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The effectiveness of substrate roughness and bond angle between old and new concrete in improving the flexural performance of hybrid concrete prisms

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Abstract. This study aimed to evaluate the structural behavior of sustainable hybrid concrete produced using recycled plastic as a partial sand replacement at percentages of 0%, 5%, 10% and 15% with the addition of 2% recycled steel wire fibers by volume. The focus was on improving the bond performance between old and new concrete under bending loads. The experimental program included compressive strength tests cubes, split tensile strength tests cylinders and slump tests for fresh concrete. Additionally, bending tests were conducted on prisms measuring 10 x 10 x 40 cm at contact angles of 30°, 45° and 60° with various surface treatments applied to increase the roughness of the face. The results showed a gradual decrease in mechanical properties with increasing plastic content. The compressive strength decreased by 16% when 15% of the sand was replaced with a compressive strength of 19.24 MPa recorded at 28 days. The bond angle also significantly affected flexural strength and failure mode 60° angle reduced strength by 17%-20% compared to smaller angles. Conversely, surface treatments applying horizontal and radial roughening of 1 cm improved bond strength by 16% -26%, while reducing the likelihood of surface bond failure in samples with high plastic content. These results suggest the possibility of producing sustainable concrete using recycled materials without significantly impacting structural performance and in an environmentally friendly manner, provided that the concrete's surface bonding properties are improved to ensure effective structural behavior.

Keywords: bond angle; flexural load; hybrid concrete; recycled plastic; recycled wire steel; roughness surface

1. Introduction

The continuous evolution of modern lifestyles has led to a noticeable rise in plastic consumption across many aspects of daily life. Despite its practical advantages, plastic waste

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presents a serious environmental challenge due to its extremely slow natural degradation. Current reports indicate that less than 10% of global plastic waste is recycled, while the majority is disposed of in landfills or through incineration, both of which generate significant environmental impacts ((Harihanandh and Karthik 2022, Lumina *et al.* 2022).

In response to this issue, increasing research attention has been directed toward incorporating plastic waste into construction materials, particularly concrete, by using it as a partial replacement for fine aggregates (Ashok *et al.* 2020, Diana *et al.* 2021). This approach contributes to reduce environmental burdens while promoting sustainable construction practices. Previous investigations have reported mixed outcomes. For example, Adnan and Dawood's (2021) demonstrated that replacing a portion of sand with plastic waste bins improved both compressive strength and flexural performance of concrete beams. In contrast, other studies observed a reduction in strength when plastic-modified concrete was exposed to elevated temperatures, although durability and corrosion resistance remained satisfactory (Ullah *et al.* 2022). Additionally, the incorporation of PET plastic waste in structural applications has been linked to enhanced seismic performance due to reduced structural weight (Saadulla *et al.* 2023)

Nevertheless, some scientific concerns remain regarding the influence of higher plastic replacement ratios on the overall mechanical performance of concrete, including compressive strength, tensile strength, and bond behavior with reinforcing steel (Hama 2022). Certain researchers have reported that substituting specific percentages of sand with plastic materials can enhance flexural capacity by up to 20% (Al-Tayeb *et al.* 2022, Mohammed and Hama 2022). However, studies focusing on the bond performance between existing concrete containing recycled plastic and newly cast concrete layers are still limited, indicating a clear research gap (Ponmalar 2023). Investigating this interfacial behavior is therefore essential, particularly in repair and rehabilitation applications where proper surface preparation plays a crucial role in achieving reliable bonding between old and new concrete (He et al. 2017, Santos *et al.* 2012, Courard *et al.* 2014).

The bond strength between old and newly cast concrete is a key parameter in structural rehabilitation. It is mainly affected by the inclination angle at the interface and the surface treatment method applied. Previous research has confirmed that increasing surface roughness through techniques such as sandblasting or chemical etching significantly improves adhesion strength (Dinkha *et al.* 2017, Apostolinas *et al.* 2022). Moreover, the bond angle between the two concrete layers influences flexural response and failure mechanisms, highlighting its importance in structural performance evaluation.

Recent studies have also emphasized the advantages of incorporating recycled materials, including plastic and steel fibers, to improve mechanical properties while enhancing environmental sustainability. Hama *et al.* (2023) reported that recycled plastic fibers contribute to improved tensile and flexural strengths, in addition to maintaining acceptable workability and stiffness Similarly, Tahir *et al.* (2023) demonstrated that hybrid steel and polypropylene fibers enhance bond strength and durability in reinforced concrete. González-Betancur *et al.* (2024) examined lightweight concrete produced with recycled plastic aggregates and reported improvements in workability and resilience suitable for sustainable urban construction. Bendjillali and Chemrouk (2024) observed significant mechanical improvements when plastic waste was used as fibers in mortar mixtures. Meanwhile, Irshidat *et al.* (2025) investigated the feasibility of producing lightweight concrete using recycled plastic aggregates. The integration of recycled materials into emerging technologies such as 3D-printable concrete further supports sustainable development in the construction sector. Overall, these studies indicate that optimized material proportions and proper surface preparation are necessary to ensure satisfactory bonding and structural efficiency.

Based on the above, the present study aims to develop environmentally friendly concrete by partially replacing sand with recycled plastic particles and incorporating 2% recycled steel wire fibers with an L/d ratio of 70, as recommended by Chetbani *et al.* (2023) to enhance tensile performance. In addition, the study evaluates the effect of bond inclination angles of 30°, 45°, and 60° between the existing plastic-modified concrete and newly cast concrete, while also examining the influence of surface treatment on bond strength and flexural behavior of composite beams. It is important to note that improvements reported in earlier studies are often associated with treated plastic materials or relatively low replacement ratios. In this investigation, untreated plastic particles were used as partial sand replacement, and particular attention was given to interfacial bond behavior under flexural loading, which explains the variations observed in mechanical performance. The importance of this study lies in its contribution to the comprehension of the interactions between recycled materials and the various factors that influence the structural performance of composite concrete elements, thereby providing an empirical foundation for sustainable practices in restoration and reuse methodologies.

