Simultaneous effects of fiber and glass on the mechanical properties of self-compacting concrete

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Abstract: A variety of materials are added to concrete so as to improve its mechanical behavior. Moreover, it can help reduce the environmental pollution by replacing certain waste materials as cement or aggregate. This study involved waste glass as a replacement for aggregate. The polypropylene fiber was added to the glass-containing concrete so as to improve its behavior at different percentages (0, 0.5, 1 and 1.5%). Replacement of glass as aggregate can curtail the compressive and tensile strengths of the concrete. Furthermore, fibers enhance the tensile strength and slightly reduce the compressive strength of the concrete. Glass and fibers in concrete reduce slump. Therefore, the slump required by the concrete can be supplied by adding a lubricant. There were eighty cubic specimens (15 cm) constructed to investigate the compressive strength as well as sixty concrete beams (10 * 10 * 40 cm) to evaluate the flexural behavior of the glass-containing concrete and polypropylene fibers. The results demonstrated that the addition of 0.5–1% of fibers to the glass-containing concrete can enhance the compressive strength of the glass containing
Fiber-free concrete. The flexural strength of the concrete containing 50–70% of glass entails variations of less than 1%.

1. Introduction

The recycling of glass is an environmental issue. The risk of wastes is aggravated by the excessive cost of recycling and insolubility of glass in the environment. The chances to use the entire glass wastes are weakened by the type of additive materials and dyes, different glass resistance levels and combination with various polymers. Such diversity in composition will hinder the recycling of glasses. There are many techniques to use waste glasses, one of which involves cement mortars applied as pozzolanic. Glass is also used as an aggregate in concrete. The glass particles used in certain studies account for 100% of the aggregate. The use of recycled glass powder in concrete and cement brings about many environmental benefits. This will reduce the consumption of raw materials as well as the CO2 and NOx emission.

Moreover, it can minimize the cost of recycling and cement production. In most research projects on the addition of glass to concrete, the glass contains fine particles with a diameter of about 150 lm. Studies have also focused on different percentages of glass increase as a replacement powder of cement and aggregates. The smaller recycled, crushed glass particles can enhance the pozzolanic properties. According to the results of various studies, an increase by up to 60% in the amount of glass particles in the concrete can curtail the compressive strength of the concrete by 40%. However, the results of applying glass powders in different percentages (lower than 20%) were indicative of a slight increase in the compressive strength of the concrete. The weight of aggregates in percentages less than 15% enhanced the tensile strength of the concrete. Shao et al. studied the addition of three different glasses to the concrete, replacing by up to 30% of the weight of cement with concrete. The results indicated that glass powder has pozzolanic behavior in particles smaller than 38 lm. The compressive strength of the glass used in the experiments was calculated to be 4.1 M-Pa on the verge of being fractured. The results showed that the size of glass particles affects its compressive strength and pozzolonic mode. Madandoust and Ghavidel examined the mechanical properties of the concrete containing glass powder and rice husk.

The specimens were constructed in cubic and cylindrical shapes. The amounts of glass added to the concrete were 5, 10, 15 and 20% of the weight of the cement. The rice husk powder was also added to the concrete both separately and in combination with the glass powder. The pozzolonic effects of these particles on the compressive and tensile strengths were controlled. Fig. 3 shows the compressive strength of the concrete in 28 days with different percentages of glass powder and rice husk. The results suggested that the addition of 5–10% glass powder enhances the compressive strength of the concrete. Similarly, the addition of rice husk powder curtails the compressive strength. The combination of glass powder and rice husk behaves like a pozzolan, achieving the strength of normal concrete within 90 days. Park et al. studied the mechanical properties of the concrete made with glass aggregate. The maximum diameter of particles applied in the glass was 25 mm, and the water-cement ratio was about 50%. The percentages applied to the glass as an aggregate in the concrete were 30, 50 and 70%. The compressive strengths of the concrete at different ages were calculated along with the percentages. The compressive strength of the concrete decreases as the amount of glass as an aggregate decrease. In fact, 30% of the glass in reinforced concrete shows strength nearly equal to that of normal concrete. Penacho et al. examined the tensile behavior of the concrete made with glass. It was found that the tensile behavior increases as the concrete grows.

The tensile strength of the concrete with glass was 71% of normal concrete made at the age of 7 days. Within 90 days, the tensile strength amount to 97% of that of normal concrete.

