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Structural Behavior of Reinforced Shotcrete Slabs Incorporating Plastic Fibers

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Keywords:
Compressive strength; Flexural one-way slab; Plastic fiber; Polypropylene fiber; Shotcrete.

Highlights:

- *Structural performance of Reinforced shotcrete one-way slab containing plastic fiber through finding crack maps, and load-deflection behavior.*
- *Improvement of an experimental program to produce shotcrete concrete by developing a shotcrete machine.*
- *The researcher faced two challenges, first: how to control shooting concrete with plastic without segregation and second- how to choose suitable mixing that includes plastic fiber.*

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Abstract: Shotcrete technology is developed to be used in places difficult to reach by traditional methods. The technique was developed to apply to strengthening work, slope stabilization, tunnel lining, and constructed structural members. These applications necessitate the use of a shotcrete mixture to enhance the strength and crack resistance. As a result, incorporating fiber is necessary to eliminate these issues. The American Concrete Institute's (ACI) code guided the design of eleven one-way slab specimens. Three types of fiber were studied: Waste plastic fiber (PET), macro-synthetic polypropylene fiber (PP), and hybrid fiber (PET+PP), with three percentages for each type: 0.35%, 0.7%, and 1% by volume of the mixture. The test results indicated that the shotcrete reinforced with polypropylene fiber had better mechanical properties than the plain shotcrete. On the other hand, shotcrete containing 1% waste plastic fiber showed better flexural performance of the one-way slab through an increase in the ultimate load, energy absorption, stiffness, and ductility by about 12.66%, 135.978%, 5.7%, and 47.2%, respectively, due to the mechanical work of the fiber bridging the concrete matrix, which could improve resistance for formation and development cracks.

السلوك الهيكلي لألواح الخرسانة المسلحة المعززة بالألياف البلاستيكية

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الخلاصة

طُوّرت تقنية الخرسانة المرشوشة لاستخدامها في الأماكن التي يصعب الوصول إليها بالطرق التقليدية. طُوّرت هذه التقنية لتطبيقها في أعمال التقوية، وتثبيت المنحدرات، وتبطين الأنفاق، والعناصر الإنشائية المُنشأة. تتطلب هذه التطبيقات استخدام خليط من الخرسانة المرشوشة لتعزيز المتانة ومقاومة التشققات. ونتيجةً لذلك، يُعدّ دمج الألياف ضروريًا للتخلص من هذه المشكلات. وقد استرشد تصميم إحدى عشرة عينة بلاطة أحادية الاتجاه بكود المعهد الأمريكي للخرسانة (ACI). دُرست ثلاثة أنواع من الألياف: ألياف البلاستيك المُهدرة (PET)، وألياف البولي بروبيلين الاصطناعية الكبيرة (PP)، والألياف الهجينة (PET+PP)، بثلاث نسب مئوية لكل نوع: ٠,٣٥٪، و٠,٧٪، و١٪ حجمًا من الخليط. أشارت نتائج الاختبار إلى أن الخرسانة المرشوشة المُدعّمة بألياف البولي بروبيلين تتمتّع بخصائص ميكانيكية أفضل من الخرسانة المرشوشة العادية. من ناحية أخرى، أظهرت الخرسانة الرشاشة المحتوية على ١٪ من ألياف البلاستيك المهدرة أداءً أفضل في الانحناء للبلاطة أحادية الاتجاه من خلال زيادة الحمل الأقصى، وامتصاص الطاقة، والصلابة، والسحب بنحو ١٢,٦٦٪، و١٣٥,٩٧٨٪، و٥,٧٪، و٤٧,٢٪ على التوالي، وذلك بسبب العمل الميكانيكي للألياف التي تربط مصفوفة الخرسانة، مما قد يحسن مقاومة الشقوق التكوينية والتطورية.

الكلمات الدالة: قوة الضغط؛ بلاطة أحادية الاتجاه قابلة للانحناء؛ ألياف بلاستيكية؛ ألياف البولي بروبيلين؛ الخرسانة الرشاشة.

1.INTRODUCTION

According to the American Concrete Institute (ACI) committee in 1995, shotcrete can be defined as pneumatically sprayed concrete with high velocity, which makes it a good choice in places and surfaces that are difficult to utilize the traditional concrete placement method, such as structural repairing and rehabilitation works, tunnel lining, and rock, and slope stabilization [1]. Six potential shotcrete failure modes were identified by Barrett and McCreath. Fig. 1 provides a visual representation of these modes, including adhesion loss, flexural failure, direct shear failure, punch shear failure, compressive failure, and tensile failure. The most typical type of shotcrete failure is flexural failure, for example, which is often related to the bulking of the rock mass and can follow a variety of failure mechanisms for rock mass [2-4]. In 1920, Fuller tested the first slab cast by shotcrete (Gunite) at Lehigh University. The slab's span (2.4 m) and thickness (82.6 mm) were tested for 14 years. During that time, the slab deflected by 50 mm, and the stress in the reinforced steel bar reached 160 kN. No further deflection was measured after the third year [5]. Besides that, Kompen [6] performed bending experiments on one-way slabs of steel fiber-reinforced shotcrete and plain shotcrete. Steel fiber was used with the type of end-hook 'Dramix-1' ZC 30/50. Tests on cubes showed that the shotcrete had an unconfined compressive strength of 50 MPa. Peak strength increased by approximately 85 percent and 185 percent, respectively, for these slabs with 1.0 and 1.5 volume fractions of fibers. For the same volume fraction of fibers of 1.0 and 1.5, the ductility of the fiber-reinforced slabs was enhanced by around 20 and 30 times, respectively. Shotcrete more often uses steel or synthetic fibres due to their enhanced impact resistance, fracture toughness, shear, and flexural capacity with typical addition rates (0.3–1) percent volume [7]. Synthetic fibers cover common types of fiber, such as PP, polyester, polyethylene, and nylon. PP is considered the most commercially used polyolefin fiber [8-10]. Malmgren [11] investigated the effect of PP and steel fiber on shotcrete. The result showed that the energy absorption was almost the same for shotcrete reinforced with these two types of fiber.