2. Signification of the research

With the global trend toward sustainable construction and reducing the environmental impact of traditional construction materials the use of recycled materials such as plastic and steel fibers is emerging as an effective option for improving concrete properties and reducing natural resource consumption. Although so many studies tested the influence of replacing sand with plastic on concrete strength the overall effect of this change on the bond strength between old and new concrete remains insufficiently studied particularly when there are casting intervals or changes in the bond angle. Moreover, the correlation between the bond angle and the failure characteristics under applied loads particularly in composite beams fabricated from recycled concrete remains inadequately represented in the academic corpus. Therefore, this research highlights a knowledge gap by conducting laboratory experiments to investigate the impact of varying proportions of recycled plastic and specific bond angles (30°, 45°, and 60°) on the mechanical interconnection efficacy and failure characteristics of composite concrete samples. The findings are expected to contribute to the development of sustainable concrete rehabilitation methodologies, thereby improving structural efficiency in the construction sector.

3. Experimental work

The experimental concrete mixes were designed to achieve a specific compressive strength of 30 MPa at 28 days. The American Concrete Institute (ACI) 211.1 method was applied to determine the weight ratios of the constituent materials. Four distinct concrete mixtures were formulated: one control mixture M1 and three experimental mixtures M2, M3, M4 which integrated varying proportions of recycled plastic 5%, 10%, 15% as a partial substitute for sand while maintaining the original proportions of cement, aggregates, water and recycled steel fibers. Recycled steel wire fibers were added at a constant ratio in all concrete mixes to control tensile behavior and reduce brittle failure. The fiber content was kept constant to isolate the effects of recycled plastic content,

Fig. 1 Prepare material and cast hybrid concrete mixes

Table 1 The control concrete mixture and concrete mixtures contain 5%, 10%, and 15% plastic waste as partial replacement of sand

Material type	Cement (kg)	Sand (kg)	Gravel (kg)	Water (kg)	Recycled steel fiber	Recycled plastic
M1	15.2	21.9	24.1	7.1	2%	0%
M2	15.2	21.9	22.9	7.1	2%	5%
M3	15.2	21.9	21.7	7.1	2%	10%
M4	15.2	21.9	20.4	7.1	2%	15%

bond angle and surface preparation on the performance of the composite beams. Table 1 delineates the weight ratios of the components for each respective mixture. All mixtures were treated under the same laboratory conditions till ages 7, 14 and 28 days (see Fig. 1).

3.1 Materials used

Cement: Ordinary Portland cement product of Kabisa Cement Factory, which was consistent with Iraqi specifications.

Sand: A fine aggregate grading used in concrete mixes was made from a quarry in Anbar Governorate which was consistent with Iraqi specifications.

Gravel: The coarse aggregate used in the concrete mix was from Anbar Governorate with a maximum size of 10 mm. A grading of coarse aggregate was conducted and the results met Iraqi specifications.

Recycled plastic: A type of used plastic obtained from a factory in Baghdad that was through a 4.75 sieve whose size is less than 4.75 mm. The recycled plastic used in this study was obtained from local waste sources and mechanically shredded before use. The material passed through a 4.75 mm sieve to ensure particle sizes comparable to fine aggregate. During mixing the plastic particles showed smooth and non-absorbent surfaces which was observed to influence the bonding with the cement paste and subsequently affect the mechanical performance of the concrete.

Recycled wire: The waste steel wire was used as fiber with a diameter of 0.5 mm and a length of 30 mm which means the fiber aspect ratio was 60. It had tensile strength and an elasticity modulus of about 1800 MPa and 200 GPa, respectively. Prior to mixing the recycled steel wire fibers were visually inspected and cleaned to remove dust and loose surface impurities. No active corrosion or severe rust was observed during preparation or mixing ensuring that the fibers did not introduce uncontrolled effects on the mechanical behavior of the concrete.

Water: It was used as drinking water in concrete mixes as well as concrete curing.

3.2 Prepare recycle concrete samples

Concrete samples were cast as follows: cubes, cylinders and prisms according to the established standards and procedures to ensure the accuracy and reliability of the test results. Clean them well, then oil the casting molds with a thin layer to facilitate removing the samples from the molds after casting. Prepare the materials according to the required weights for each concrete mix.

Fine aggregate, specifically sand and coarse aggregates such as gravel were systematically combined with cement and various additives including plastic and recycled wire within a container to achieve a thorough and uniform dry mixture. Subsequently, water was added to the mixture. The concrete was then poured into molds in uniform layers and a vibrator was utilized to compact the concrete thereby eliminating air voids and ensuring optimal density. The surface of the concrete was precisely leveled and the concrete was maintained within the molds under controlled laboratory conditions for a hardening duration of no less than 24 hours. Following this period, the concrete was extricated from the molds with great care to avert any potential fracture.

Samples were treated in water under standard laboratory conditions for a period of up to 7, 14 and 28 days to test compressive strength, indirect tensile strength and flexural strength after the hardening period.