The results suggested that the different lies in the rice husk powder within the concrete mix. Lower compressive strength is associated with a reduction in tensile and flexural strengths. Hence, the tensile strength of the concrete can be enhanced by adding fibers. It should be noted that the addition of fibers to concrete impacts on the compressive strength. Numerous studies have focused on concrete, special concrete and fiber concretes made with different compound percentages. One of the techniques to increase the tensile strength is to add different fibers to the concrete. The type of fiber and the percentage of mixed fiber affect the tensile strength, compressive strength, modulus of elasticity and slump of the concrete. Mertol et al. examined the behavior of reinforced heavy and lightweight concrete beams containing steel fibers. The specimens of reinforced concrete beams were in dimensions of 3500 _ 250 _ 180 mm, whose behavior was evaluated through 20 models. Researchers studied light and heavy concretes. The results of the study on the compressive strength of reinforced concrete beams demonstrated that an increase in steel fibers in low reinforced beams can either enhance or lower its strength. Nonetheless, it enhances the flexural strength of the beam in reinforced sections. Yoo et al. examined the behavior of the concrete beams reinforced with steel fibers. Researchers focused on the flexural behavior of the concrete beams under quasi-static and impact loading.

The concrete specimens were made with compressive strengths of 180, 90, 49 M-Pa. The results showed that the deformation of the concrete beams is due to load-dependent on fibers the compressive strength of fiber-less specimens. Such dependence lies in the flexural and shear cracks along the concrete beam. In fact, the expanded cracks in the middle section are controlled by the steel fiber after the micro-cracks are created (fig. 1). Yap et al. studied the effect of different steel ratios on normal and light-weighted concrete. In that study, angular aggregates and almond shells were used to construct the concrete specimens. The steel fiber ratios applied to the reinforced concrete were 55, 65 and 80%. They also studied the behavior of the concrete beams made with steel fibers and almond shells. The amounts of steel fibers in that study were 0.25, 0.50, 0.75 and 1%. The research generally showed that the addition of steel fibers enhances the mechanical properties and tensile strength of the concrete. In addition, the results demonstrated that an increase in steel fibers enhances the torsion tolerance under the initial crack, final crack and rupture crack. In 2016, Siddique et al. studied the mechanical properties of self-compacting concrete (SCC) containing steel fibers and fly ash. The amounts of steel fibers used in that study were 1.5, 1, and 0.5%. Similarly, Grabois et al. examined the behavior of SCCs containing steel fibers and fly ash. The properties were tested on fresh and hardened concrete. The study on the properties of hardened concrete demonstrated that the modulus of elasticity of the concrete made with cement free of fly ash by 10% steel fibers was not much different from 0% steel fibers. In reviewing the results of the two studies, it was found that the slump of SCC is affected differently by the addition of steel fibers. Nevertheless, this could be associated with the different lengths of the steel fibers used in the experiment.

The effect of fiber length on the concrete behavior has been studied in different research projects. Moreover, the effect of the type of fibers used in the concrete is significant. Lanzoni et al. presented the results of their research on the concrete reinforced with steel and polypropylene fibers. The flexural behavior, toughness, shrinkage cracks were examined in the specimens. The fibers used in this study comprised five types of fibers with lengths of 30, 35, 40, 50 and 70 mm. Four types of fibers were polymer, and the other was steel. The results showed that the level of crack opening depends on the type of fiber. Yin et al. studied the effects of synthetic fibers on tri-axial compressive strength of the concrete. The synthetic fibers used in this study were a combination of steel and polypropylene fibers. The comparison between the failure envelope for concretes made with steel fibers and polypropylene fibers revealed that the increase in fibers in both scenarios affected the failure mode equally. Jameran et al. studied the behavior of reinforced concrete reinforced with steel and polypropylene fibers under high temperatures. Studies indicated that fiber-reinforced concrete tends to have greater strength and durability than normal concrete. The effect of temperature on concrete containing polypropylene fibers is more than the concrete containing steel fibers.

