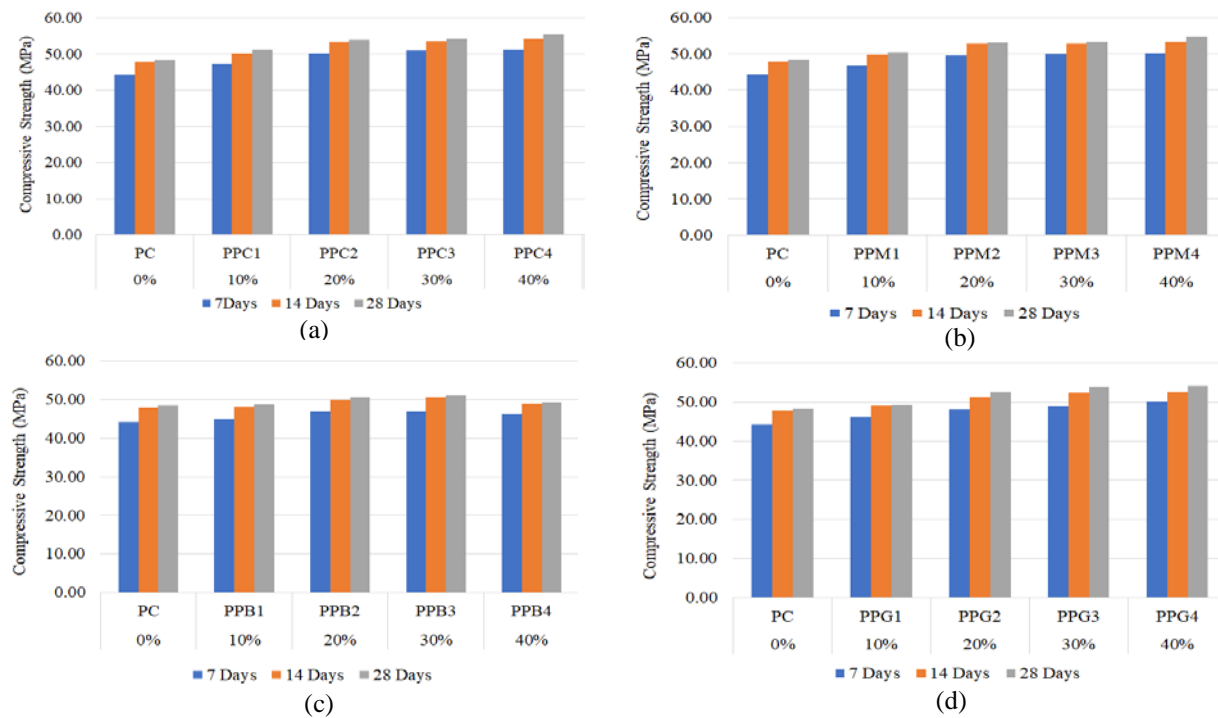


Fig.5 Compressive strength for reference and sustainable modified PC at 7,14, and 28 days. (a) Crushed concrete CC was used in place of NS. (b) Crushed mortar CM was used in place of NS. (c) Crushed clay bricks CB was used in place of NS. (d) waste glass WG was used in place of NS

Table 4 Compressive strength results (MPa) of conventional PC and SMPC with recycled aggregate

Series No.	Replacement of NS %	Mixes title	Compressive strength (N/mm ²)			Description
			7days	14days	28days	
Reference	0	PC	44.20	47.80	48.40	Control Crushed concrete CC was used in place of NS.
	10	PPC1	47.20	50.20	51.10	
Series 1	20	PPC2	50.10	53.40	53.90	
	30	PPC3	50.90	53.60	54.10	
	40	PPC4	51.10	54.20	55.60	
Series 2	10	PPM1	46.80	49.70	50.40	Crushed mortar CM was used in place of NS.
	20	PPM2	49.60	52.80	53.10	
	30	PPM3	50.00	52.80	53.20	
	40	PPM4	50.20	53.30	54.80	
Series 3	10	PPB1	44.90	48.10	48.70	Crushed clay bricks CB was used in place of NS
	20	PPB2	46.90	49.80	50.70	
	30	PPB3	47.00	50.60	51.10	
	40	PPB4	46.40	48.80	49.20	
Series 4	10	PPG1	46.20	49.10	49.40	waste glass WG was used in place of NS
	20	PPG2	48.10	51.30	52.60	
	30	PPG3	48.90	52.40	53.90	
	40	PPG4	50.1	52.6	54.1	