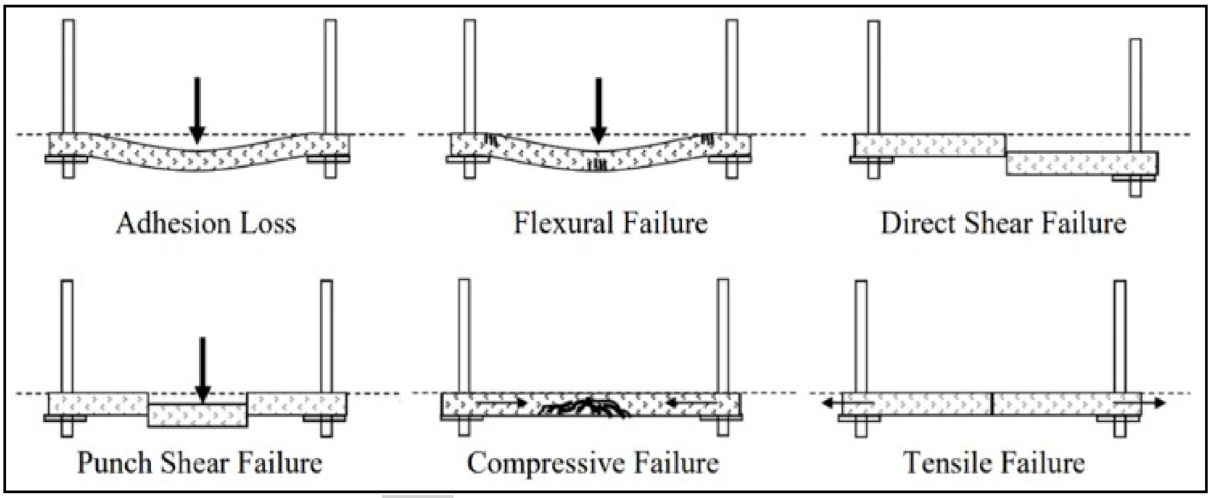

Fig. 1 Failure Modes of Shotcrete [2].

According to Ali Shah's research [12], shotcrete's compressive strength could be increased by over 20% by adding 3 kg/m³ of polypropylene fiber. The tensile and flexural strengths would also continue to improve as the amount of fiber increased. The research concluded that shotcrete was better than ordinary concrete in terms of mechanical properties. Waste polyethylene terephthalate (PET) fiber is made from recycled PET bottles; such beverage bottles are classified as an environmentally preferable fiber, and it has been established that they significantly decrease the shrinkage of concrete and improve its ductility. Furthermore, engineers have recently been encouraged to utilize these waste materials in engineering construction, like shotcrete support, due to the environmental benefits of consuming these disposal materials [13, 14]. Jawheer [15] investigated the use of waste plastic as coarse aggregate and fiber in shotcrete. The compressive and flexural test results confirmed that adding 0.5% of plastic fiber improved shotcrete concrete's strength performance by approximately 5.11% after 7 days. Hussein [16] conducted an experimental investigation on the compressive and flexural strength of concrete containing waste plastic fiber (PET), PP fiber, and their incorporation together covered forty mixes. From the results, the compressive strength of the concrete containing PP fiber was superior to that reinforced with waste plastic fiber (PET) up to 1.5% volumetric dosage of the polypropylene fiber, which reached 6.6% as the maximum value. Conversely, the study revealed that PET fibers significantly enhanced the flexural behavior of concrete. The percentage of hybrid fiber (25% PET and 75 % PP) was the best to enhance the flexural strength of concrete. Al-Hadithi et al. investigated how waste plastic fiber, in varying percentages between 0.5% and 2%, affected the structural behavior of beams made of reinforced concrete. The findings demonstrated that adding fiber raised both the maximum load and the ductility index up to 1% before they declined. In addition, the mode of failure changed to become more ductile. The present research aims to contribute to the effective use of waste plastic bottles as fibers in shotcrete to reduce environmental pollution and natural resource consumption by investigating the effect of the addition of polypropylene (PP) fiber, waste plastic fiber (PET) fiber, and hybrid (PET + PP) with different volume fractions on the flexural performance of a one-way reinforced shotcrete slab. The novelty of this research compared to the previous studies is in using different dimensions and types of fibers, as well as employing the shooting process using a local machine for casting shotcrete.

2.EXPERIMENTAL PROGRAM

2.1.Materials

In this study, shotcrete mixes were prepared using ordinary Portland cement (OPC) that has been certified under Iraqi specifications (IQS No. 5/2019) [17]. The chemical and physical properties of the cement used are shown in Tables 1 and 2, respectively. The maximum sizes of the aggregate (fine and coarse) utilized were 4.75 mm and 10 mm, respectively, and they both agreed with Iraqi specifications (IQS) No. 45/84 [18]. The sieve analysis of fine and coarse aggregate is seen in Fig. 2 and Fig. 3. Waste plastic drink bottles were chopped using a shredding machine to make PET fiber with an aspect ratio of 22.24. PET fiber had a rectangular form and dimensions of 27 × 4 × 0.3 mm (length × width × depth). The density of the PET fiber was 1370 kg/m³, and its tensile strength was 105 MPa. While a polypropylene (PP) fiber's length was 60 mm. These fibers were chopped with scissors to a length of 30 mm. The density of PP fiber was 910 kg/m², and its tensile strength was 465 MPa. These two types are shown in Fig. 4. The present research has been conducted using Master Glenium® 51 superplasticizer as a high-range water-reducing material with physical properties, as shown in Table 3. Sika® Rapid-1 was used in this investigation. For the reinforcement of reinforced shotcrete (RS) slabs, steel bars with a diameter of 8 mm were used. ASTM A615 [19] was followed in the testing of the steel bar. The test results of the tensile test are shown in Table 4. The bottom of the slab was reinforced longitudinally with 3Ø8mm bars and transversely with 4Ø8mm bars, according to ACI-318-sec. 7.6.1.

Table 1 Chemical Compositions of Cement Used.

Chemical Composition	Content Percent by Weight	The Boundary of Iraqi Specification No.5/2019
Alumina (AL_2O_3)	4.86	....
Silica (SiO_2)	20.15	....
Lime (Cao)	62.86	....
Iron Oxide (Fe_2O_3)	5.2	....
Sulfate (SO_3)	2.32	Not more than 2.8 %
Loss of ignition (L.O.I)	1.8	Not more than 4%
Magnesia (MgO)	3.07	Not more than 5%
Insoluble residue (I.R)	0.46	Not more than 1.5 %
Lime saturation factor (L.S.F)	0.98	0.66-1
Main Compounds		
C4AF	14.62	
C3A	4.11	
C3S	49.5	
C2S	19.40	

Table 2 Physical Properties of Cement Used.

Physical properties	Result	Boundary Iraqi specification No.5/2019
Fineness (Blain method) (m^2/kg)	3344	≥ 250 m^2/kg
Autoclave %	0.1	≤ 0.8%
Soundness (mm)	1	≤ 10 mm
Final setting time (minutes)	220	≤ 10 hr
Initial setting time (minutes)	165	≥ 45 min
The mortar's compressive strength		
28 days (MPa)	48	≥ 42.5 MPa
2 days (MPa)	22	≥ 10 MPa

Table 3 Physical Properties of MasterGlenium® 51 Superplasticizer.