Bosnjak et al. studied the high strength concrete along with heated polypropylene fibers. The studies focused on the behavior of high-strength concrete at temperatures ranging from laboratory up to 300 _C. It was indicated that the actual permeability of the concrete without polypropylene fibers increases at higher temperatures. Nonetheless, the permeability of specimens containing polypropylene fiber slightly varies. Any increase in temperature up to 200 _C did not affect the permeability of polypropylene-reinforced concrete. Numerous studies concentrated on the behavior of the concrete containing polypropylene fibers in concrete. Mazaheripour et al. examined the effect of polypropylene fibers on the properties of light fresh and hardened aggregate SCC. The light SCC weighed about 75% of the normal SCC. Moreover, 40% of the slump in the SCC curtailed due to addition of polypropylene fibers. The results showed that the addition of polypropylene fibers enhances the V-funnel test of SCC, the maximum value of which is 0.15%. The highest tensile and compressive strengths for SCC reinforced with polypropylene fibers can be found at fiber percentages above 20%, which is around 14% of the normal concrete. This study focused on the mechanical properties of mortar and concrete of the concrete made with glass and polypropylene fibers. By changing the percentages of glass as a replacement of aggregate and fibers, effort was made to achieve maximum tensile strength for the concrete. Nonetheless, this might lead to maximum decline in compressive strength. Hence, the standard cubic specimens were prepared from the different concrete mixture scheme and then tested. The mixture scheme produced several rectangular concrete specimens tested under flexural conditions.

2. EXPERIMENTAL STUDY

This study examined the mechanical properties of mortar and concrete of the concrete containing glass and fibers. Moreover, the flexural and tensile strengths of the specimens were studied at the age of 28 days. The fibers were made of polypropylene. The recycled glass replaced the concrete aggregates. The results can be affected by the granulation chart, glass type and properties/ length of the fiber. These parameters were fixed during the experiments and the only variable was the percentage of materials.

2.1. Materials

The construction materials used in the scheme mixture of the specimens included normal Portland cement, angular aggregate and lubricant. Micro-silica and filler were used at fixed percentages in all specimens. The SCC was constructed in two normal and fiber modes. Table 1 displays the polypropylene fibers. Moreover, Table 1 shows the granulation and flake structure in the glass fragments replacing the aggregates. This chart consists of two parts of sand and gravel granulations. Fig. 2 displays the percentages of flake and acicular particles in the glass fragments. The thickness of the glass was 6 mm, and the largest flake particle had a diameter of 2 cm. In the concrete mix scheme, a lubricant and micro-silica were used at a constant percentage (3%). The water-cement ratio was also constant. The percentages in Table 2 are the weight ratios of materials. The weight percentage of fiber in the cement ranged from 0 to 1.5%. The amount of glass replacing the aggregates ranged from 30 to 100%. The concrete was tested in terms of compressive and flexural strengths with various mixtures and percentages of glass and fibers. The polypropylene fibers at percentages of 0, 0.5, 1 and 1.5 in the concrete mix scheme were accompanied by recycled glass at percentages of 30, 50, 70 and 100 (Fig. 3).

Table-1:- Fiber qualifications.

Name	Diameter (mm)	Length (mm)	Density (g/cm3)	Tensile strength (MPa)
PP	0.045	12	1100	550

2.2. Specimens

Eighty standard cubic models (150 * 150 * 150 mm) were tested for compressive strength. Sixty Rectangular cubic specimens (400 * 100 * 100 mm) were tested for flexural strength (Fig. 4). The specimens were made from 20 mixtures listed in Table 2. The flexural strength tests were conducted on 100 x100 x 400 mm3 concrete beam specimens. In addition, these tests indirectly investigated tensile and shear strengths of the concrete specimens.