Results indicate that tests on mixes with crushed brick aggregate show a marginal increase. An increase of 5.6% is seen in the results of the 28- days compressive strength testing. These findings demonstrate the viability of using the crushed bricks from destroyed buildings as aggregate in PC up to 30%, as shown in Fig. 5c.

As anticipated, the use of the waste glass had a positive impact on compressive strength as shown in Fig. 5d because the glass aggregate particles were still widely dispersed and well encircled by the polymer matrix. This suggests that the glass aggregate may act as a strengthening agent to help close microcracks, which in turn helps to develop compressive strength in the sustainable PC mix [28].

It is obvious that the maximum compressive strength is equal to (55.6, 54.8, and 54.1) MPa for 40% CC, CM, and WG replacements of NS in Series 1, 2, and 4, respectively, and 51.1 MPa for 30% CB replacements of NS in Series 3 as shown in Fig 4.

5.2 Tensile Strength

Unlike conventional concrete, polyester PC is renowned for its comparatively high tensile strength. Dog bone-shaped samples with 76 mm in length, 25 mm in thickness, and 645 mm² in cross section were used to test the tensile strength of the original PC and SMPC at the mid-lengths depicted in Fig.2b. According to B.S. 6319-7:1985) [29], the direct tensile strength test was performed. Tensile tests were used to assess the tensile strength of PC at 7, 14, and 28 days after curing. It should be mentioned that the original PC with ordinary FA was used as the control mixture so that the outcomes could be compared. The difference in tensile strength of four series of sustainable modified PC using various types of recycled aggregates and various curing ages is shown in Table 5 and Fig. 6.

Recycled aggregate clearly has a good impact on the tensile strength of PC. According to the results, recycled aggregate in PC boosts the tensile strength. Tensile strength increased when recycled aggregate content was increased from 10% to 40%, but it increased up to 30% when recycled aggregate from crushed bricks was used.

It is known from Table 5 that the tensile strength of the sustainable modified PC produced ranges between 6.89 and 8.61 MPa after 28 days. This table shows that flexural strength increases with the amount of original aggregate replaced with recycled aggregate. With a 40% substitution of the OFA with CC aggregate, the highest tensile strength of 8.61 MPa was achieved. The tensile strength of reference PC is 6.89 MPa. The cavity in the PC will be filled with recycled aggregate; hence, the more recycled material added, the better the tensile strength. Tensile strength results for PC samples with varying sand replacement percentages are shown in Fig. 7. It was evident that variations in tensile strength are caused by variations in the type of recycled aggregate.

Overall, a high recycled aggregate ratio produced high tensile strength. The tensile strength of the PPC4 sample was 8.61 MPa at 28 days; this value was greater than the tensile strength of any other sample. The tensile strength of PPC4 with CC has increased by about 24 percent when compared to reference PC's (6.89 MPa) tensile strength, as shown in Fig. 7a. The results of the tensile strength tests were computed after 7, 14, and 28 days. The tensile strength of reference PC and SMC (substitution of natural sand with crushed mortar, substitution of natural sand with crushed clay bricks, and substitution of natural sand with waste) is shown in Fig. 7b, c, and d, respectively. The effect of substitution ratios and age is then plotted. It is obvious that recycled aggregate has a good impact on the compressive strength of polymers.

