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Flexural Behaviour of Reinforced Shotcrete beams Comprehending Waste Plastic Fiber

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Abstract

Wet-mix shotcrete is often used as a placement method in tunnelling and ground support. However, to date, only a limited number of studies have been identified the roles of waste plastic fiber (WPF) on wet-mix shotcrete mixtures. This experimental study show the flexural performance of reinforced shotcrete concrete members (beams) having waste plastic fiber, which may be considered as a new study. In order to achieve that, a manufacturing of wet-mix shotcrete machine has been developed to product special wet-mix shotcrete that will be used to cast reinforced shotcrete concrete members containing waste plastic fiber. Extensive attempts were done in this project to generate a special wet-mix shotcrete combinations using locally sourced waste materials like beverage bottles. The qualities of WPF shotcrete concrete (SC) were investigated in terms of fresh, hardened, mechanical, and bending behaviour, with extensive results analysis. Five SC formulations (0.25, 0.5, 0.75, 1.0, and 1.25) percent WPF content, as well as the control shotcrete (SC0.00), were used in the experiments. In addition, the flexural behaviour of SC beams casted from the same waste materials was investigated. The results revealed that all SC beams had almost similar flexural behaviour when compared to the creation of crack patterns, as well as the ductility index and stiffness. The maximum ductility index was 2.29 for SC0.25, while the minimum stiffness was 1.31 for SC 1.25 beam. The flexural resistance of SC beams show in beams deflection state, the primary crack with presence the waste plastic fibers was small, because of the resistance of plastic fibers to tensile stresses happening at a moment of growth the crack. It also shows that adding WPFs to SC up to (Vf=1%) results in a rise in the loads that cause initial cracks when compared to beams made with reference mix.

Keywords: Sustainability shotcrete concrete, Shotcrete concrete beam, Flexural failure

1. INTRODUCTION

Shotcrete is a concrete placing technique in which the mix is sprayed onto a surface at a high velocity utilizing compressed air. Its use in North America has risen significantly in recent years, and structural elements such as retaining walls, columns, beams, and shells are now built wholly with it, owing to the lack of requirement for formwork (if any).[1],[2],[3],[4]. However, the existence of reinforced shotcrete concrete as a "shadow" concept behind the reinforced concrete has prompted concerns about the reinforcing bars and shotcrete concrete encapsulation quality. To avoid the formation of faults in that composition, good practice suggestions propose using an appropriate spraying technique in amalgamation with a sufficient mixture consistency.[5]

While spraying concrete, nozzle operators (also known as nozzle men) must, among other things, transfer the nozzle in small circles constantly, standpoint at the proper space from the receiving surface, and keep the nozzle at the proper angle relative to the receiving surface. Although this is true for both dry-mix and wet-mix shotcrete processes, the dry-mix method is unique in that the nozzle men regulate the water flow, therefore their experience is crucial. When it comes to the encapsulation of reinforcing bars, it plays the bigger protagonist than in the wet-mix process.[6],[7].

Mixes sprayed "too wet" will likely slough off the surface before the appropriate accumulation thickness is achieved, whereas mixes sprayed "too dry" may absence the flexibility to flow around the bars and voids behind them may be generated. Nonetheless, voids formed by expert nozzle men will be smaller than those created by inexperienced nozzle men for a given consistency above the ideal.[7].

Fiber reinforced concrete (FRC) have been developed as a new approaches to increase concrete's structural capability in the 1960s. Fibers have been shown to improve structural strength, reduce permeability, reduce shrinkage and expansion, and increase overall durability in terms of mechanical performance.[8].

Shotcrete with fiber reinforcement has been used as a perpetual support rather regularly over the past 25 years. To address the challenges of installing wire-mesh, structural fiber is added to fiber reinforced shotcrete (FRS). Practically all tunneling projects throughout the world use FRS. In cementitious composites, and especially shotcrete, fiber can significantly increase durability, impact resistance, impact fatigue resistance, residual strength (after cracking), and fracture resistance.[9][10][11]. For commercial and experimental use, a variety of fiber kinds are available. steel, glass, synthetic, and natural fiber materials are the four basic fiber categories.[12]. Fiber come in a variety of qualities, shapes, and sizes. To provide proper bonding and cover paste between fiber in shotcrete, fiber length should be many times the maximum aggregate size.[13]

Maryam K. and Javad T. Alkali Resistant (AR) glass fiber has been applied to shotcrete concrete in a study to improve concrete continuity, tensile and compressive strengths, and to address changes in the mechanical properties of the fiber created by alkaline concrete. According to test results, the greatest enhancement of modified shotcrete concrete's compression and flexural strengths was 22.9 and 75% of its ideal formulations for 0.7 percent glass fiber with 1% Nano-Al_2O_3 and 1.5 percent Nano-SiO_2, respectively.[14] [15].