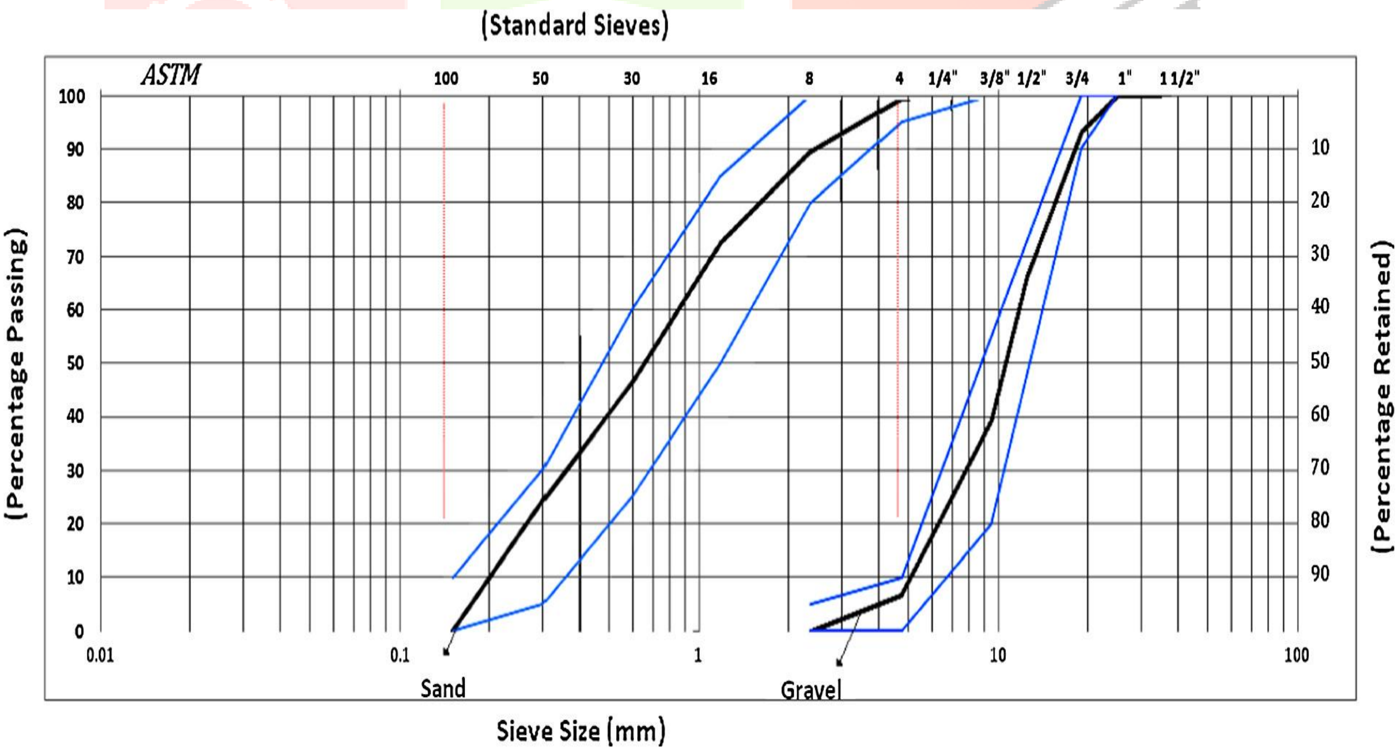

Fig. 1. Grading curve.

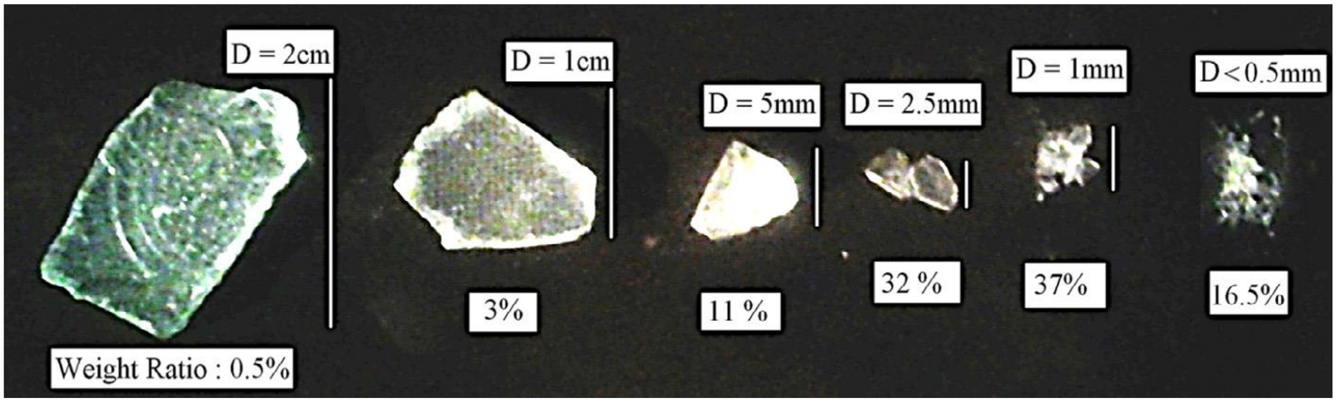

Fig. 2. Sample of waste glass (0.5% of replacing Glass fragments, had a diameter of 2 cm).

Table 2:-Properties of the concrete mix (Glass fragments replacing the aggregate).