A prism beam had with different proportions of recycled plastic and wire was examined with dimensions of 10 x10x 40 cm to conduct bending tests. The prism beam was cast in two stages, the first part is cast at an incline angle 30°, 45°, and 60°, after than initial cohesion was achieved, the inclined surface was treated to rough by using grooves to made an approximately 1 cm deep as well as a binder was also used. Second part was cast at an incline angle 30°, 45° and 60° to complete prism beam. Also, Styrene-Butadiene Rubber SBR was used as an additive in this study to improve the bonding properties between old and freshly poured concrete. SPR is a flexible synthetic polymer with a high ability to interact with cementitious materials and form an effective bonding layer. This material is widely used in concrete repair applications due to its role in enhancing bond strength reducing permeability and increasing crack resistance at the contact area

Fig. 2 Prepare and cast recycle concrete samples

between concrete layers. The prism beam was cured in water aquariums at a laboratory temperature of approximately 23°C for 28 days. Accordingly, the prism beams were prepared for flexural testing as shown in Fig. 2.

To ensure reliable statistical evaluation of the results, the following were used for each concrete mix and each test age 7, 14, and 28 days:

Three concrete cubes 10×10×10 cm for compressive strength testing according to BS. 1881: Part 116: 1989.

Three concrete cylinders 10 cm diameter and 20 cm height for indirect tensile strength testing according to ASTM C496.

Sixteen prismatic beams 10×10×40 cm at different inclination angles 30°, 45° and 60° to study the effect the percentage recycled plastic on the maximum flexure load sixteen prismatic beams to study the effect of bond angle on the maximum flexure load and twelve prismatic beams to study the effect different types of surface roughening on the maximum flexure load.

Thus, a total of 36 samples were used for compressive strength test a total of 36 samples were used for tensile strength test and a total of 28 samples were used for flexural and bonding tests.

4. Results and discussion

4.1 Slump testing

To verify the workability of concrete, a slump test was conducted for fresh concrete mixes to obtain concrete that is easy to work with mixing pouring and compacting without separating as shown in Fig. 3. The concrete had good workability 5 mm, 6.5 mm, 7 mm and 8.5 mm for 15%, 10%, 5% and 0% of waste plastic concrete mix, respectively. So, it notices that the slump values decrease approximately with the increase in the amount of plastic and the lowest value of slump was 5 cm as the percentage of plastic was 15%.

Fig. 3 Slump test

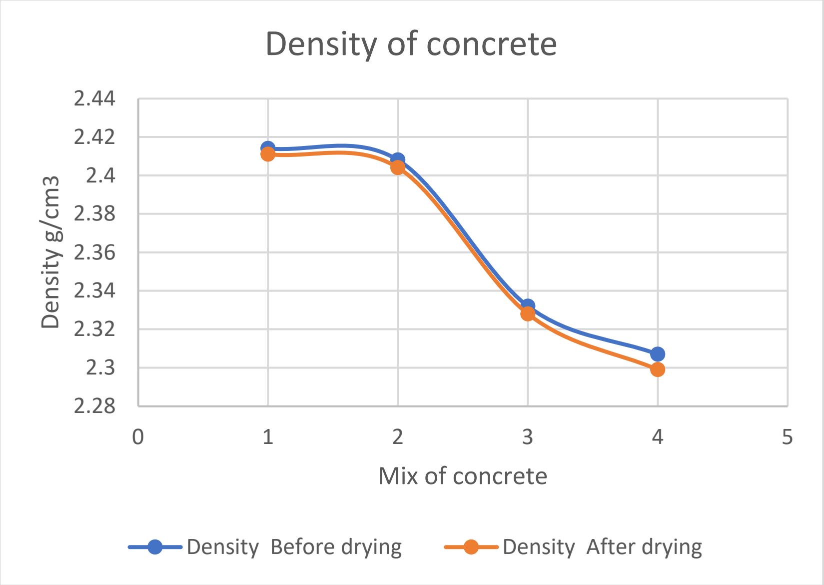

Fig. 4 Density values of plastic concrete

4.2 Density values

Fig. 4 shows the density values of plastic concrete. The density percentages in case of acceptable decrease for the samples were 0.29%, 3.57% and 4.87% for 5%, 10% and 15% of waste plastic, respectively. The decrease of plastic concrete density due to the density of plastic being less than the density of sand. In general, the density of plastic concrete has recycled wire as fiber was acceptable compared to control concrete.

4.3 Compressive strength

To verify the strength of hardened concrete had plastic waste of 0%, 5%, 10% and 15% as well