The applicability of steel fiber concrete in permanent lining is assessed using a mechanical analysis of the value of steel fiber concrete construction. To compare spray concrete with ordinary spray without steel fiber, laboratory experiments are done to determine the reasonable proportion, tension, compression resistance, and shear of steel fiber in the layer. When tensile strength and datum concretes are compared, the tensile strength and datum concretes are lowered by 11.4 percent and 8.7%, respectively, when the amount of fiber shotcrete concretes is increased from 0 to 1.2kg/m3. The experimental variables were determined to be the breadth, length, and content of terephthalate (PET) fiber from a used plastic bottle. Slump, compressive strength, splitting strength, and other properties of wet-mix shotcrete reinforced with PET fiber. According to the contribution percentage of the analysis of variance, PET fiber length had the greatest impact on slump, build-up thickness, and splitting strength, contributing 57.91 percent, 62.6 percent, and 67.54 percent, respectively. The most effective parameter on pressure drop and compressive strength was PET fiber width, which contributed 80.24 percent and 90.21 percent, respectively. PET fiber width was frequently considered, particularly when considering compressive strength and pressure drop. Particularly when it comes to results for pressure drop and compressive strength, PET fiber width was a frequent factor. [16].

Shotcrete contains steel and polypropylene fiber of various weights and shapes. After testing the samples for 7 and 28 days to get hardened, Shotcrete with intriguing qualities is developed. Shotcrete's tensile and compressive strength improved with the addition of fiber, according to the findings. Shotcrete possesses qualities that are indistinguishable from concrete, and adding polypropylene fiber up to 3kg/m3 increased the compressive strength of Shotcrete by about 20%. As the amount of fiber per m3 increased beyond 3kg/m3, the compressive strength decreased [13]. The main aim of research is to product a good strength shotcrete from local sustainability material that use for casting a structural member.

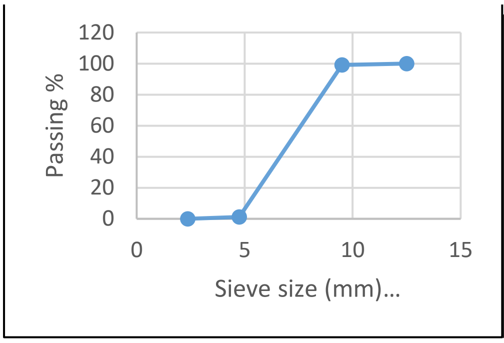
2. Material and mix proportions

A. Cement and aggregate

With a fineness of 3610 cm2/g, a specific gravity of 3.15, and chemical make-up of 61.7% CaO, 2.7% MgO, and 2.5% SO_3, ASTM C150 Type I ordinary Portland cement (Type I) was employed according to ASTM C150. ,and specification (ASTM C128). With a specific gravity of 2.65 was utilized as coarse aggregate, and washed red sand with a specific gravity of 2.64 and a fineness modulus of 3.3% was used as fine aggregate. Fig. 1 depicts the gradation chart for the coarse and fine particles used. In response to the ASTM C33 specified upper and lower gradation limits (for the coarse aggregate, size number 10 grading requirement was used while the maximum size for fine aggregate was 4.75mm).

B. High-strength cement mineral accelator

Superplasticizers (SPs), commonly referred to as high-range water reducers, are additives used in the production of high-strength concrete. Master Glenium® 51 is a new generation water-reducing superplasticizer concrete additive designed for ready-mix concrete that employed according to ASTM C 494m-08. Also it need to use accelerator to accelerate hardening of shotcrete concrete, the SikaRabid ®-1 was used. The specific gravity of accelerator was 1.17.



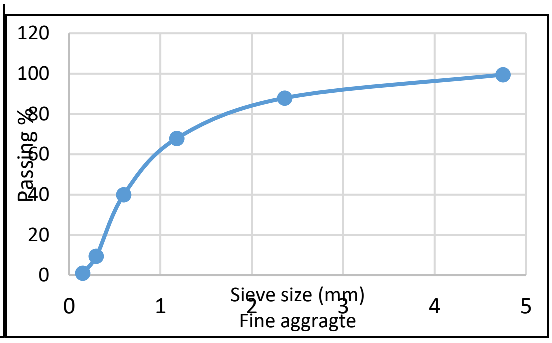


Figure .1. Sieve analysis of coarse aggregate and fine aggregate

C. Waste plastic fiber (WPF)

The fibers were obtained by cutting WPF, gathered directly from disposed drinking bottles in trash sites. The fibers made into pieces with aspect ratio (22) by using shredder see figure 2. The dimensions and physical properties WPF are given in Table 1