Name	Cement Weight Ratio (475 kg/m3)			Aggregate Ratio		Slump flow (cm)
	Plasticizer / Cement	fiber / Cement	Water / Cement	glass / Aggregate	Sand / Aggregate	
FCO-0	3%	0%	32%	0%	50%	69
FC1-0	3%	0%	32%	30%	35%	68
FC2-0	3%	0%	32%	50%	25%	66
FC3-0	3%	0%	32%	70%	15%	63
FC4-0	3%	0%	32%	100%	0%	59
FCO-5	3%	0.5%	32%	0%	50%	67
FC1-5	3%	0.5%	32%	30%	35%	66
FC2-5	3%	0.5%	32%	50%	25%	64
FC3-5	3%	0.5%	32%	70%	15%	61
FC4-5	3%	0.5%	32%	100%	0%	57
FCO-10	3%	1.0%	32%	0%	50%	65
FC1-10	3%	1.0%	32%	30%	35%	64
FC2-10	3%	1.0%	32%	50%	25%	60
FC3-10	3%	1.0%	32%	70%	15%	58
FC4-10	3%	1.0%	32%	100%	0%	55
FCO-15	3%	1.5%	32%	0%	50%	60
FC1-15	3%	1.5%	32%	30%	35%	58
FC2-15	3%	1.5%	32%	50%	25%	55
FC3-15	3%	1.5%	32%	70%	15%	51
FC4-15	3%	1.5%	32%	100%	0%	47

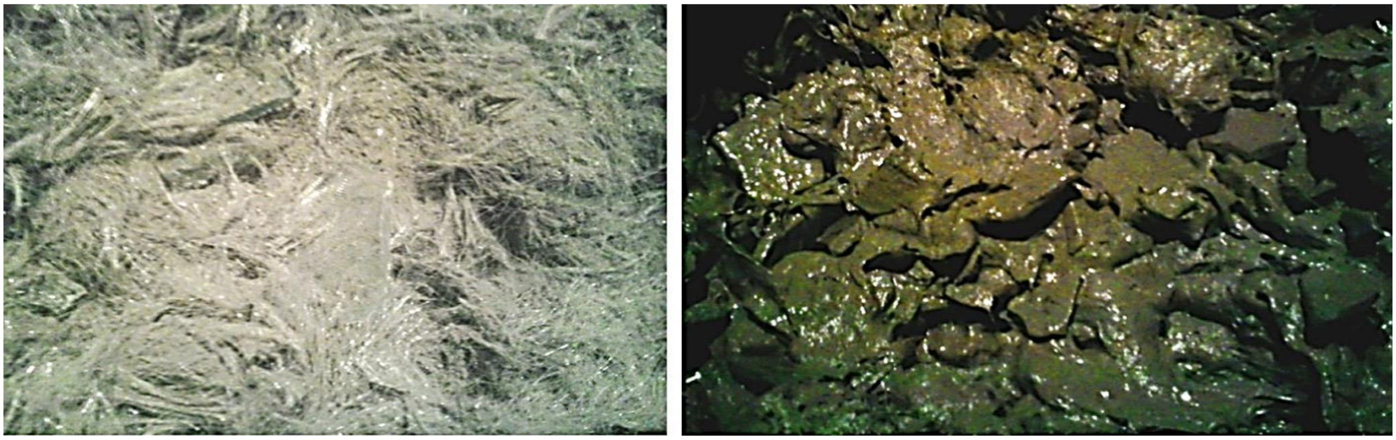

Fig. 3. FC4-15 (fiber ratio: 1.5%; glass ratio: 100%).

At the age of 27 days, the specimens were removed out of storage and then dried for a day at laboratory temperature. At the age of 28 days, they went under uniform uniaxial compressive and three-point flexural tests.

3. RESULT & DISCUSSION

This section discusses the mechanical behavior of the concrete containing waste glass and fibers at different percentages. The compressive strength and flexural strength of the specimens follow the changes in the percentages of glass and polypropylene fibers. In this section, 20 mixed schemes were tested and the mix scheme with the greatest flexural strength was paired with the lowest reduction in shear strength.

3.1. Compressive strength

The compressive strength of cubic specimens was tested at the age of 28 days. Studies showed that glass as an alternative to aggregate curtails the compressive strength more than polypropylene fibers. In fact, the decrease in compressive strength due to glass fibers is lower than that due to glass particles (Fig. 5). Due to the fact that the compression tests were uniaxial, the cubic specimen was subjected to tension along two directions perpendicular to the compression axis. Addition of glass bits dramatically reduced compressive strength. Addition of fibers increased compressive strength as a result of the increase in tensile strength occurring along other directions. As shown in Fig. 5, the greatest increase in compressive strength as a result of adding fibers occurred at a glass-to-aggregate ratio of 50%.