Properties	Value
Color	Light Brown
Form	Viscous Liquid
Relative density	1.1 @ 20 °C
Viscosity	128 +/ - 30 cps @ 20 °C
pH	6.6

Table 4 Steel Bar Properties.

Diameter	Actual size (mm)	Yield Stress (MPa)	Ultimate stress (MPa)	Elongation (%)
8 mm	7.8	491	688	18

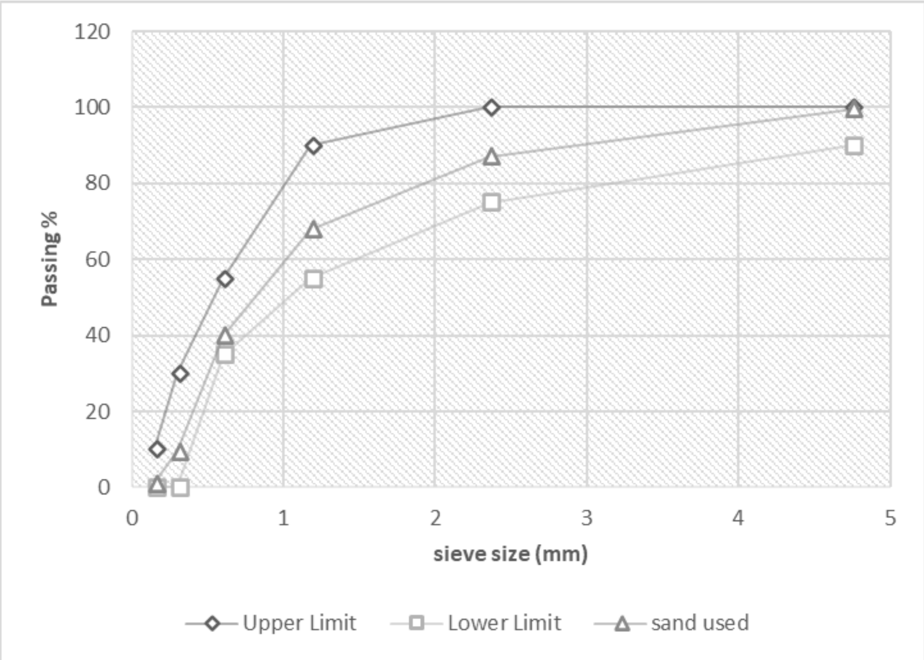

Fig. 2 Sieve Analysis of Fine Aggregate.

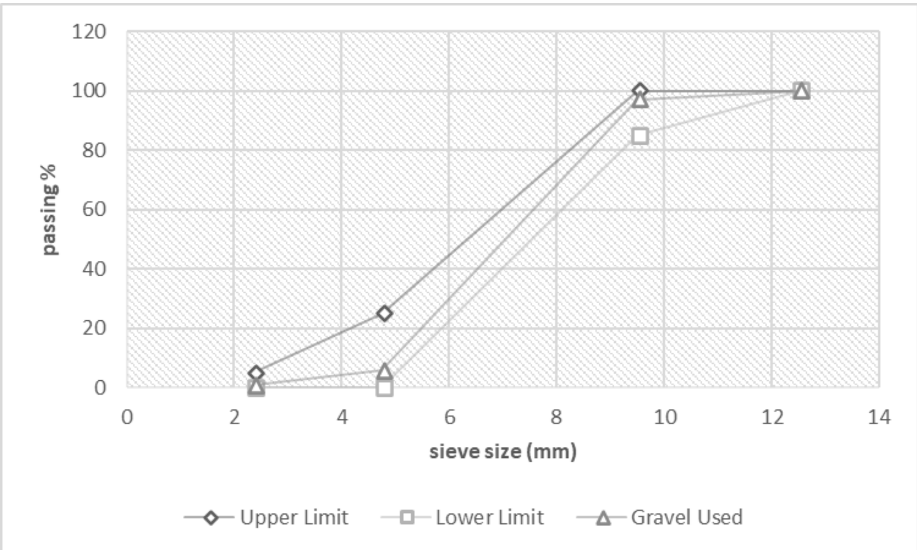

Fig. 3 Sieve Analysis of Coarse Aggregate.

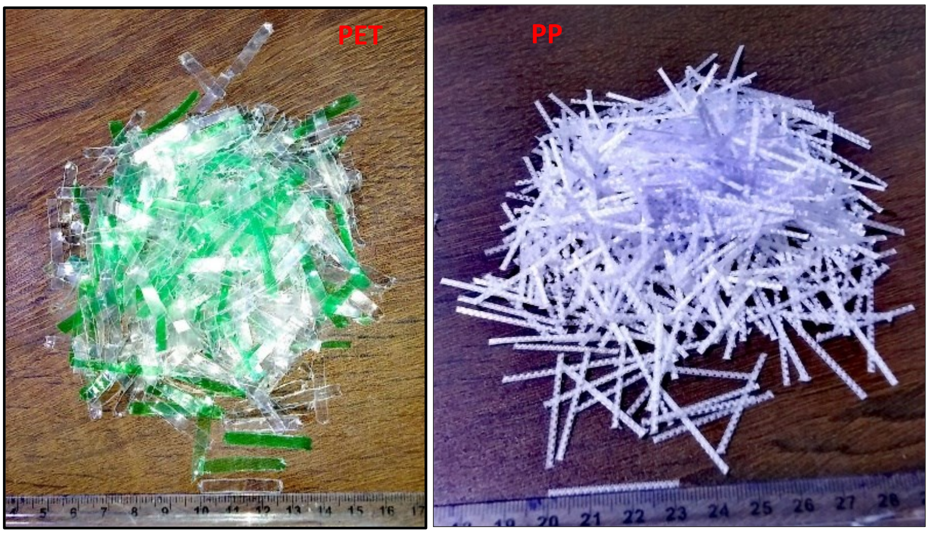

Fig. 4 PET and PP Fibers Used for Shotcrete.

2.2.Mixing Proportions

The ACI PRC-506-16 standards and previous research [20, 21] guided the design of the shotcrete concrete mix. The control mix's compressive strength was designed to be 40 MPa. Table 5 presents the quantities of mixtures used to cast shotcrete specimens for three different mix types based on the types of fibers. Following ASTM C1611/C1611M-18, a slump flow test of freshly laid concrete was conducted [22]. The slump flow test was 700 mm for the control mix (0% fiber) with a water/cement ratio of 0.368. For this investigation, eleven slab specimens were prepared and sorted into four groups: Group-1 comprises a reference mixture that includes plain shotcrete (FRS), Group-2 comprises three mixtures of shotcrete reinforced with waste plastic (PET) fiber (WFRS-0.35, WFRS-0.7, WFRS-1), Group-3 comprises three mixtures of shotcrete reinforced with macro-synthetic (polypropylene) fiber (PFRS-0.35, PFRS-0.7, PFRS-1), and Group-4 comprises three mixtures of shotcrete reinforced with hybrid fiber (HFRS-0.35, HFRS-0.7, HFRS-1).