Figure .2 Waste plastic fiber

TABLE I. DIMENSIONS AND PHYSICAL PROPERTIES OF WPF

Waste plastic Fiber (PET)	Properties
Length (mm)	27
Width (mm)	4
Thickness (mm)	0.29
Aspect Ratio	22
Tensile Strength (MPa)	91
Density (kg/m3)	1375
Water absorption	0.00

D. Steel reinforcement bars

The longitudinal orientation of the beams was reinforced with 10 mm diameter steel bar at the bottom and top. Stirrups with an 8 mm diameter used for the shear reinforcement requirements. The steel bar tested with ASTM A615 standard.

E. Mix proportions

Machines for spraying wet concrete are known as shotcrete machines. As seen in fig.3, a wet shotcrete machine was created using components from the neighborhood market. This machine uses a hydraulic pressure mechanism and compressed air speed control to project light, wet shotcrete concrete over a range of distances. In this investigation, the proportions of cement, water, coarse aggregate, fine aggregate, and additives were taken into account. As a replacement for shotcrete volume, the content of WPF was 0.25, 0.50, 0.75, 1.0, and 1.25 percent. The wet-mix shotcrete mix proportion is listed in Table 2. According to ACI PRC-506-16, the six shotcrete compositions in Table II were created.[17]. Many trials mixes are using for the references mix in order to obtain the optimum shotcrete mix.

TABLE 2. SHOTCRETE MIXTURES PROPORTION RATIOS

Mix *Code	C. kg/m3	G. kg/m3	S. kg/m3	W. kg/m3	Acc. kg/m3	S.P kg/m3	WPF kg/m3
SC0.00	497.0	738.4	880.0	206.0	22.00	3.10	0
SC0.25	495.8	736.5	877.8	205.5	21.95	3.10	3.44
SC0.50	494.5	734.7	875.6	205.0	21.98	3.09	6.88
SC0.75	493.3	732.9	873.4	204.5	21.84	3.08	10.31
SC1.00	492.0	731.0	871.2	203.9	21.78	3.07	13.75
SC1.25	490.8	729.2	869.0	203.4	21.73	3.07	17.19

*SC0.00: shotcrete concrete mix.0.platic fiber =0, C : Cement, G : Gravel, S : Sand, W : Water, Acc. : Accelerator, S.P : Superplasticizer, and WPF : Waste Plastic Fibers

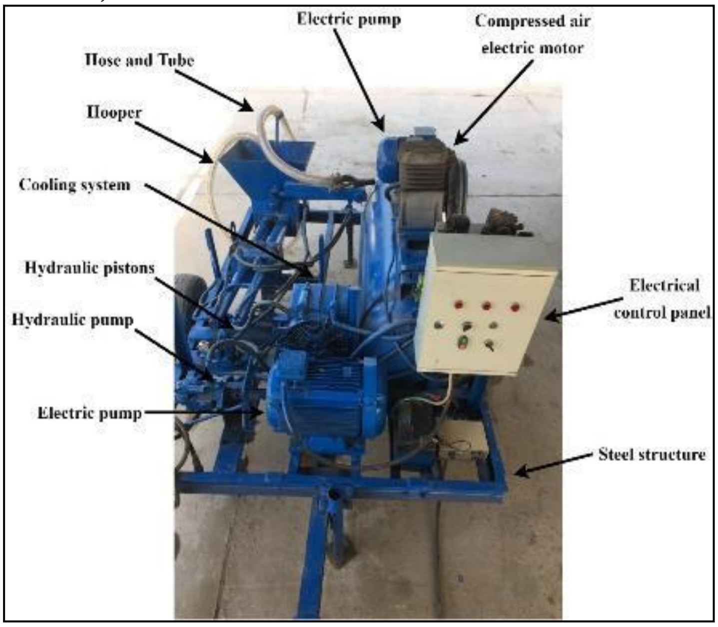


Figure.3 Developing Shotcrete machine details

Shotcrete contents were mixed including water in separated mixer than poured in shotcrete mixer. Shotcrete were propped up at an angle while the nozzle man shot the concrete to reduce rebound and improve encapsulation as shown in fig. 4.

Figure .4 Shotcrete concrete casting process

3. Experimental test

A. Rheological test

The main tests applied to check the rheological properties were the slump flow test (ASTM C1611/C1611M-18). In the other hand to determine the shotcrete concrete resistance, segregation index (SI) test was conducted with each mix according to EFNARC [18]..