FIG. 4. TEST DEVICES AND SPECIMENS.

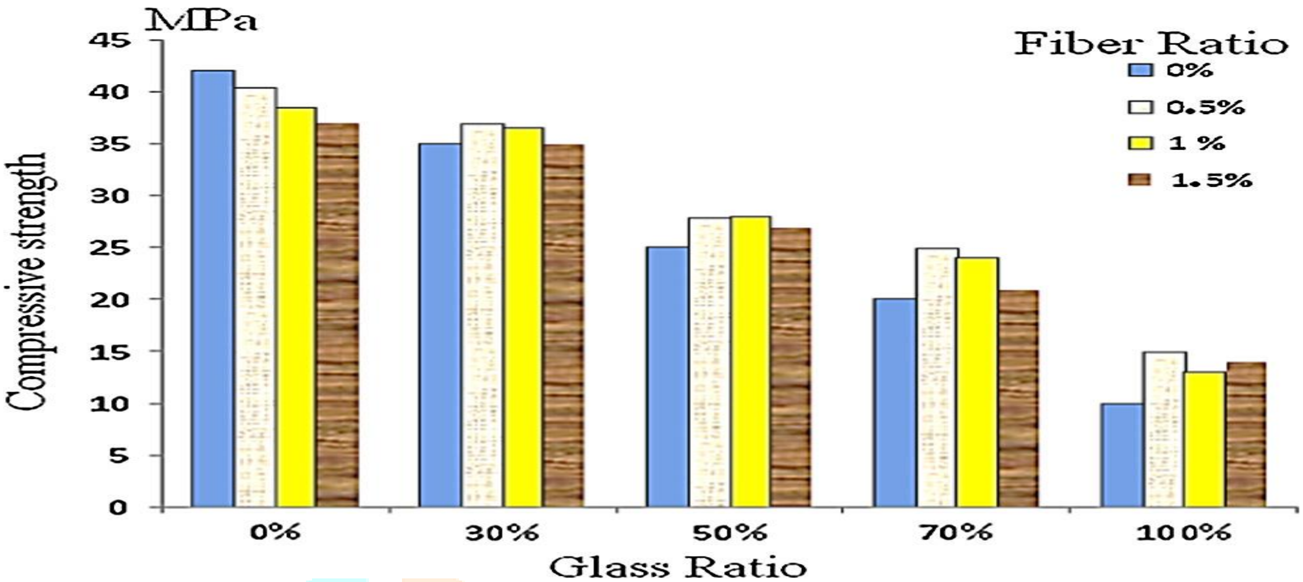

Fig. 5. Compressive strength.