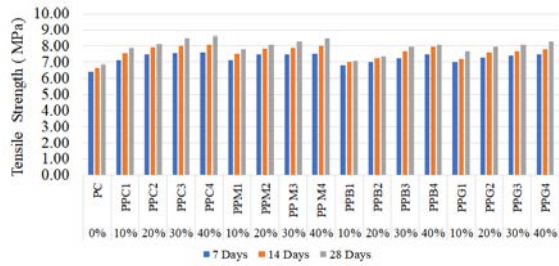


Fig.6 Tensile strength of all mixtures at 7, 14, and 28 days.

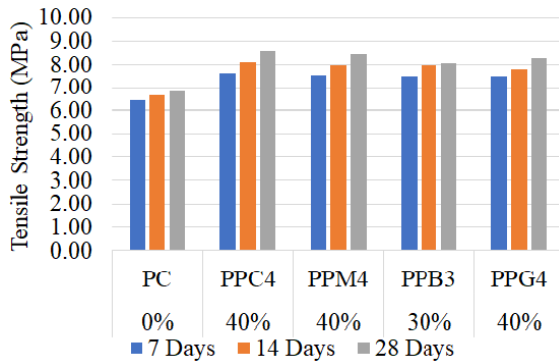
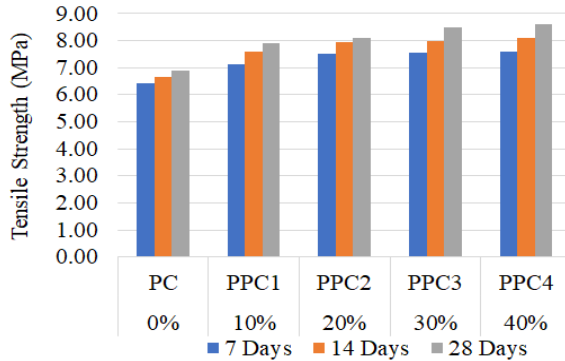
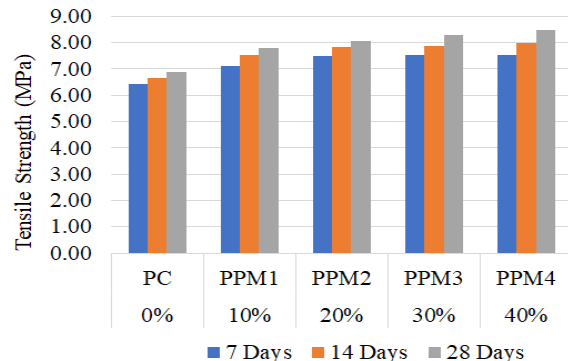


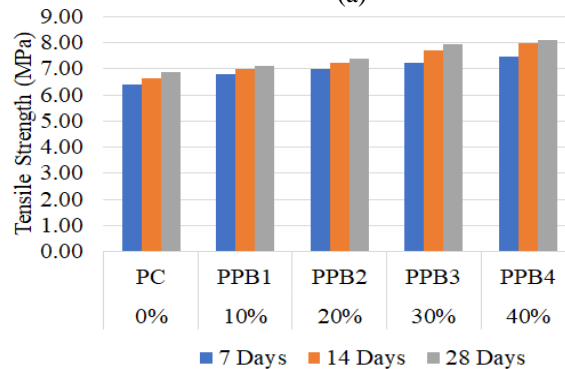
Fig.7 The tensile strength of the reference PC and the highest tensile strength of all series at 7, 14, and 28days.



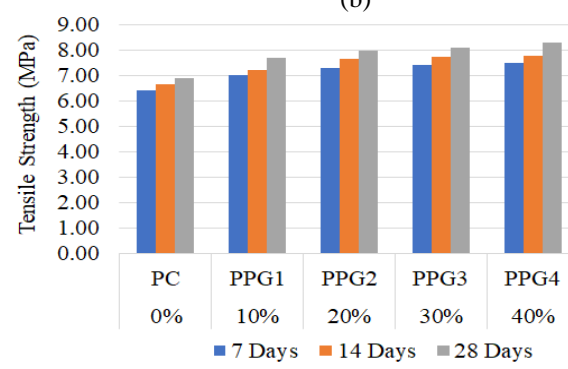
(a)