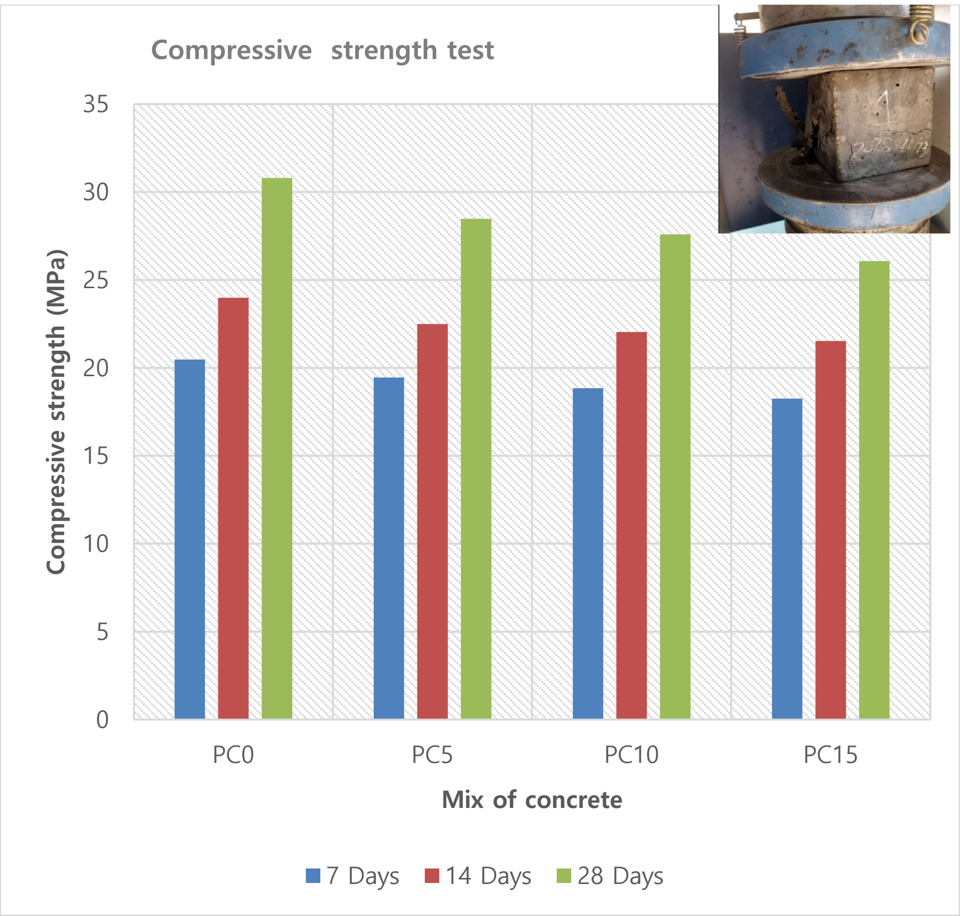

Fig. 5 The Compressive strength of hybrid concrete

the percentages of recycled wire fixed at 2% of concrete volume a compressive strength test was performed on concrete cubes. The 10x10x10cm cubes were placed under uniaxial compression at a constant loading rate over the cross-sectional area to calculate the compressive strength of the concrete N/mm2. Samples aged 7, 14 and 28 days were tested using a compression testing machine CTM with a loading rate of 2.25 kN until failure occurred. The compressive strength of the reference concrete is 30.11 N/mm^2 at 28 days. As a result, the value of compressive strength depends on the percentage of recycled plastic in concrete that it notices a decrease in compressive strength from 28.47 N/mm^2, 27.59 N/mm^2 and 26.07 N/mm^2 that it decreases in compressive strength of up to 7.53%, 10.39% and 15.33% with percentages of plastic waste of 5%, 10% and 15%, respectively as shown in Fig. 5.

The results indicate that the compressive strength of concrete incorporating recycled plastic waste exhibited a progressive decline, ultimately diminishing by 15.33% when 15% of the sand was replaced with plastic. A multitude of mechanical and microstructural factors which are intrinsically linked to the nature of plastic as a chemically inert substance characterized by a smooth non-porous surface contribute to this decline by engendering inadequate cohesion between

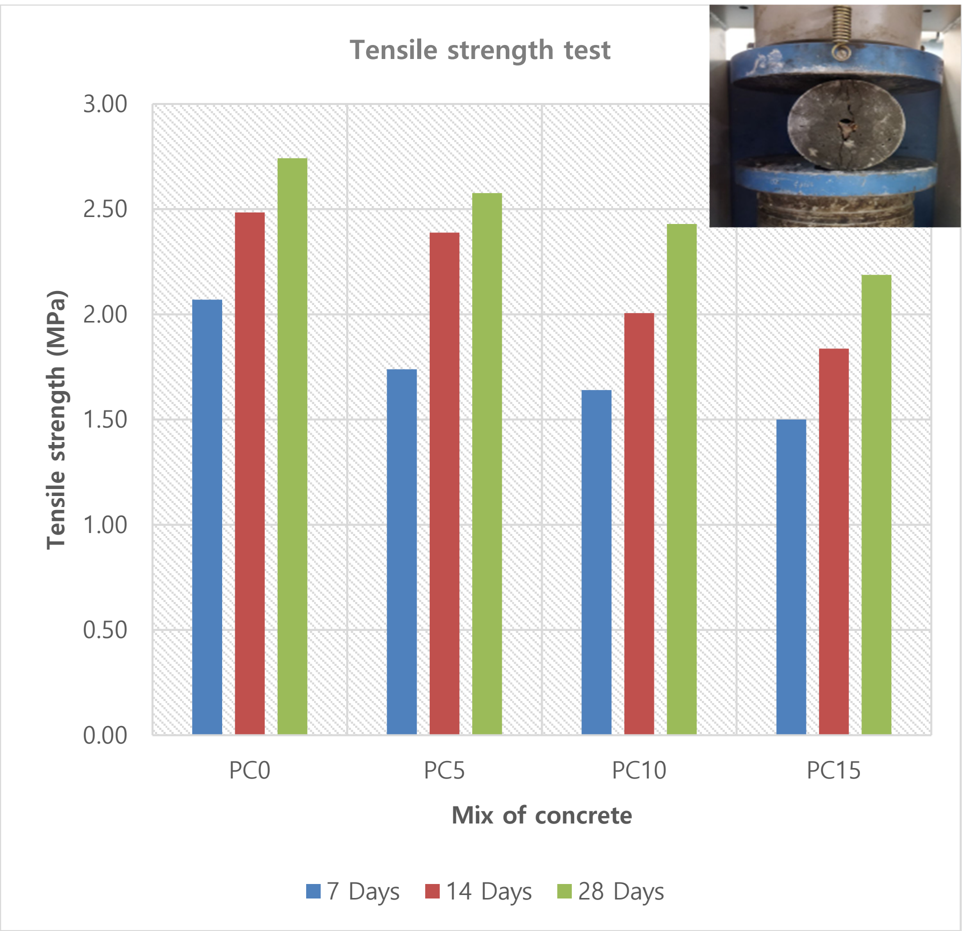

Fig. 6 Tensile strength of hybrid concrete

its particles and the cement paste. Furthermore, the presence of plastic particles induces the formation of weak interfacial transition zones (ITZs) within the concrete matrix which in turn detrimentally affects the overall structural density and enhances porosity.