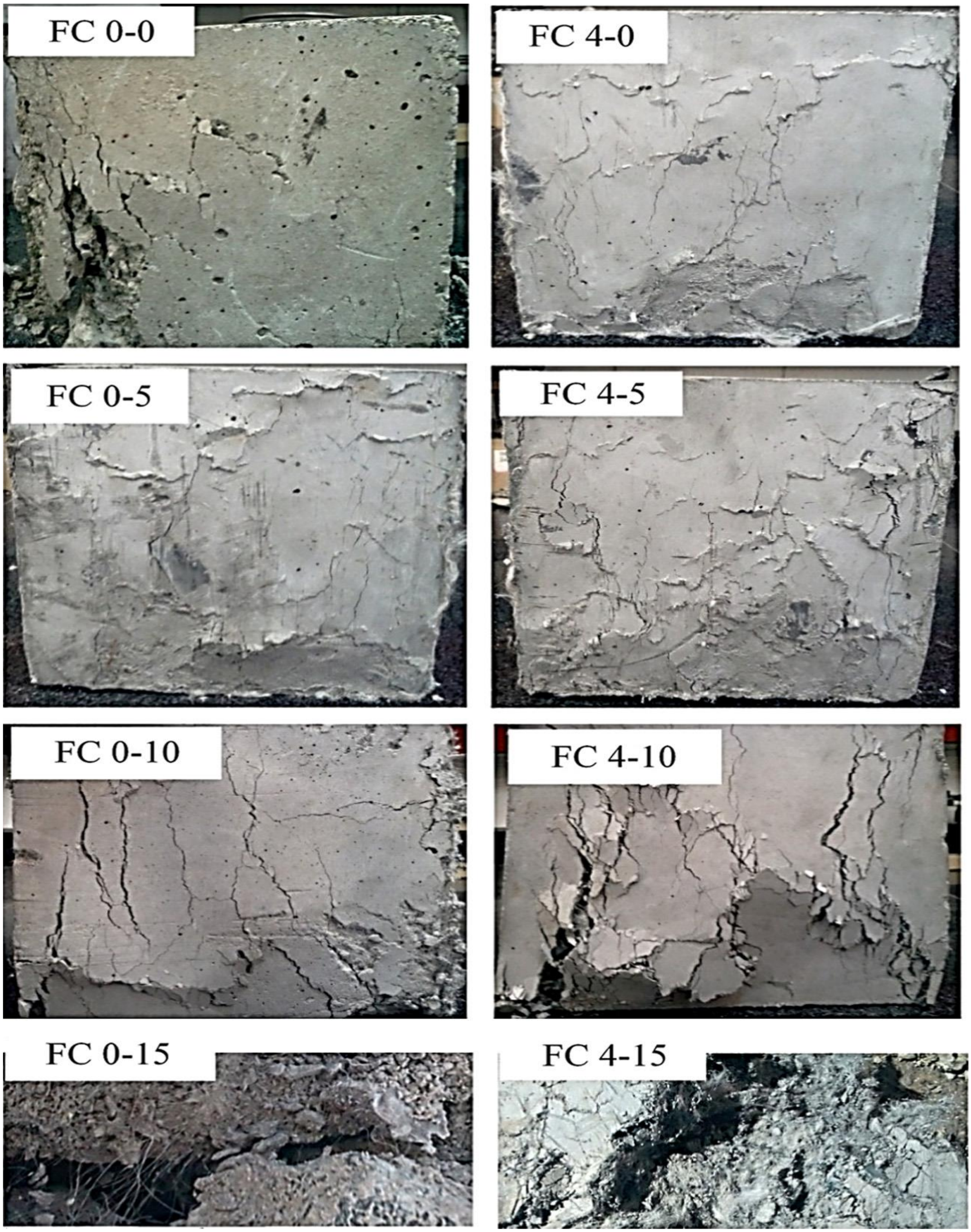

FIG. 6. FRACTURED SURFACE.

The results indicated that the addition of fibers to concrete along with glass aggregates enhances the compressive strength, even though it is not significant. In fact, fiber affects the tensile strength of the concrete in the transverse direction, thus enhancing uniaxial compressive strength of the cubic specimens (Fig. 6). The examination of fracture surface in the specimens showed that the replacement of aggregate with glass in the concrete led to a vertical fracture surface. By changing the tensile strength, the addition of fibers to glass-containing concrete curtails the brittleness. This in turn leads to diagonal cracks in V and Y shapes under uniaxial compressive strength.

3.2. Flexural strength

The tensile and flexural strengths of the concrete are enhanced by addition of polypropylene fibers. Fig. 7 compares the tensile strength of the concrete and the percentage of fiber. It also displays the effect of replacing glass by aggregate. It was found that increased fiber from 0 to 0.5% remarkably affected the tensile strength of the concrete. The tensile strength of the concrete slightly varied from 0.5% to 1%. Replacement of the concrete aggregates with recycled glass reduced the effect of fibers on enhancing the tensile strength.