(b)



(c)



(d)

Fig.8 Tensile strength for reference and sustainable modified polymer concrete at 7,14, and 28 days. (a) Crushed concrete CC was used in place of NS. (b) Crushed mortar CM was used in place of NS. (c) Crushed clay bricks CB was used in place of NS. (d) waste glass WG was used in place of NS

The maximum compressive strength, as indicated in Fig. 8, is clearly equal to (8.61, 8.48, and 8.28) MPa for 40% CC, CM, and WG replacements of NS in Series 1, 2, and 4, and 8.08MPa for 30% CB replacements of NS in Series 3. Rasheed et al. [10], Saiz et al. [21], and Thari et al. [28], also noted such outcomes.

5.3 Flexural Strength

A third point loading test method was used to determine the flexural strength of all sustainable modified polymer concrete mixes. Prisms measuring (4*4*16) cm³ were used test as shown in Fig. 2c, which was carried out using a 10 KN testing machine from ELE International Company in line with ASTM C348-18 [30]. At 7, 14, and 28 days after curing, flexural tests were done to evaluate the flexural strength of polymer concretes.

The flexural strength values for all sustainable modified polymer concrete mixtures that use recycled aggregate in place of natural sand are shown in Table 6. The impact of substitution ratios and age on all mixes is plotted in Fig. 9.

Overall, this examination yielded a flexural strength at the age of 28 days that varied from 13.99 to 16.34 MPa. The results show that recycling material increases the flexural strengths of polymer concrete.

Table 5. Tensile strength results (MPa) of conventional PC and SMPC with recycled aggregate

Series No.	Replacement of NS %	Mixes title	Tensile strength (N/mm ²)			Description
			7days	14days	28days	
Reference	0	PC	6.41	6.64	6.89	Control
Series 1	10	PPC1	7.12	7.59	7.89	Crushed concrete CC was used in place of NS.
	20	PPC2	7.51	7.93	8.11	
	30	PPC3	7.56	7.99	8.48	
	40	PPC4	7.61	8.09	8.61	
Series 2	10	PPM1	7.10	7.52	7.81	Crushed mortar CM was used in place of NS.
	20	PPM2	7.49	7.84	8.07	
	30	PPM3	7.51	7.86	8.28	
	40	PPM4	7.54	7.99	8.48	
Series 3	10	PPB1	6.81	6.98	7.09	Crushed clay bricks CB was used in place of NS
	20	PPB2	7.01	7.24	7.38	
	30	PPB3	7.23	7.71	7.96	
	40	PPB4	7.48	7.97	8.08	
Series 4	10	PPG1	7.01	7.22	7.69	Waste glass WG was used in place of NS
	20	PPG2	7.29	7.64	7.97	
	30	PPG3	7.41	7.71	8.08	
	40	PPG4	7.48	7.78	8.28	

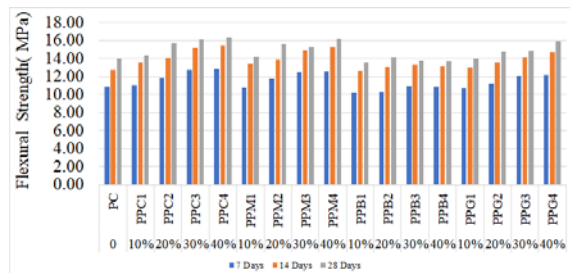


Fig.9 Flexural strength for all mixes at 7,14, and 28 days

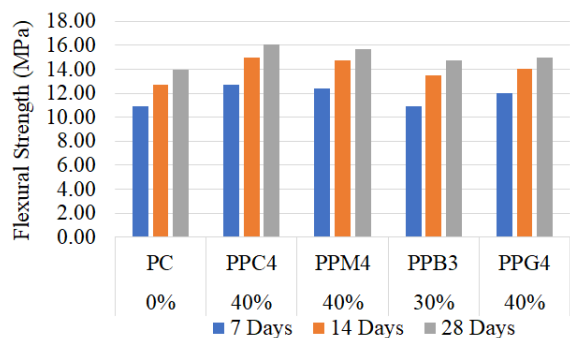


Fig.10 Flexural strength of the reference PC and the highest flexural strength of all series at 7, 14, and 28 days