The results are consistent with those of a study performed by Ismail and Al-Hashemi (2008) which found that the integration of fine aggregates with a high plastic content significantly reduces compressive strength. The noted reduction can be ascribed to insufficient interactions between the surfaces and ineffective stress transmission among the plastic particulates (Ismail and Al-Hashemi 2008). However, the 5% reduction remained below 7.53% which may be acceptable for non-load bearing concrete elements or those lacking structural significance particularly if the incorporation of fibers or bonding-enhancing materials such as polymers compensate for the adverse effect.

4.4 Split tensile strength

Fig. 6 gives the results of indirect tensile strength for three cylinders 10 cmx 20 cm at each age 7, 14 and 28 days. It notices the effect of split tensile values with the proportions of recycled

Table 2 The effect the percentage recycled plastic on the maximum flexure load of prism concrete beams

Prism beams	Load (kN)	Decrease ratio %
P0BA	21.84	-
P5BA	21.77	0%
P10BA	20.13	-8%
P15BA	19.24	-12%
P0BA30	19.24	-
P5BA30	19.06	-1%
P10BA30	18.5	-4%
P15BA30	17.39	-10%
P0BA45	21.67	-
P5BA45	21.45	-1%
P10BA45	19.44	-10%
P15BA45	18.29	-16%
P0BA60	17.83	-
P5BA60	17.77	0%
P10BA60	16.19	-9%
P15BA60	16.01	-10%

*P =prism, 15 =15% recycle plastic, BA60= beams with interfaces angle 60°

plastic as the tensile strength decreases with increase plastic ratio. Adding 5% of plastic to concrete gave the same value, very close to concrete without plastic. It also gave a decrease in split tensile strength of up to 6.04%, 11.38% and 20.21% when replacing plastic with sand by 5%, 10% and 15%, respectively as compared to control concrete mix. Therefore, care must be taken regarding the amount of replacement and adding fiber to improve the tensile strength.

The results regarding split tensile strength reveal a significant reduction that coincides with an increase in the ratio of recycled plastic incorporated into the concrete formulation reaching a 20.21% decline at a 15% substitution rate compared to the reference concrete specimen. This reduction can be clarified by the recognition that the tensile strength of concrete is dependent on the extent of bonding achieved between the aggregates and the cement paste this bonding is adversely affected by the introduction of chemically inert plastic fragments distinguished by a smooth texture which are unable to promote sufficient interlocking with the cementitious matrix. Furthermore, these particles cause the formation of micropores and voids, reducing the concrete's ability to resist transverse expansion under tensile stresses. These findings are consistent with research conducted by Saikia and de Brito (2014) which demonstrated that using PET plastic as a partial substitute for aggregates leads to a reduction in split tensile strength due to inadequate bonding within the concrete matrix. Additionally, the study conducted by Rahmani *et al.* (2013) clarified that the incorporation of plastic particulates results in variability in stress distribution which consequently leads to the initiation of crack propagation under tensile loading conditions. Therefore, it is prudent to avoid surpassing a plastic content threshold of 5-10% in concrete compositions unless such formulations are augmented with fibers or polymers that improve internal adhesion especially in structural components subjected to tensile or bending stresses.

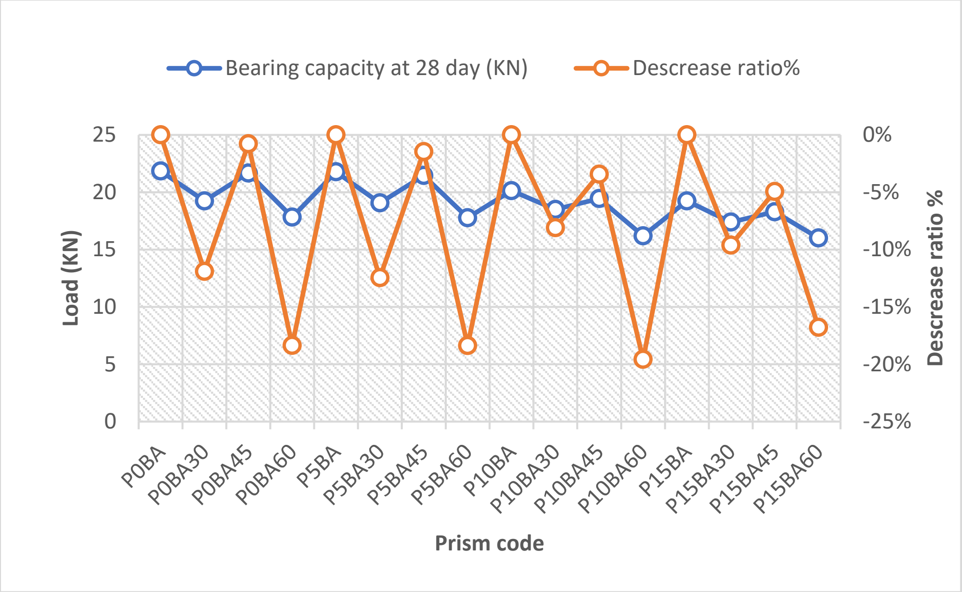

Fig. 7 Effect the ratio of recycled plastic on bearing capacity of bond between old and new concrete

4.5 Flexural behavior of recycle concrete prism beams

The effect of the percentage of recycled plastic on the bond strength between old and new concrete was investigated. So, the behavior of prism beams with interfaces angle 45° under mid-span bending load was studied the maximin flexure load was 21.67 kN, 21.45 kN, 19.44 kN and 18.29 kN at 28 days for the 0%, 5%, 10% and 15% plastic ratios, respectively. So, it was found that the effect recycled plastic causes a decrease of 1%, 10% and 16%, respectively. Meanwhile, the maximin flexure load of prisms concrete beams with interfaces angle 30° with 0%, 5%, 10% and 15% recycled plastic ratios were 19.24 kN, 19.06 kN, 18.5 kN and 17.39 kN at 28 days, that it decreased of 1%, 4% and 10%, respectively. Table 2 also showed the effect of the percentage of recycled plastic on the prism beams were completely cast without bond. The 15% recycled plastic in concrete prism has the lowest strength 19.24 at 28 days with decrease 16%. As result, the ratio of plastic affected clearly on the bearing strength of the prism beam.