B. Flexural beams

Six flexural beams with suitable shear reinforcement were cast by shotcrete concrete and investigation. All beams were designed as under-reinforced tensile as shown in fig.5.

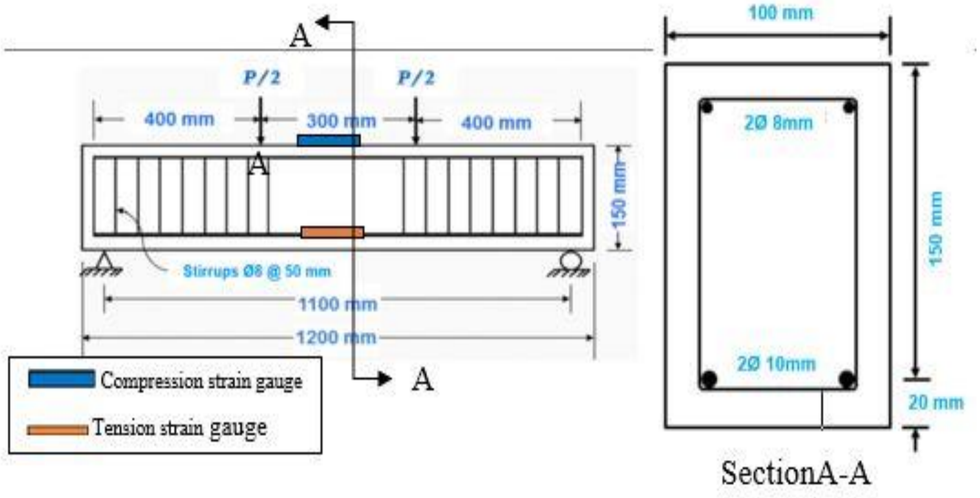


Figure .5 Detailed dimensions of tested beam instrumentation

C. Experimental Setup and Instrumentation

The specimens were simply evaluated as supported beams under four-point loading. Digital gauges used to measure the deflections at the mid span and loading point. Figure.6 depicts the experimental setup and placement of the digital gauges for measuring strain in shotcrete concrete. Two strain gauges were fixed at the critical positions.

Figure .6 Experimental setup for flexural beams

4. Results and discussion

A. Rheological properties

The T500 results confirmed the end of the downturn. In reality, a variety of factors, including the kinds and amounts of superplasticizer and the pressures of the air that cooperates with the concrete shooter, affect the workability of freshly shotcrete concrete. After much trial and error, the slump is 880 mm considered to examine the shotcrete mixture. However, as seen in fig. 7, the slump flow for 0.75% WFP replacement (SC0.075) demonstrates an increase in slump. Table 3 shows that the SR% values index ranged from 8 to 13, which is less than the usual value (15%). Result was closed to other researcher [19].

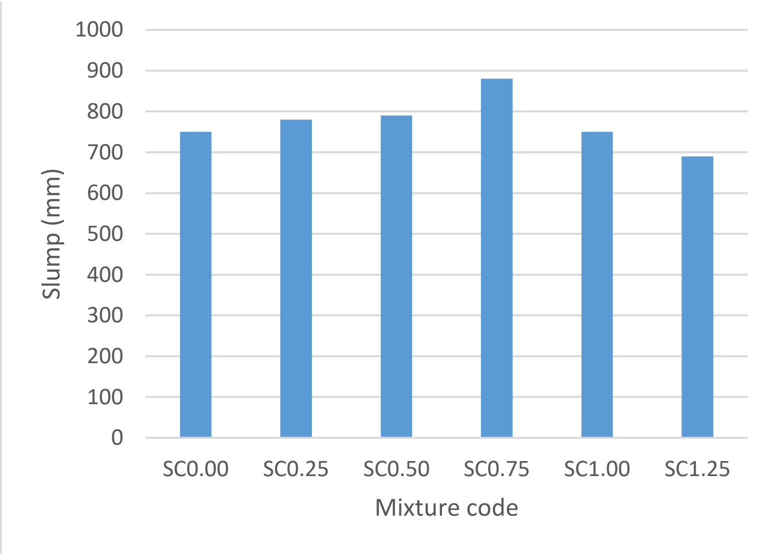


Figure .7 Slump flow tests results for all mixtures

TABLE 3. SEGREGATION RESISTANCE (SR%) TEST RESULTS FOR ALL MIXTURES

Mix Codes	Segregation Resistance (SR%)
SC0.00	**15.1**
SC0.25	**13.4**
SC0.50	**11.2**
SC0.75	**9.6**
SC1.00	**9.1**
SC1.25	**8.3**

B. Structural Behavior of Shotcrete Beams

- Load deflection relationship:

The beams with different WFP had tested monotonically under four-point load prior uncracking stage. The loads – deflection curves at mid span for all beams were notified in Figures 8. The experimental setup test results are summed up in table 4.