Flexural strength increased with recycled aggregate content by 10% to 40%, but the maximum proportion of recycled aggregate from broken bricks

is 30%, as shown in Fig. 11. As seen in Fig. 11a, using crushed concrete in place of natural sand improves flexural strength when compared to the reference polymer concrete. Fig. 11b and c display the flexural strength of the reference PC and SMPC (natural sand replacement with crushed mortar and natural sand substitution with crushed clay bricks), respectively. As anticipated, replacing waste glass has a favorable impact on the flexural strength depicted in Fig. 11d. The percentage of waste glass used in the mixture directly correlates with this rise. When compared to the reference pc mix, the use of 40% waste glass increased the flexure strength by 2.5 percent, 12.1 percent, and 13.83 percent at the ages of 7, 14, and 28 days, respectively. The WG's low absorption and the fine particles it contains, which fill in the minuscule spaces and densify the matrix's structure, are the causes of the jump in the replacement rate to 40% of glass waste [16].

5.4 Compressive Strength For SMPC After Different Temperatures Of Curing

One of the most important qualities of the materials used in the building and civil engineering sectors is durability. The ability of a substance to withstand external stresses without undergoing form deformation or character change is known as durability [5,8]. The optimal percentage of sustainable modified polymer concrete in every group, which was chosen because of the results of the previously described tests, was taken to study the