Table 5 Proportions of Material Used in Shotcrete Mixes.

Group Num.	Symbol	Component K_g/m^3							
		Cement	Sand	Gravel	Water	Superplasticizers (L/ m³)	Accelerator(L/ m³)	PET fiber	Synthetic fiber
Group-1	FRS-0	498	881	738.5	182	3.12	21.9	0	0
Group-2	WFRS-1	498	881	738.5	182	3.12	21.9	1.37	0
	WFRS-0.7	498	881	738.5	182	3.12	21.9	0.96	0
	WFRS-0.35	498	881	738.5	182	3.12	21.9	0.48	0
Group-3	PFRS-1	498	881	738.5	182	3.12	21.9	0	0.91
	PFRS-0.7	498	881	738.5	182	3.12	21.9	0	0.64
	PFRS-0.35	498	881	738.5	182	3.12	21.9	0	0.32
Group-4	HFRS-1	498	881	738.5	182	3.12	21.9	0.69	0.46
	HFRS-0.7	498	881	738.5	182	3.12	21.9	0.48	0.32
	HFRS-0.35	498	881	738.5	182	3.12	21.9	0.69	0.16

2.3.Experimental Sets

To compute the compressive strength of shotcrete concrete, ASTM C1604/C1604M [23] recommended a procedure to prepare specimens (for each mix), including three-cylinder cores (75 mm diameter × 150 mm height) extracted from shotcrete panels (500× 500× 150) mm. Three prisms with dimensions of 100× 100× 350 mm were used for the determination of flexural strength. Ten one-way slab specimens with dimensions of 350 mm in width, 100 mm in depth, and 800 mm in length for each mix were cast to check the flexural performance of the slab. Fig. 5 shows the geometry and reinforced details of the RS slabs. All samples, i.e., cores, prisms, and slabs, were cured in the water bath for 28 days. Fig. 6 shows the casting. Fig. 7 shows the cutting processes of all samples used.

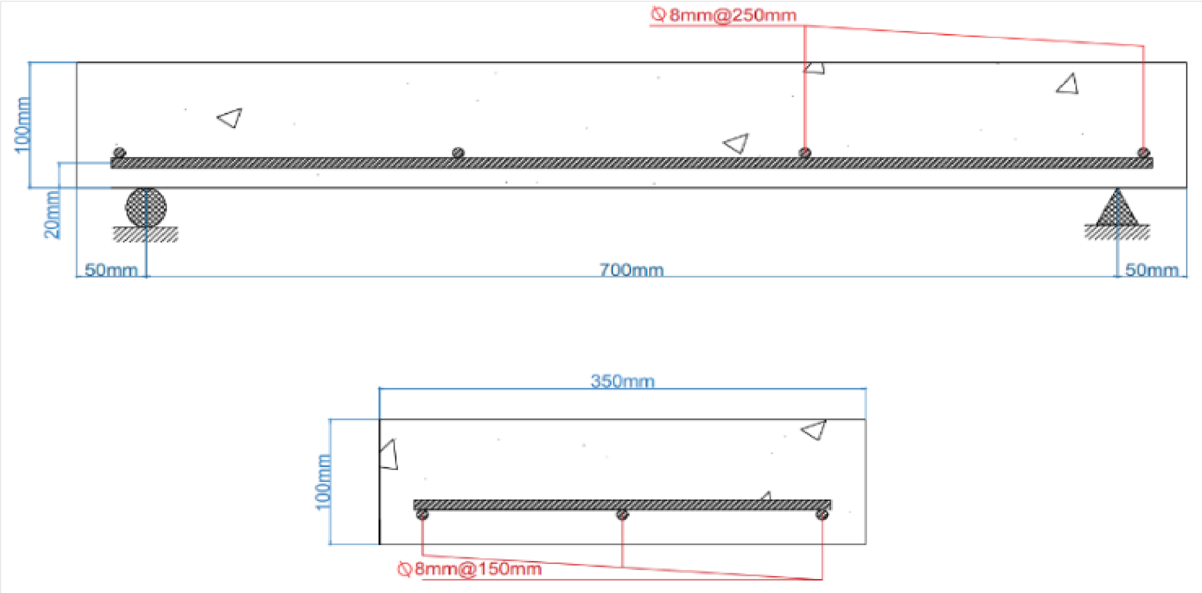

Fig. 5 Geometry and Reinforced Details for the RS Slabs.

Fig. 6 Casting with Wet-Shotcrete Process: A-Casing Concrete Panel for Compression Test, (B) Casting of Concrete Prisms for Flexural Test, and (C) Casting One-Way Slab Specimens.

Fig. 7 Extracting and Cutting Process.

2.3.Compressive and Flexural Prism Tests

Three 75 × 150 mm cores were prepared, and the average of these core results was recorded. The age of testing was 28 days. The compressive strength test was conducted in accordance with ASTM C1604 [23] using a hydraulic machine with a maximum load capacity of 2000 kN, as illustrated in Fig. 8. Flexural strength of shotcrete tested with prisms at 28 days, according to ASTM C78-02 [24] and ASTM C1609 [25].

Fig. 8 (A) Compressive Testing of Specimens, (B) Core Samples.

2.4.Flexural Test of One-Way Slab Specimens

The flexural performance of the RS slabs was examined using a hydraulic machine with a 500 kN static loading capacity. The span of the specimen between supports was 700 mm, and the roller supports were made of steel to sustain loads without deforming, to distribute the affecting load at two central points (P/2) on the specimen loading system. A data logger and a computer were used to electronically record the experimental data. The deflection of a one-way slab was measured using three Linear Variable Differential Transformer (LVDT) indicators installed on the bottom surface of the slab utilizing special holders, as shown in Fig. 9.