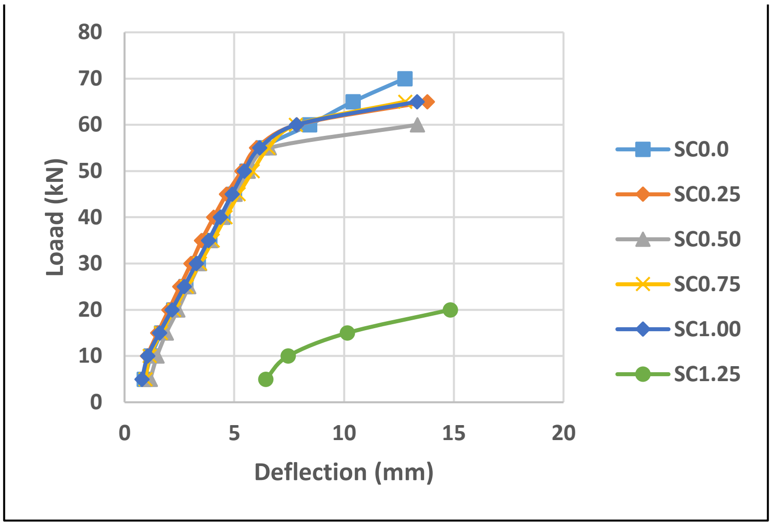


Figure .8 Deflection vs. load graph for all selected beams

The idea of measuring the deflection to assess reinforced shotcrete concrete beam to revealed the mechanism of failure beam. The maximum deflection was 14.48 mm with 1.25% WFP which show negative effect for 1.25 ratio. While the maximum deflection performed for normal concrete contain PET was 20 mm.[20]

Through the test result of all selected beams for ultimate load, SC1.25 beam showed an increase of crack width more than SC0.75 beam due to minimum of shear reinforcement in the bending moment region. It can be gotten from test results that the incidence of WPF accelerated appearance first crack load and influenced wider of the crack width.

TABLE 4 ULTIMATE LOAD AND DEFLECTION TEST RESULTS FOR SELECTED BEAMS

Beam Mark	WPF Replacement (%)	First Crack Load (kN)	Ultimate Load (kN)	Maximum Crack width (mm)	Ultimate Deflection (mm)
SC0.00	0	10	70.4	1.7	12.8
SC0.25	0.25	12	63.35	1.2	13.8
SC0.50	0.50	13	59.53	0.9	13.3
SC0.75	0.75	14	64.18	0.6	12.8
SC1.00	1.0	11	64.0	1.8	13.3
SC1.25	1.25	9	19.45	2.1	14.84

Table 4 and Figure 8 make it evident that adding WPFs with volumetric ratios ranging from 0.25 to 1.0% has an impact on how RC beams behave. It also shows that adding WPFs to SC up to (Vf=1%) results in a rise in the loads that cause initial cracks when compared to beams made with reference mix. The value of the first crack increased the most when WPFs were added at a volumetric ratio of (0.75%). While it is important to note that the presence of waste plastic fibers at the beginning of the crack only slightly reduced the beams' deflection, this is because the plastic fibers' resistance to tensile stresses began to develop at this time, whereas in the case of using steel fibers, the resistance to tensile stresses start before appear the first crack and that lead to increase the load of the first crack and significantly decreasing in the deflection of beams.

- Crack pattern:

The fracture propagation was diverse across tested beams, as shown by crack patterns in the shear zone and bending moment area. The first hairline vertical flexural fractures appeared in the beams' mid-span, with the first vertical flexural crack occurring at roughly 30 to 50 percent of the ultimate load. These findings show that the first fracture appears at a lower ultimate load at the reinforcement ratio. Furthermore, the quantity of transverse reinforcement had an impact on the fracture angle as shown in fig.9.