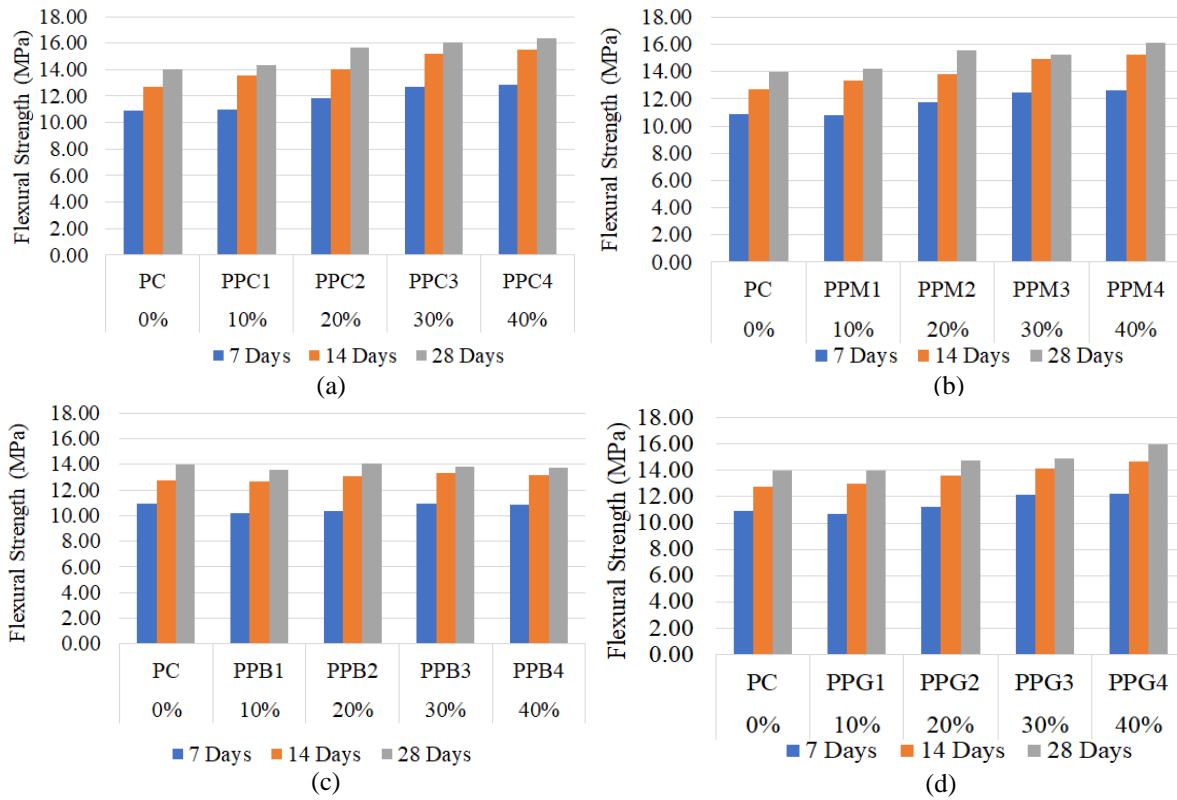


Fig.11 Flexural strength for reference and sustainable modified polymer concrete at 7,14, and28 days. (a) Crushed concrete CC was used in place of NS. (b) Crushed mortar CM was used in place of NS. (c) Crushed clay bricks CB was used in place of NS. (d) waste glass WG was used in place of NS

Table 6. Flexural strength results (MPa) of conventional PC and SMPC with recycled aggregate

Series No.	Replacement of NS %	Mixes title	Flexural strength (N/mm ²)			Description
			7days	14days	28days	
Reference	0	PC	10.9	12.73	13.99	Control
Series 1	10	PPC1	10.99	13.56	14.34	Crushed concrete CC was used in place of NS.
	20	PPC2	11.82	14.05	15.68	
	30	PPC3	12.71	15.22	16.09	
	40	PPC4	12.84	15.47	16.34	
Series 2	10	PPM1	10.79	13.36	14.24	Crushed mortar CM was used in place of NS.
	20	PPM2	11.75	13.85	15.58	
	30	PPM3	12.51	14.95	15.24	
	40	PPM4	12.61	15.27	16.14	
Series 3	10	PPB1	10.19	12.66	13.59	Crushed clay bricks CB was used in place of NS
	20	PPB2	10.32	13.08	14.10	
	30	PPB3	10.91	13.35	14.84	
	40	PPB4	10.88	13.18	13.76	
Series 4	10	PPG1	10.68	13.01	14.00	Waste glass WG was used in place of NS
	20	PPG2	11.22	13.58	14.78	
	30	PPG3	12.11	14.15	14.89	
	40	PPG4	12.20	14.67	15.96	

effect of temperature on the compressive strength of polymer concrete. The compressive strengths of polymer concrete specimens were measured at curing temperatures of 20 °C, 40 °C, and 60 °C using the mixtures listed in Fig. 12.

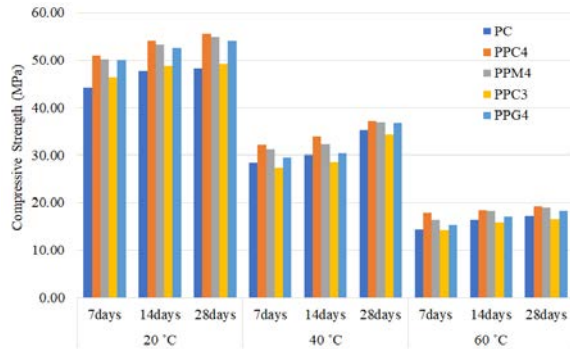


Fig.12 Compressive strength of SMPC at various curing temperatures

These curing temperatures were set across a broad spectrum, taking into account the maximum curing temperatures that polyester polymer concrete can withstand.

They were based on the 20-year average readings of the hottest months in Iraq (20 °C, 40 °C, and 60 °C). The mechanical properties of polymers can change depending on the temperature at which they are treated. If the temperature of the polymer concrete during treatment is within the range of the glass transition temperature, the applied temperature will have a substantial impact on the mechanical parameters, such as the compressive strength [31, 32].

Table 7 displays the results of compressive strength at 20 °C, 40 °C, and 60 °C during curing. The findings demonstrated that high temperatures have a significant impact on polymer concrete, and a discernible drop in compressive strength when compared to findings for compressive strength at 20° C implies that compressive strength rises as the heat of cure decreases.