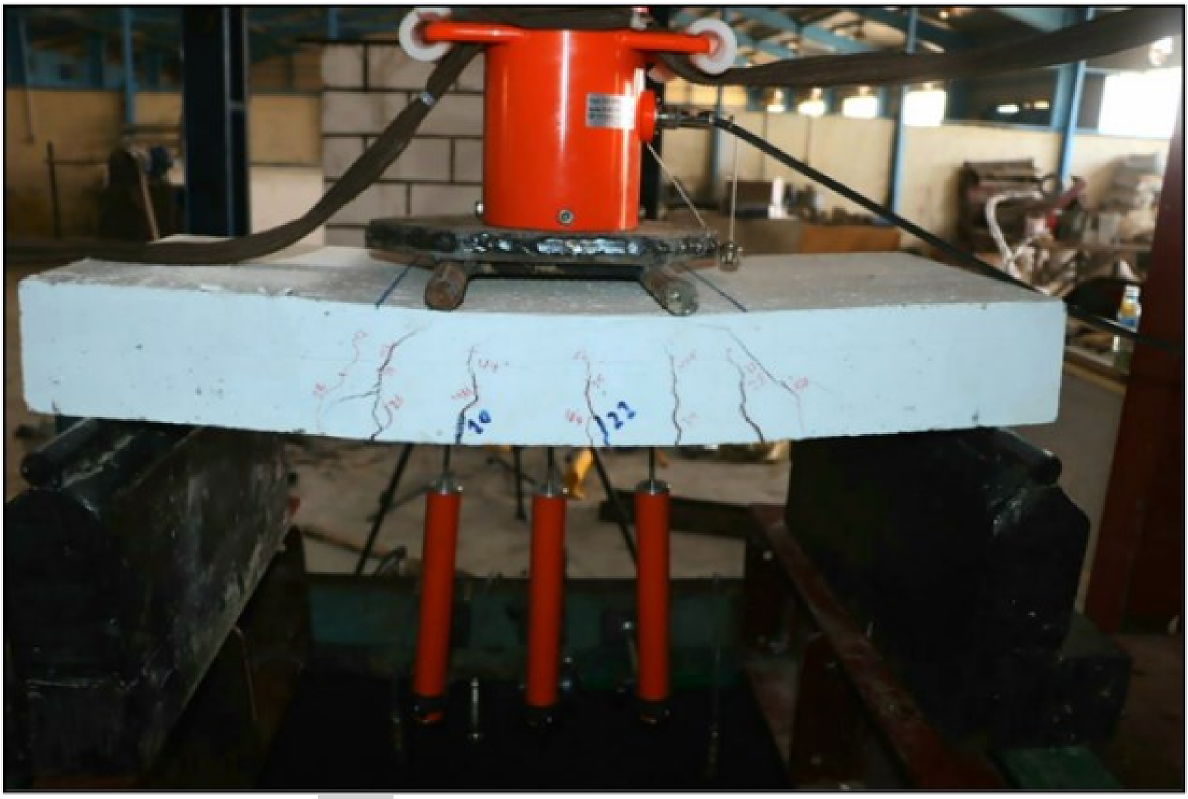

Fig. 9 Setup Test with Three LVDT Indicators.

3.RESULTS and DISCUSSIONS

3.1.Mechanical Properties

Table 6 describes the compressive and flexural strength results, with an average of three specimens aged 28 days. The waste plastic fiber tends to decrease in compressive strength compared to the reference shotcrete mix. This result matches the finding of Mohammed [26]. Microcracks, formed when the matrix became more porous, could be the reason why the compressive strength seemed to decrease as the WF content increased [27]. On the other hand, mixtures including polypropylene fibers showed increases in compressive strength of around 8.2%, 2.8%, and 3.9% for fiber percentages of 0.35, 0.7, and 1.0%, respectively.

Table 6 Mechanical Properties Results.

Group	Mix symbol	Compressive strength (MPa) value	Compressive strength (MPa) (%) increase	Flexural strength (MPa) value	Flexural strength (MPa) (%) increase
Group-1	FRS-0	34.64	-	3.86	-
Group-2	WFRS-1	27.32	-20.91	3.79	-1.81
	WFRS-0.7	30.28	-12.34	4.17	8.12
	WFRS-0.35	29.38	-14.91	4.75	23.12
Group-3	PFRS-0.35	37.38	8.21	4.6	19.21
	PFRS-0.7	35.49	2.81	5.14	33.21
	PFRS-1	35.9	3.91	6.25	62.1
Group-4	HFRS-0.35	29.15	-15.7	5.14	33.21
	HFRS-0.7	32.21	-6.76	5.1	29.91
	HFRS-1	34.04	-1.51	4.42	14.56

Except 1% waste plastic fiber, which experienced a 1.8% loss in flexural strength due to the waste plastic's flaky structure, causing voids and porosity to develop, the flexural strength generally increased with the addition of fibers. The shotcrete enhanced with 1% polypropylene fiber showed the most improvement in flexural strength, measured at 62%. Therefore, in terms of hybrid fiber, combining polypropylene and waste plastic fiber may provide greater outcomes than utilizing waste plastic fiber alone.

3.2.Flexural Behavior of One-Way Slab

The failure mode of all tested slabs was flexural failure, as shown in Figure 10 and Table 7. Also, Table 7 describes the load, deflection (δ) in the middle third of the slab span, and failure. Shotcrete slabs containing 1% waste plastic were the worst. The deflection value was slightly high due to the small depth of the slab specimens, which gave a low value for the moment of inertia.

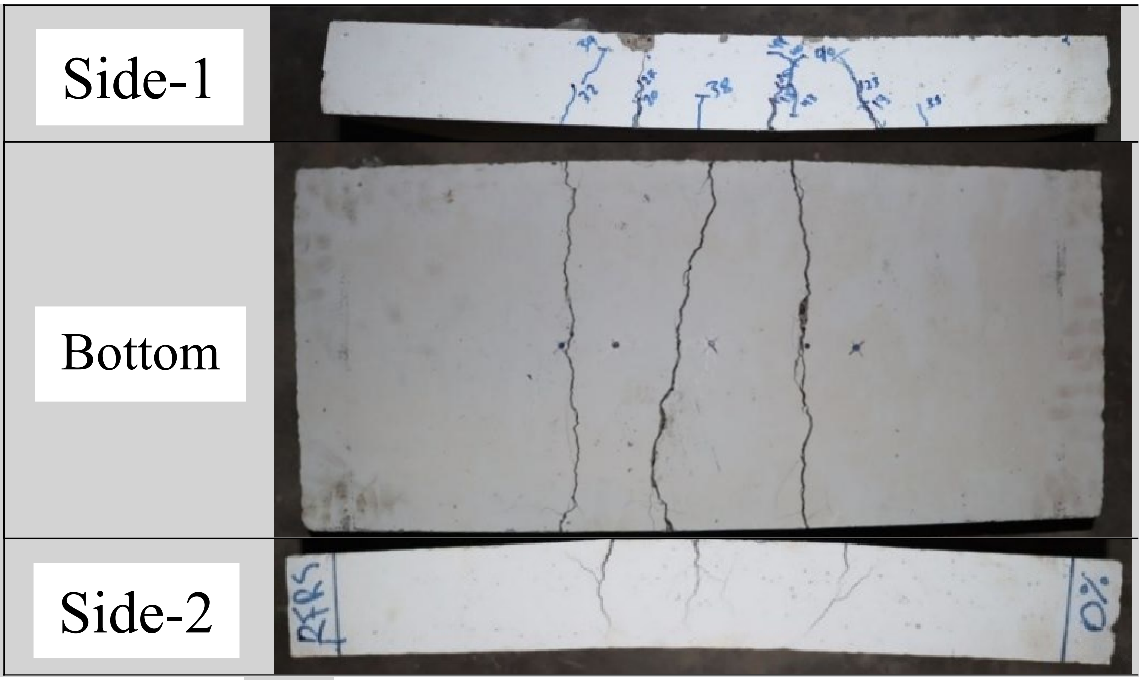

Fig. 10 Flexural Behavior of One-Way Slab Specimens.