Test results showed that the flexural behavior of concrete beams was negatively affected by increasing the percentage of recycled plastic. A gradual decrease in the beam's ability to withstand flexural loads was observed at 30°, 45° and 60° angles (see Fig. 7). This reduction can be attributed to the insufficient bonding among the constituents of the concrete matrix particularly at the juncture between the pre-existing and the subsequently introduced concrete. The incorporation of plastic particulates further diminishes the capacity for stress transfer throughout the concrete cross-section resulting in enhanced susceptibility to cracking and a reduction in the ultimate load-bearing capacity.

These results are consistent with Frigione (2010) study which demonstrated a decrease in concrete flexural strength due to the use of plastic materials, attributed to the weak bond between the plastic and the cement paste. Furthermore, a study by Almohana *et al*. (2022) demonstrated improved sustainability by using recycled plastic, but high replacement ratios reduced flexural strength.

Table 3 The effect of bond angle on the maximum flexure load of prism concrete beams

Prism beams	Load (kN)	Decrease ratio %	Type of failure
P0BA	21.84	-	Flexure
P0BA30	19.24	-12%	Flexure
P0BA45	21.67	-1%	Flexure
P0BA60	17.83	-18%	Flexure
P5BA	21.77	-	Flexure
P5BA30	19.06	-12%	Flexure
P5BA45	21.45	-1%	Flexure
P5BA60	17.77	-18%	Flexure
P10BA	20.13	-	Flexure
P10BA30	18.5	-8%	Flexure
P10BA45	19.44	-3%	Flexure
P10BA60	16.19	-20%	Flexure- Interfacial
P15BA	19.24	0%	Flexure
P15BA30	17.39	-10%	Flexure- Interfacial
P15BA45	18.29	-5%	Flexure- Interfacial
P15BA60	16.01	-17%	Flexure- Interfacial

The results also revealed that the 45° angle exhibited the best performance. This phenomenon can be ascribed to an improved stress distribution at this particular angle along with a diminished probability of catastrophic failure resulting from direct shear which is recognized as the most perilous mode as corroborated by various research studies.

Therefore, these results point to the importance of adjusting the percentage of plastic added to avoid negatively impacting structural performance along with improving bonding surfaces and the possibility of using chemical bonds or fibers to enhance shear and flexural performance in composite concrete.

Table 3 illustrates the effect of bond angle on the maximum values of concrete beams that flexure strength of plastic concrete beams with interfaces angles 30°, 45° and 60° that the interfaces of the old and new plastic concrete treated by grooves holes to obtain good bond. As example, the flexure capacity of the prism beams P0BA, P0BA30, P0BA45 and P0BA60 were 21.84 kN, 19.24 kN, 21.67 kN and 17.83 kN at 28 days. Accordingly, the flexure capacity at failure were achieved for beams P5BA, P5BA30, P5BA45 and P5BA60 were 21.77 kN, 19.06 kN, 21.45 kN and 17.77 kN at 28 days. The interfaces angles 60° has the lowest strength that it decreased about 18%. Although the same treatment was followed between the old and new surfaces but the type of failure was shear cracking in the interface area at an angle of 60° which is the most dangerous and causes a decrease in the bearing capacity of the beams P0B60, P5B60, P10B60 and P15B60. By result, optimum strength was obtained for the bond angle of 45° the type of failure was in flexure zone while a decrease of strength was recorded at the interface bond angle of 60° the type of failure was in shear. Resulting in the type of failure was flexural cracking which it is considered safer. According to the results, the mean 19.11, median 19.15 and mode 19.24 are close to each other indicating that the data has a normal distribution without significant deviation. However, the standard deviation 1.89 shows moderate dispersion in the data, with individual values deviating

Fig. 8 Flexure strength of hybrid concrete

from the mean by an average of 1.89 units. This means that the results are not tightly concentrated around the mean but rather spread within a reasonable range around it. This indicates that the distribution is relatively homogeneous but not without some variation reflected by the standard deviation. Consequently, the results have a reasonable degree of reliability.

Fig. 8 showed that the bond angle had a significant impact on the flexural strength of the beams. It is worth noting the similarity in behaviour for beams with approximately the same interface bond angle within increase the ratio of plastic replaced sand in concrete prisms. Figs. 9 to 12 present the crack pattern and types of failure in the prism beams that the presence of plastic in mixes concrete have been caused the concrete to weaken and reduced the bonding of the components. So, the prism beams with interfaces angle 60º were failed at interfacial zone but the prism beams with interfaces angle 30º and 45º failed at flexural zone. Visual inspection of the tested prism beams revealed distinct crack patterns depending on the interface angle. Beams with interface angles of 30° and 45° mainly exhibited flexural cracks away from the joint region while specimens with a 60° interface angle showed cracking concentrated along the interface zone indicating interfacial shear failure.

Also, in this research, different types of surface roughening were studied to obtain acceptable bonding between old concrete and new concrete through the following steps:

1- The old concrete surface was cleaned of dust and weak suspended parts that affect the bonding strength.

2. The old surface was prepared in different ways where only the first surface was cleaned without roughened the second sample was roughened by sandblast the third sample was drilled 1 cm deep horizontally and the fourth sample was roughened by drilling 1 cm deep obliquely as shown in the Fig. 13.