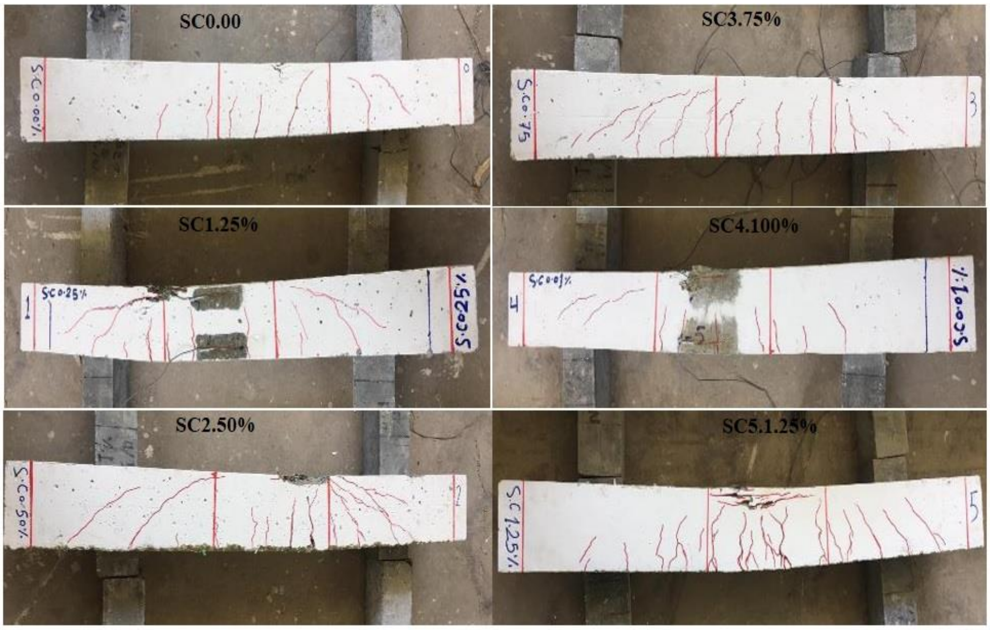


Figure .9 Crack pattern for all beams

- Stiffness

The results listed in the fig.10 refer to all tested beams. Beam SC0.00 recorded the highest stiffness result to (5.50 kn/mm), while beam SC1.25 recorded the lowest result (1.31 kn/mm). It is noticed that the beams which achieved the highest ductility recorded the lowest stiffness.

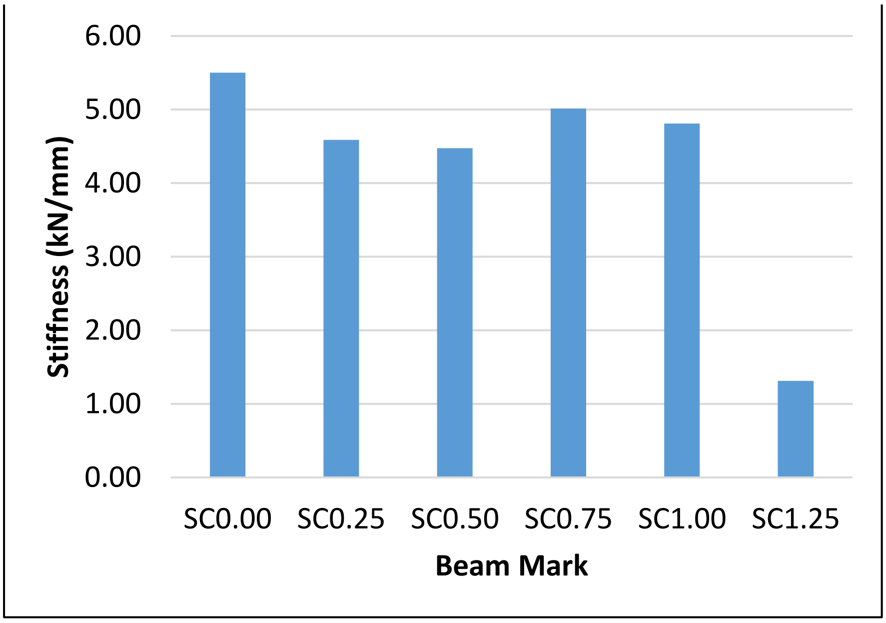


Figure .10 Stiffness results

- Load-strain responses of shotcrete:

The lowest and maximum strain values for all beams are shown in Table 4. Because of concrete cracking, the slopes of the curves dropped after that, the load-strain curves developed linearly, and the peak strains were distant from reaching the yielding strain. Furthermore, there was a clear distinction between the specimens with various WPF compositions. The load-strain relation of shotcrete incorporating varied WPF contents showed the same increase pattern until the yield point (9246, 6808, 16981, 12352, 36053) m strain for (0.25, 0.50, 0.75, 1.00, and 1.25) percent WPF, the shotcrete strain increased linearly, indicating that the flexural capabilities were resisted. The inclusion of polypropylene fibers produced a delay in the onset of the degradation process by reducing which can have a substantial impact on the structure's lifespan [8].