Table 7 Results of Slab Tested.

Group	Mix symbol	First crack load stage P_{cr} (kN)	First crack load stage δ_{cr} (mm)	% increase of P_{cr}	Ultimate load stage P_u (kN)	Ultimate load stage δ_u (mm)	% increase of P_u	Crack width mm	
Group-1	FRS-0	18	0.62		45.95	9.21		1.7	-
	WFRS-0.35	20	0.896	11.11	47.7	10.1	3.67	1.85	8.82
Group-2	WFRS-0.7	18	1.06	0	40.1	3.27	-14.59	1	-41.12
	WFRS-1	27	1.33	50	52.61	13.99	12.66	1	-41.12
	PFRS-0.35	19	0.929	5.55	45.3	11.2	-1.43	0.95	-44.12
Group-3	PFRS-0.7	17	0.619	-5.55	50.7	9.4	9.37	1.45	-14.71
	PFRS-1	17	0.61	-5.55	52.61	11.93	12.66	1.4	-17.65
	HFRS-0.35	9	0.97	-50	44.8	6.3	-2.57	1.3	-23.53
Group-4	HFRS-0.7	11	0.48	-38.88	41.8	9.1	-9.93	0.9	-47.06
	HFRS-1	14	1.3	-22.22	34.9	11.7	-31.66	1	-41.18

3.2.1. Load-Deflection Relationship

Generally, when subjecting a gradually increasing load to the slab specimen, the deflection increased linearly in an elastic way with the applied load. The slab's deflection developed more quickly as the cracks began to appear. After the growth of cracks in the slab, the curve of load deflection maintained a linear path until reinforcement yielded. After that point, the slab's deflection kept developing without a noticeable increase in load, as shown in Fig. 11. There was no compatibility in some results of load deflection with the fiber content, which may be due to the random distribution of fiber through the shooting and casting processes that led to these outcomes. For WFRS-0.35 and WFRS-1, the reinforced shotcrete slab showed a significant increase in first crack load of about 11.11% and 50%, respectively. The use of waste plastic fiber increased the shotcrete's modulus of rupture, delaying the appearance of the first crack. Group-2 and Group-3 showed the highest value in the slab's ultimate loading capacity when they used 1% fiber. Compared to the reference shotcrete slab, both waste plastic and polypropylene fiber increased the ultimate load by approximately 12.66%. Shotcrete slabs with 1% waste plastic fiber also showed maximum deflection at the first crack load and at the ultimate load measured by the LVDT in the middle of the slab span. The deflection at the first crack and ultimate load was 1.33 and 13.99 mm, compared to 0.62mm and 9.21 mm, respectively, for the reference shotcrete slab, due to the high percentage of fiber content that allowed a high level of deflection. All slabs that contained fiber showed a decrease in the crack width compared to the reference shotcrete slab, except the slab that included 0.35% waste plastic, which appeared to increase the crack width by about 8.82%. Sunaga [28] illustrated that the increase in fiber volume led to a minimized crack opening due to the increasing bridging force of the fiber at cracks.