3. Styrene-Butadiene Rubber (SBR) was used as an additive to improve the bonding in concrete by about 5% of the cement weight and increase its resistance to failure.

Improving the interface bonding factors led to a good improvement in the resistance of new concrete to old concrete. From the results of the Table 4, it notes that the interface roughness

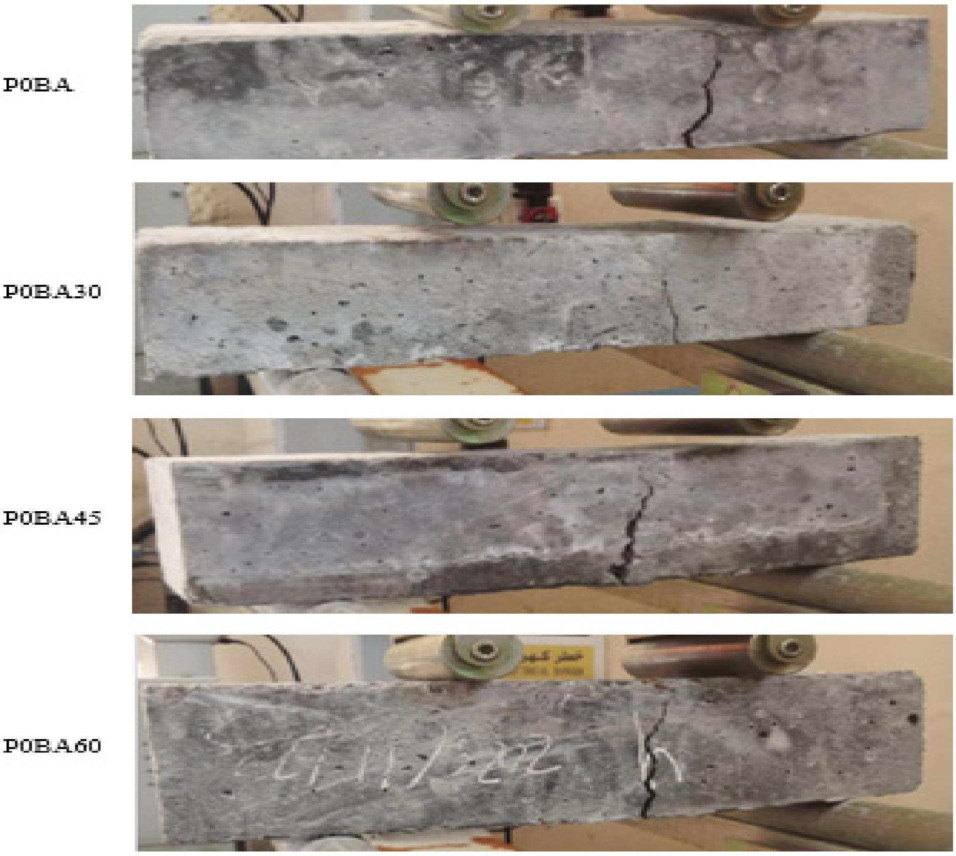

Fig. 9 The crack pattern in the prism beam with 0% recycled plastic

Table 4 The effect different types of surface roughening on the maximum flexure load

Prism beams	Describe of beam	Load (kN)	Increase ratio %
P10BA45	without prepare surface	18.73	-
P10BA45	with sandblast surface	23.28	25%
P10BA45	with drilled 1 cm deep horizontally	21.86	17%
P10BA45	with drilling 1 cm deep obliquely	21.70	16%
P10BA30	without prepare surface	17.11	-
P10BA30	with sandblast surface	21.64	26%
P10BA30	with drilled 1 cm deep horizontally	20.42	19%
P10BA30	with drilling 1 cm deep obliquely	20.76	21%
P10BA60	without prepare surface	16.33	-
P10BA60	with sandblast surface	20.25	24%
P10BA60	with drilled 1 cm deep horizontally	19.22	18%
P10BA60	with drilling 1 cm deep obliquely	18.89	16%