The minimum required compressive strength per the ACI 584.9 guideline [33] is 34 MPa. The minimum required compressive strength per the ACI 584.9 guideline [33] is 34 MPa. On the other hand, samples that underwent a 40 °C cure had a compressive strength of 34 MPa. The compressive strength values for the specimens that were cured at temperatures higher than 40 °C were less than 34 MPa, which is the minimal value advised by the ACI guideline.

6. CONCLUSIONS

The findings of this investigation allow for a number of inferences to be made:

- sustainable modified Polymer concrete can be produced when using recycled fine aggregate from CC,CM,CB, and WG as a partial substitute for natural sand in different proportions (10,20,30 and 40) % .
- The workability of SMPC is positively impacted by the fractional replacement of ordinary fine aggregate in polymer concrete. Using CC, CM, CB, and WG at a replacement percentage of 30%, respectively, boosts the flowability of each of these recycled materials by 22.1%, 19.1%, 16.2%, and 26.5% in comparison to the reference mixture and this is due to the fact that the rate at which the polymer concrete reacts chemically may be explained by the theory underlying this phenomenon. The polymer concrete's initial strength is positively impacted by the high treatment temperature, as it speeds up the chemical reaction; however, the final strength is adversely affected.
- The mechanical properties (compressive strength, direct tensile strength, flexural strength) of SMPC are improved by adding (10%, 20%, 30%, and 40%) of (CC, CM, CB, and WG) as a partial substitute for natural fine aggregate. When using crushed concrete, the results were the best and highest when compared to the results of other waste materials.

Table 7 Compressive strength of SMPC at various curing temperatures

Mixes title	Compressive strength (N/mm ²) at 20 ⁰ C			Compressive strength (N/mm ²) at 40 ⁰ C			Compressive strength (N/mm ²) at 60 ⁰ C		
	7 days	14 days	28 days	7 days	14 days	28 days	7 days	14 days	28 days
PC	44.20	47.80	48.40	28.40	30.10	35.30	14.50	16.40	17.30
PPC4	51.10	54.20	55.60	32.30	33.90	37.20	17.80	18.40	19.20
PPM4	50.20	53.30	54.80	31.30	32.40	36.90	16.40	18.20	18.90
PPC3	46.40	48.80	49.20	27.30	28.60	34.30	14.30	15.90	16.60
PPG4	50.10	52.60	54.10	29.60	30.40	36.80	15.30	17.10	18.20

- A progressive improvement in strength was noted in the SMPC utilizing CC and CM as recycled aggregates as the RA content rose. This outcome may have resulted in an enhancement in the SMPC's strength because of the old mortar's strong link to the recycled concrete aggregate.
- The strength characteristics of polymer concrete are enhanced by the addition of wasted glass aggregate to the mixture.
- The optimum level of aggregate substitution for CC, CM, and WG was also shown by the results to be around forty percent, whereas for CB it was thirty percent. Therefore, recycled fine aggregate from demolished buildings may be a suitable replacement for fine aggregate in polymer concrete.
- Comparing the mixes with 40% replacement of OFA by CC, CM, and WG, respectively, yielded increases in compressive strength of 14.9%, 13.2%, 11.8%, splitting tensile strength of 24.9%, 23.1%, 20.2% and flexural strength of 16.8%, 15.4%, 14.1% for the reference PC mix. Conversely, the mixes with a 30% replacement of OFA by CB showed increases in compressive strength of 5.6%, splitting tensile strength by 17.2% and flexural strength by 6.1% at 28 days.
- Based on the results of this investigation, it was discovered that the properties of polymer concrete allow for the production of sustainable modified polymer concrete with a temperature of 20 °C or below 40°C.

Further investigation is necessary to determine the effect on density, elasticity modulus, absorption, and durability. Finally, the results of this study demonstrated a workable technological option for enhancing the quality of making polymer concrete with recycled aggregate, opening the door to selective recycling of construction waste and its application in the creation of sustainable polymer concrete.

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