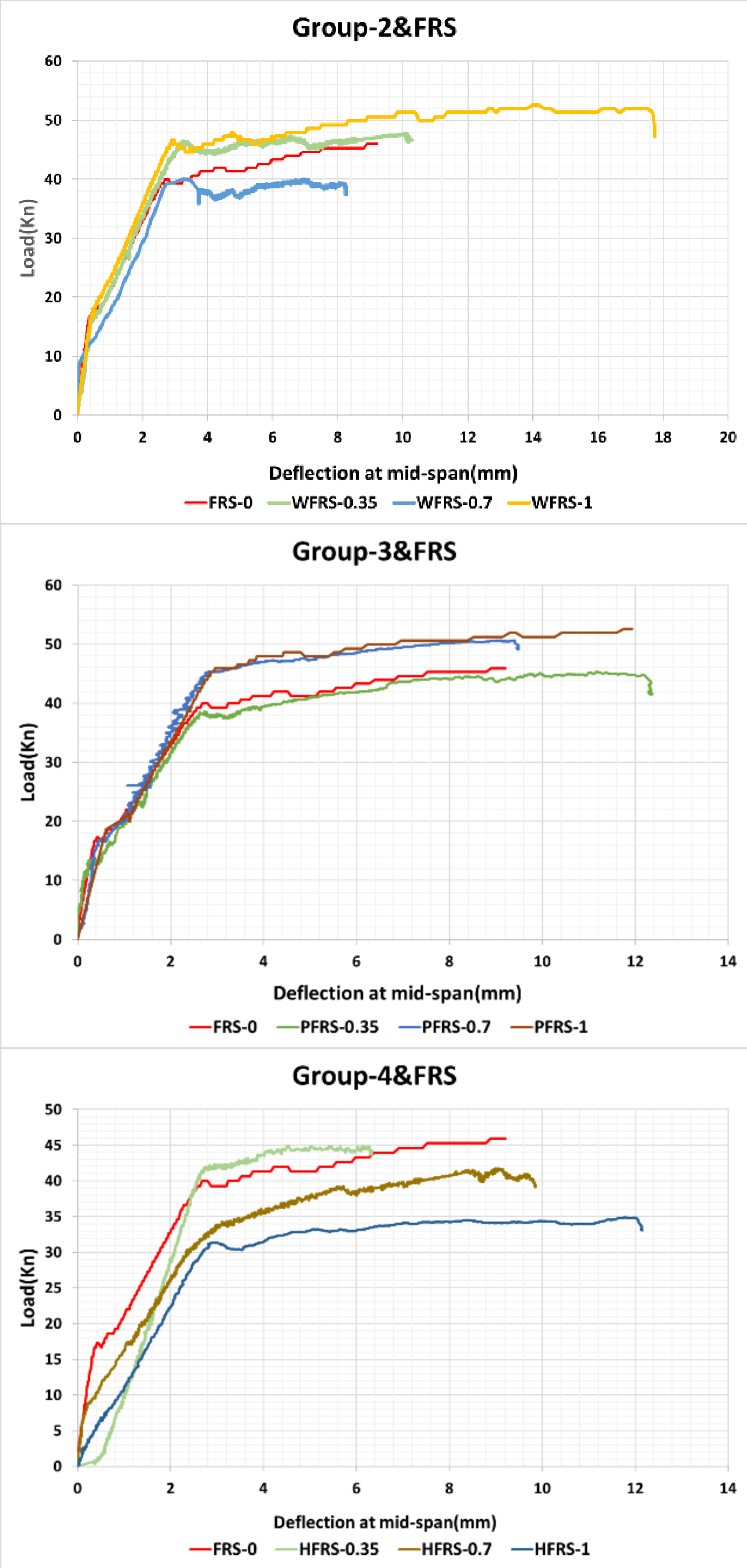

Fig. 11 Load-Deflection Curves of Tested Slabs.

3.2.2.Energy Absorption

This research defines energy absorption as the energy that the slab specimen absorbs during loading and prior to failure. Fig. 12 illustrates that the slab containing 1% waste plastic fiber exhibited the highest increase in energy absorption, by about 135.978% compared to the reference shotcrete slab. In contrast, the slab containing 0.35% hybrid fiber showed the lowest energy absorption value by about 40.71%. Khaloo [29] investigated the effect of adding fiber on a slab's structural behavior. The results showed that the fiber could improve the slabs' energy absorption capacity.

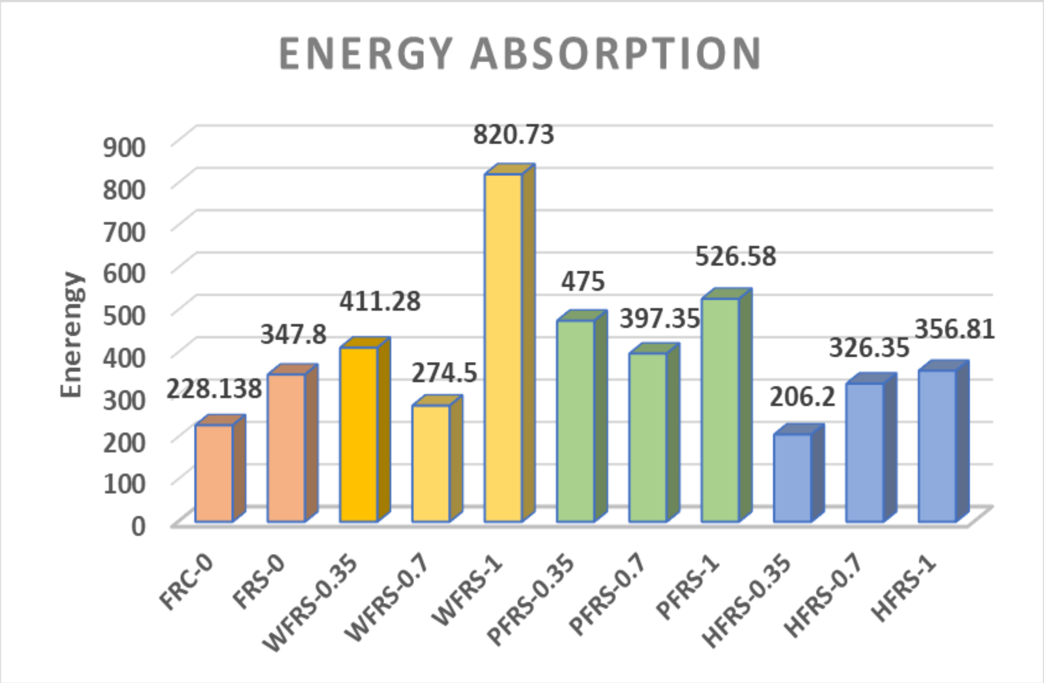

Fig. 12 Energy Absorption (J) for All Slabs.

3.2.3.Stiffness

The ability of a material to withstand deformation and regain its original shape after the removal of a load is known as stiffness. The stiffness of a one-way reinforced concrete slab was obtained by dividing the load that equals 45% of the ultimate load by the deflection that corresponds to this load, as shown in Fig. 13 [30, 31]. This percentage of 45% is due to the linear relationship between stress strain and up to 45% of the ultimate load for all concrete strengths. Fig. 13 illustrates the stiffness results.

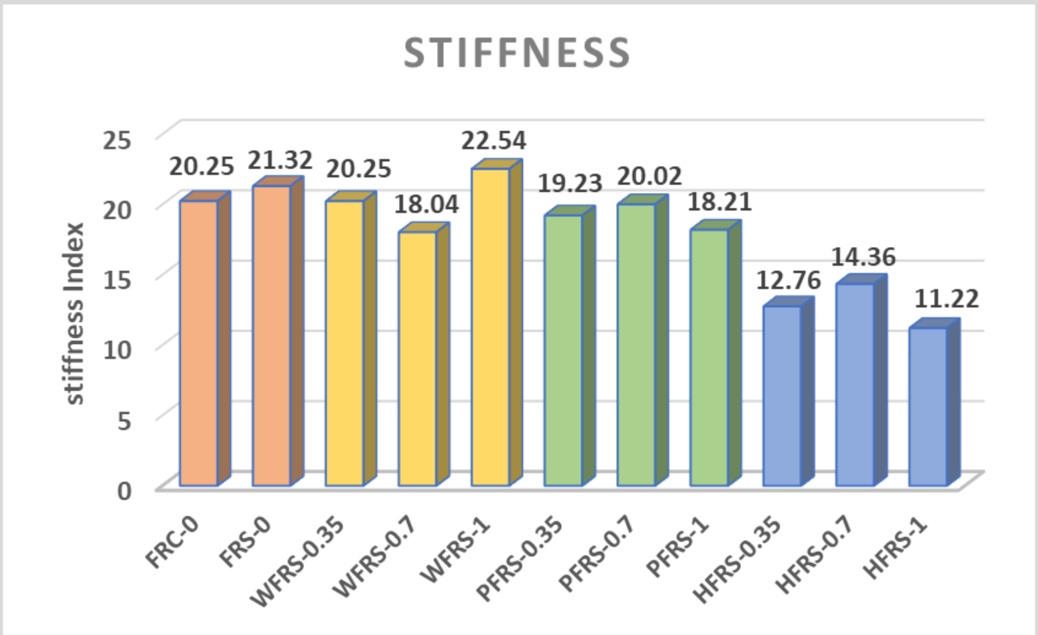

Fig. 13 Stiffness Index (kN/mm) for One-Way Slab Specimens.