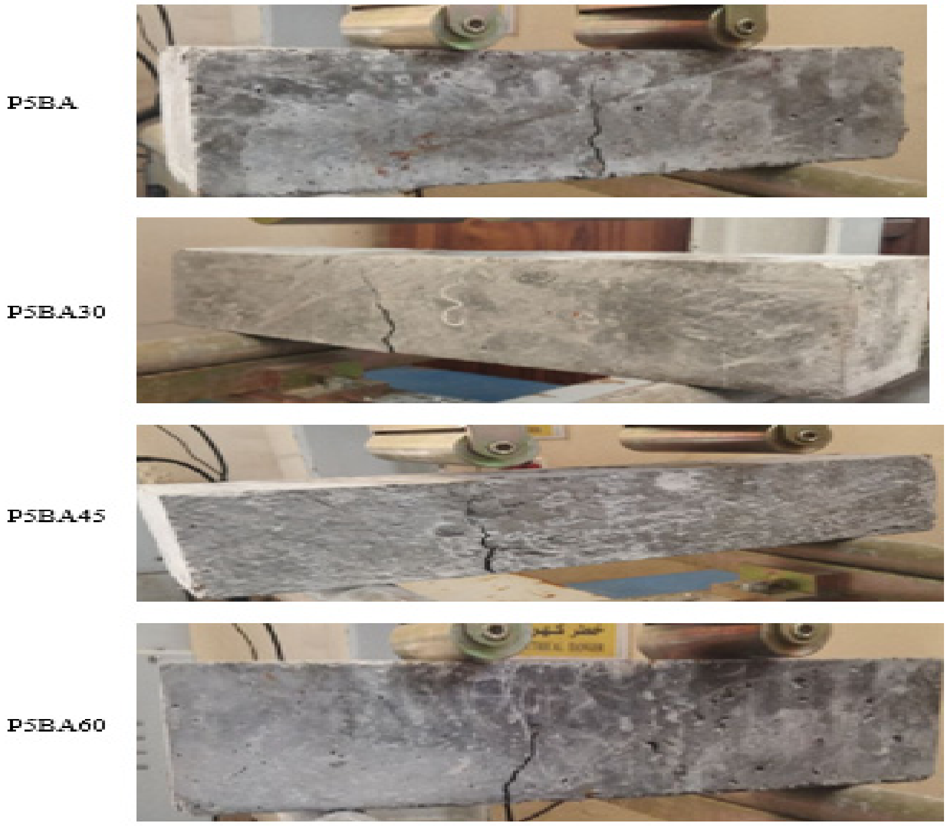

Fig. 10 The crack pattern in the prism beam with 5% recycled plastic

improved the resistance by an increase of 26% as a result of the correct transfer of loads between old and new concrete as all types of bonding contributed to the development of the bonding performance of new concrete to old.

The results indicated that the treatment of concrete surfaces has a substantial impact on their load-bearing capacity with specimens subjected to sand treatment exhibiting the peak load-bearing value of 23.28 kN which represents an increase of 25-26% in comparison to untreated specimens. Furthermore, specimens displaying both horizontal and inclined perforations exhibited a notable improvement in performance metrics within the range of 16-21% thereby clarifying the positive relationship between surface roughness and the effectiveness of structural components. From a statistical perspective, the data show a reliable distribution, with the mean load capacity recorded at 20.02 kN with a standard deviation of 2.04 kN. Under all experimental conditions, the highest load-bearing values were observed for the specimens positioned at a 45° angle compared to those positioned at 30° and 60° angles. These results demonstrate that increasing the contact area between concrete surfaces through mechanical treatments such as sanding improves load transfer efficiency compared to other methods The study also indicated that horizontal perforation patterns are 2%–3% more efficient than inclined perforation patterns. Consequently, these results provide essential insights for improving the design of concrete joints and elements, particularly in contexts requiring high shear resistance.

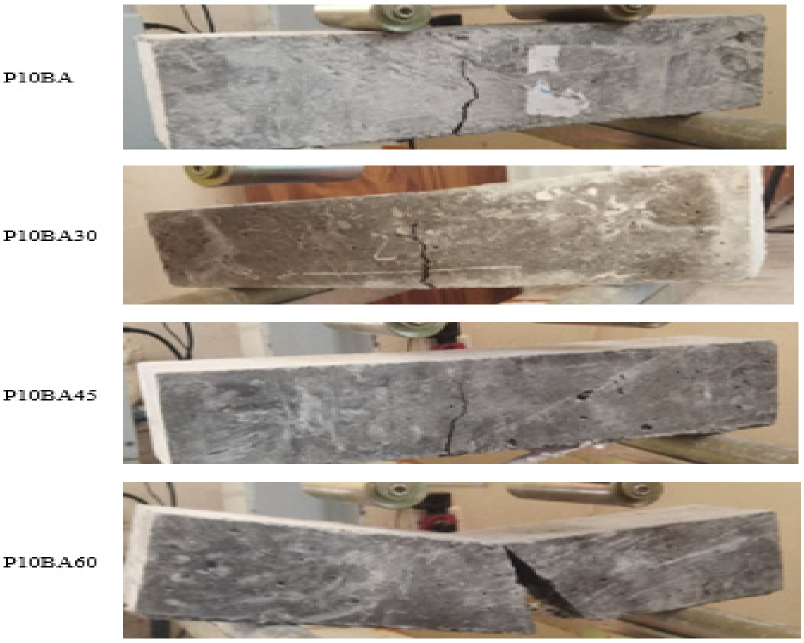

Fig. 11 The crack pattern in the prism beam with 10% recycled plastic

Fig. 12 The crack pattern in the prism beam with 15% recycled plastic

Fig. 13 Prepare surface plastic concrete prism beam

4. Conclusions

Optimizing the performance interfacial bonding angle of recycled concrete beams under flexural load was investigated in this paper. The effect 5%, 10% and 15% recycled plastic ratio causes a decrease flexural load of prism beam capacity about 0-1%, 4-10%and 10-16%, respectively. The effect interfaces angles 30°, 45° and 60° between old and new plastic prism beam decrease flexural capacity about 8-10%, 1-5% and 17-20%, respectively. Type failure of the plastic prism beams with interfaces angle 60° were at interfacial area but the prism beams with interfaces angle 30° and 45° failed at flexural zone. Optimum flexural strength was obtained for the bond angle of 45° the type of failure was in flexure zone while a decrease of strength was recorded at the interface bond angle of 60°. Therefore, high slope should be avoided. The study identified a nonlinear relationship between the percentage of recycled plastic and the load-bearing capacity of beams. The results showed that exceeding 10% leads to a severe performance degradation of up to 16% setting a critical threshold for safe construction applications. The results demonstrated that improving surface roughness with sandblast or drilling partially compensates for the poor cohesion of recycled concrete achieving a 26% improvement in strength opening new avenues for enhancing the efficiency of sustainable materials. This study provides the first quantitative analysis linking joint angle and failure mode in recycled concrete filling a gap in the previous literature that has often focused on mechanical properties without a detailed analysis of engineering design factors. The methodology used, which combines surface optimization of recycled concrete with joint angle variation, stands out as an effective model for improving its performance compared to other studies that addressed each factor separately.

Overall, this study identifies optimal design parameters for recycled concrete beams 45° angle, improved surface roughness as a result, the structural performance of composite concrete is improved by enhancing the bond angle between recycled concrete beams under flexural loads with a clear warning about the risks of sudden failure at sharp angles 60°. However, the practical application of these results requires additional studies to evaluate durability under various operational conditions, which is a key direction for our future research.

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