TABLE 5 STRAIN GAUGE RESULTS FOR SHOTCRETE BEAMS

Beam Mark	Strain ε (mm)			
	Top strain gauge		Bottom strain gauge	
	Min.	Max.	Min.	Max.
SC0.00	**0.000198**	**0.001897**	**0.000006**	**0.000331**
SC0.25	**0.000058**	**0.002438**	**0.000110**	**0.009245**
SC0.50	**0.000171**	**0.002741**	**0.000029**	**0.006808**
SC0.75	**0.000191**	**0.001394**	**0.000248**	**0.016981**
SC1.00	**0.000125**	**0.003771**	**0.000272**	**0.012352**
SC1.25	**0.002165**	**0.003280**	**0.011400**	**0.036053**

- Deflection ductility :

The ratio of absolute maximum deflection Δμ to corresponding yield deflection Δy is known as a ductility. Ductility is an essential property of structural member as it ensures that large deflection will happen through overload condition before the failure of the structure [22].

The load-deflection relationship of the section can be established for a generic reinforced concrete section and a given reinforcing ratio. The deflection ductility index, or (u), can be calculated from the connection between load and deflection. It is based on a calculation of the beam's midspan deflection. Table 5 shows the deflection ductility index, or (u), for beams that were experimentally evaluated for this work..

TABLE 6 DUCTILITY RESULTS FOR ALL TESTED BEAMS

Beam Mark	Δu	Δy	Ductility Index (u)
SC0.00	**12.77**	**6.3**	**2.03**
SC0.25	**13.8**	**6.02**	**2.29**
SC0.50	**13.34**	**6.6**	**2.02**
SC0.75	**12.79**	**6.6**	**1.94**
SC1.00	**13.33**	**6.16**	**2.16**
SC1.25	**14.85**	**7.46**	**1.99**

According to reference, the ductility index in Table 5 ranges from 1.94 to 2.29, showing significant agreement. [23],[24]. All beams have ductility indices that are less than 3.0. Broadly speaking, a structural member with a high ductility index may withstand significant deformations before failing. It is thought to be essential for beams to have a ductility index between 3 and 5, especially in the fields of seismic design and moment redistribution. [25]–[27]. Beams with ductility index only up 1.99 lacked adequate ductility and cannot redistribute moment [25].

5. Conclusion

The goal of this study is to assess the flexural performance of reinforced shotcrete concrete beams using shotcrete concrete that contains waste plastic. In the evaluation process, numerous tests on materials and beams for strength were included. The following points provide a summary of the key findings:

1. All the specimens exhibited multiple cracking behaviour under two-point bending load and uniaxial flexural load. The load-deflection capacity for the five mixtures prepared with different WPF contents ranged from 12.8 to 14.83 mm.
2. The waste plastic is lighted material therefore, the hydraulic and compressor air should adjusted in the shotcrete machine.
3. The mixing technique used in this investigation provided evidence that wet shotcrete concrete might become more shootable and pumpable.
4. The addition WPF to shotcrete concrete could improve the ductility of reinforced shotcrete concrete beam.
5. No noticeable difference in cracking patterns was observed between the different contents of WPF of shotcretes which cannot be attributed to the compressive strength of the concrete.

REFERENCES

[1] A. A. Jawheer, Y. A. Mansoor, A. I. Al-Hadithi, and O. A. Hamad, “Fuzzy logic progrss to predict of mechnical properties for shotcrete concrete contianing waste plastic,” in *2021 14th International Conference on Developments in eSystems Engineering (DeSE)*, 2021, pp. 566–570.

[2] F. E. T. III, “The Plaza Substation and Queens Structures,” *Shotcrete Mag.*, pp. 2015–2016, 2016, [Online]. Available: http://www.shotcrete.com/media/92534/SCM01-Townsend.pdf.

[3] F. E. Townsend III, “Northern Boulevard Crossing Tunnel CQ039,” *Shotcrete Mag.*, vol. 18, no. 1, pp. 34–36, 2016.

[4] B. Davis, “Holcim New Zealand Cement Terminal,” *Shotcrete Mag.*, vol. 19, no. 1, pp. 26–30, 2017.

[5] P. B. Trujillo, M. Jolin, B. Massicotte, and B. Bissonnette, “Bond strength of reinforcing bars encased with shotcrete,” *Constr. Build. Mater.*, vol. 169, pp. 678–688, 2018, doi: 10.1016/j.conbuildmat.2018.02.218.

[6] T. R. Crom, “Dry mix shotcrete nozzling,” *Concr. Int.*, vol. 3, no. 1, pp. 80–93, 1981.

[7] D. Beaupré and M. Jolin, “Effect of shotcrete consistency and nozzleman experience on reinforcement encasement quality,” *Shotcrete Mag.*, vol. 3, no. 4, pp. 20–23, 2001.