In the presence of fiber in shotcrete, the stiffness of the slabs tested decreased, except for the 1% waste plastic fiber, which led to a slight increase in stiffness of about 5.7% due to the high content of fiber that worked to bond the mix and increase stiffness. The highest decrease in stiffness was recorded at 1% hybrid fiber, which reached about 47.4% compared to the reference shotcrete slab. The incorporation of fiber in the shotcrete mix led to a decrease in stiffness as a result of the formation of air pores and gaps, resulting in reduced slab stiffness under load. The same interpretation was included in the study of Jomaa'h [31]. Amer [32] investigated the impact of varying amounts of discarded plastic fiber on the stiffness of shotcrete beams, and the outcome demonstrated that the fiber had an adverse influence on the stiffness.

3.2.4.Ductility Index

The ability of RC elements to stay in elastic deformation, with the capability to disperse the applied stress and provide sufficient indication before reaching the failure stage, is known as ductility. A yield point is a point on a curve where there is significant confusion. This behavior is due to the possibility of several specified yield points on the load-deflection curve. The ductility index results are illustrated in Fig. 14.

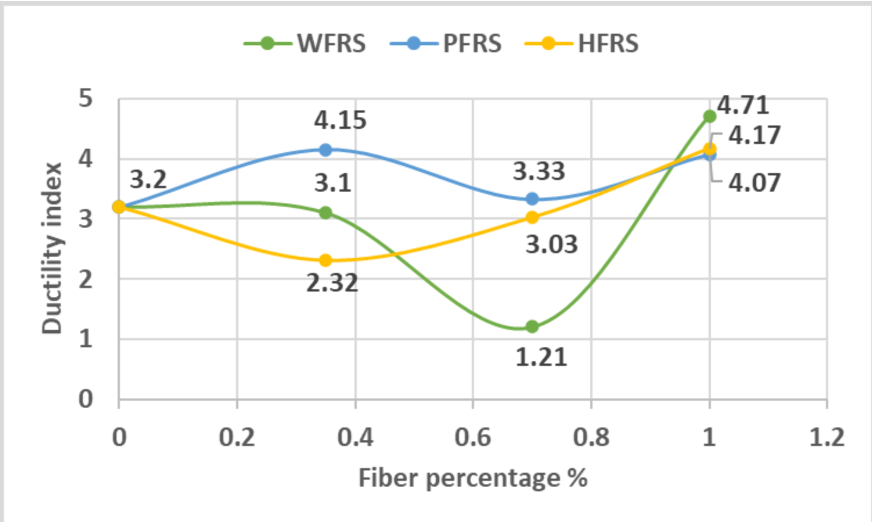

Fig. 14 Ductility Index Result for Tested Shotcrete Slabs.

The results show that using the shotcrete process to cast slabs can enhance the ductility of the slab compared to slabs cast by the conventional method. Polypropylene fiber showed a positive impact on the ductility index of shotcrete slabs, increasing by about 29.7%, 4.1%, and 27.2% for 0.35%, 0.7%, and 1% fiber, respectively. The waste plastic fiber and hybrid fiber showed an increase in ductility index with 1% fiber only, by about 47.2% and 30.3%, respectively. Fraternali [33] indicated through experiments that the addition of 1% waste plastic fiber can improve ductility better than the addition of the same percent of polypropylene fiber. This development may be related to the fiber's ability to bridge cracks driven by increased stress and to offer ductility after cracks have formed. In addition to the previously described effects, the fibers help to enhance the ultimate load and deflection of slabs, resulting in a greater area under the load-deflection curve (energy absorption).

4.CONCLUSION

This study investigated the effect of plastic fiber (PET waste plastic and macro synthetic polypropylene) on the flexural behavior of a one-way reinforced shotcrete slab. From the results, the following conclusions can be drawn:

- The compressive strength of shotcrete containing polypropylene fiber was enhanced by 8.2%, 2.8%, and 3.9% for percentages of 0.35%, 0.7%, and 1% fiber, respectively. Whereas the presence of waste plastic and hybrid fiber in the shotcrete mix negatively influenced the compressive strength.
- The flexural strength of prism specimens increased with the addition of fiber, except for the WFRS-1, which showed a slight decrease in flexural strength compared to the reference shotcrete by about 1.8%.
- WFRS-1 showed the best enhancement in the flexural performance of a one-way slab. The WFRS-1 slab showed an increase in the ultimate load, energy absorption, stiffness, and ductility by about 12.66%, 135.978%, 5.7%, and 47.2%, respectively.
- The crack width of the slab decreased by incorporating all the types and percentages of fiber used, except for 0.35% waste plastic, which increased the crack width by 8.82%.

- In terms of stiffness, all slabs showed a decrease in stiffness except the aforementioned WFRS-1 slab, and the highest decreasing ratio was 47.4% for the HFRS-1 slab.
- Polypropylene fibers showed a positive impact on the ductility index of shotcrete slabs, increasing by 29.7%, 4.1%, and 27.2% for 0.35%, 0.7%, and 1% fiber, respectively.
- The results clearly showed that propylene fiber enhanced the mechanical properties of shotcrete, while the addition of 1% of waste plastic improved the flexural performance of the shotcrete slab. Therefore, to fully comprehend the behavior of fiber in shotcrete concrete, it should employ a higher percentage and a broader range of fiber content. Additionally, it should employ a variety of shotcrete test methods to comprehensively evaluate the properties of the material.

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NOMENCLATURE

FRS-0	fiber of reinforced shotcrete with 0 percent fiber.
WFRS-0.35	waste plastic fiber of reinforced shotcrete with 0.35 % fiber.
WFRS-0.7	waste plastic fiber of reinforced shotcrete with 0.70 % fiber.
WFRS-1	waste plastic fiber of reinforced shotcrete with 1.00 % fiber.
PFRS-0.35	polypropylene plastic fiber of reinforced shotcrete with 0.35 % fiber.
PFRS-0.70	polypropylene plastic fiber of reinforced shotcrete with 0.70 % fiber.
PFRS-1	polypropylene plastic fiber of reinforced shotcrete with 1.00 % fiber.
HFRS-0.35	Hybrid plastic fiber of reinforced shotcrete with 0.35 % fiber.
HFRS-0.70	Hybrid plastic fiber of reinforced shotcrete with 0.70 % fiber.
HFRS-1	Hybrid plastic fiber of reinforced shotcrete with 1.00 % fiber.
Greek symbols	
δ	deflection (mm)

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