[8] S. Kakooei, H. Akil, M. Jamshidi, and J. Rouhi, “The effects of polypropylene fibers on the properties of reinforced concrete structures,” *Constr. Build. Mater.*, vol. 27, no. 1, pp. 73–77, 2012, doi: 10.1016/j.conbuildmat.2011.08.015.

[9] P. N. Balaguru and S. P. Shah, *Fiber-reinforced cement composites*. 1992.

[10] L. Balck, “Guide to Shotcrete,” *Concr. Int.*, vol. 39, no. 2, pp. 35–37, 2017.

[11] P. Bamonte, P. G. Gambarova, and A. Nafarieh, “High-temperature behavior of structural and non-structural shotcretes,” *Cem. Concr. Compos.*, vol. 73, pp. 42–53, 2016.

[12] J. I. Daniel *et al.*, “Report on fiber reinforced concrete,” *ACI Commitee*, vol. 544, 2002.

[13] S. Azmat *et al.*, “Effects of Fiber Reinforcements on the Strength of Shotcrete,” vol. 9, no. 1, pp. 176–183, 2021, doi: 10.13189/cea.2021.090115.

[14] A. Jawhar, A. Al-Hadithi, and Y. Mansoor, “Investigate the Fresh and Hardened Properties of Shotcrete Concrete Contains Different Types of Plastic Fibers,” *Iraqi J. Civ. Eng.*, vol. 16, no. 2, pp. 90–100, 2023, doi: 10.37650/ijce.2022.160209.

[15] M. Khooshechin and J. Tanzadeh, “Experimental and mechanical performance of shotcrete made with nanomaterials and fiber reinforcement,” *Constr. Build. Mater.*, vol. 165, pp. 199–205, 2018, doi: 10.1016/j.conbuildmat.2017.12.199.

[16] X. Cui, G. Liu, C. Wang, and Y. Qi, “Effects of PET Fibers on Pumpability , Shootability , and Mechanical Properties of Wet-Mix Shotcrete,” vol. 2019, 2019.

[17] “American Concrete Institute, ACI PRC-506-16 Guide to Shotcrete 2016.”

[18] W. Street and S. Gu, “Specification and Guidelines for Self-Compacting Concrete,” vol. 44, no. February, 2002.

[19] A. Enad, A. Al-Hadithi, and Y. Mansoor, “Flow ability and Mechanical Properties of Shotcrete concrete incorporated with Waste Plastic Fibers,” *Iraqi J. Civ. Eng.*, vol. 15, no. 2, pp. 5–15, 2021, doi: 10.37650/ijce.2021.172869.

[20] D. Foti, “Use of recycled waste pet bottles fibers for the reinforcement of concrete,” *Compos. Struct.*, vol. 96, pp. 396–404, 2013, doi: 10.1016/j.compstruct.2012.09.019.

[21] A. I. Al-Hadithi and M. A. Abbas, “Innovative technique of using carbon fibre reinforced polymer strips for shear reinforcement of reinforced concrete beams with waste plastic fibres,” *Eur. J. Environ. Civ. Eng.*, vol. 25, no. 3, pp. 516–537, 2021.

[22] İ. B. Topçu and T. Uygunoğlu, “Effect of aggregate type on properties of hardened self-consolidating lightweight concrete (SCLC),” *Constr. Build. Mater.*, vol. 24, no. 7, pp. 1286–1295, 2010.

[23] X. Yan, L. Liu, J. Zhang, Y. Li, and H. Wang, “Experimental Study on Basic Mechanical Properties of Steel Fiber-Reinforced Siliceous Wet Shotcrete,” vol. 2018, 2018.

[24] A. A. Jawhar, Y. A. Mansoor, and A. I. Al-hadithi, “Iraqi Journal of Civil Engineering Analysis of flexural behavior of one-way reinforced concrete slab casted by shotcrete contain various types of plastic fibers,” no. 2022, 2023.

[25] S. A. Ashour, “Effect of compressive strength and tensile reinforcement ratio on flexural behavior of high-strength concrete beams,” *Eng. Struct.*, vol. 22, no. 5, pp. 413–423, 2000.

[26] P. S. Kumar, M. A. Mannan, and V. J. Kurian, "DUCTILITY OF HIGH PERFORMANCE CONCRETE BEAMS USING SANDSTONE AGGREGATES," 2006.

[27] M. A. Rashid and M. A. Mansur, "Reinforced high-strength concrete beams in flexure," *ACI Struct. J.*, vol. 102, no. 3, p. 462, 2005.