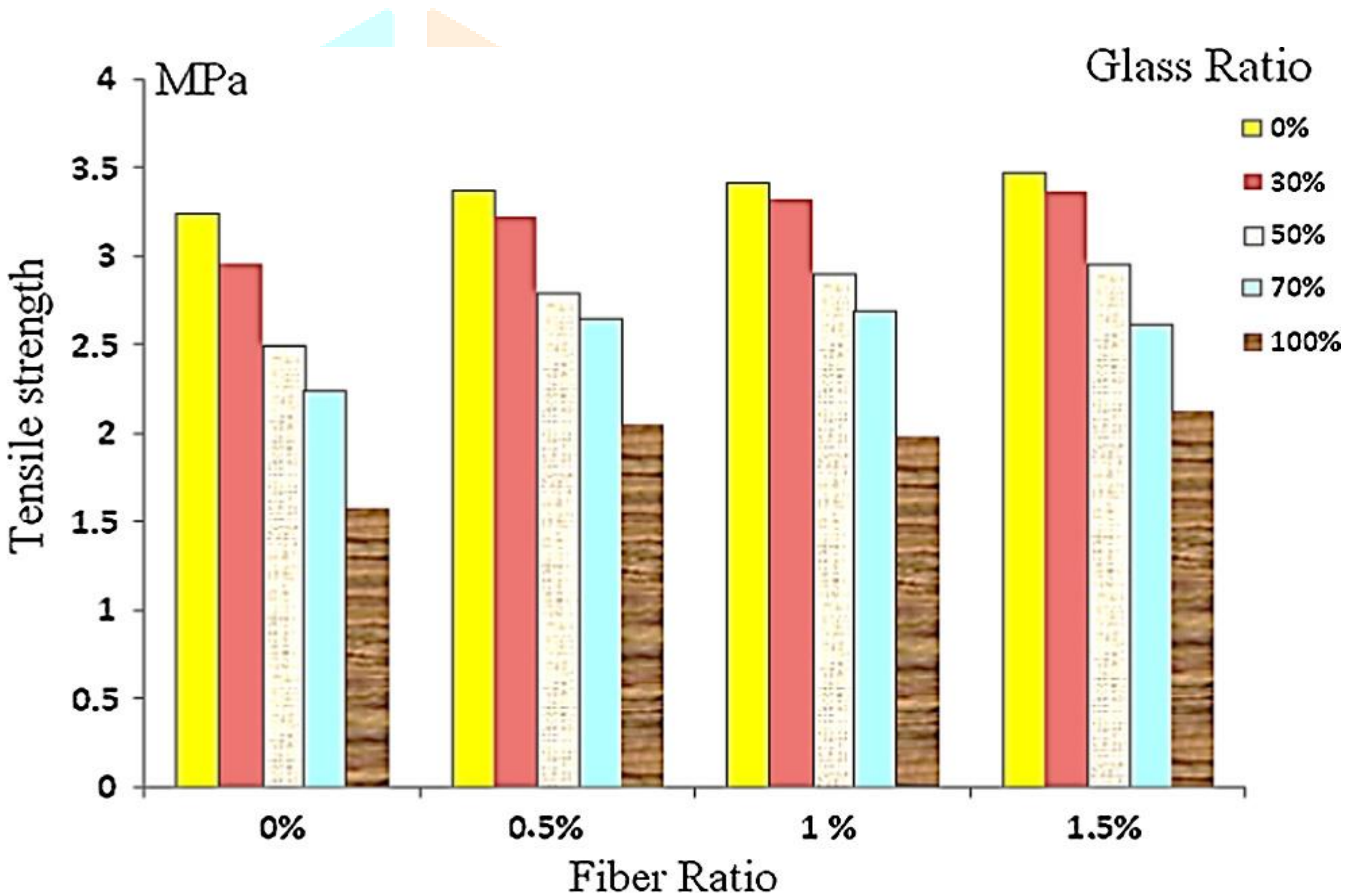

Fig. 7. Tensile strength.

3.3. Stress-strain curve

The amount of energy absorbed in the samples can be determined through the stress-strain diagram of the concrete using the area under the curve. Effects of type of the materials used in concrete on the strain are determined with respect to applied stress. The stress-strain diagrams of the tested concrete samples show distinct changes caused by different percentages of fibers and glass (Fig. 8). In addition to reduced compressive strength and increased tensile strength due to adding glass and fibers to concrete, strain in the samples increased with increasing the concrete fibers. Diagrams indicate that stress suddenly decreases after the point of failure (peak point) in the glass-containing concrete (as a replacement for aggregate). Failure of the glass in the concrete after the main failure in concrete is of significance. In fact, part of the glass aggregates failure occurs simultaneously, leading to a sudden reduction in the compressive strength. Adding fiber to a concrete that contains 100% glass can increase strain, especially after the main failure of the sample. This trend can also be observed in the glass-less concrete. However, the effect of fiber on the behavior of concrete depends on the percentage of cracks developed in concrete. In fact, fibers prevent the spread and growth of cracks. Considering the many cracks that develop in the glass-containing samples, it can be concluded that the effect of fiber (on strain and crack growth) is more significant in glass containing concretes than conventional concretes (comparison between stress-strain diagrams in Fig. 8). In the glass-less samples, addition of fiber increases strain and changes the slope of the loading curve.

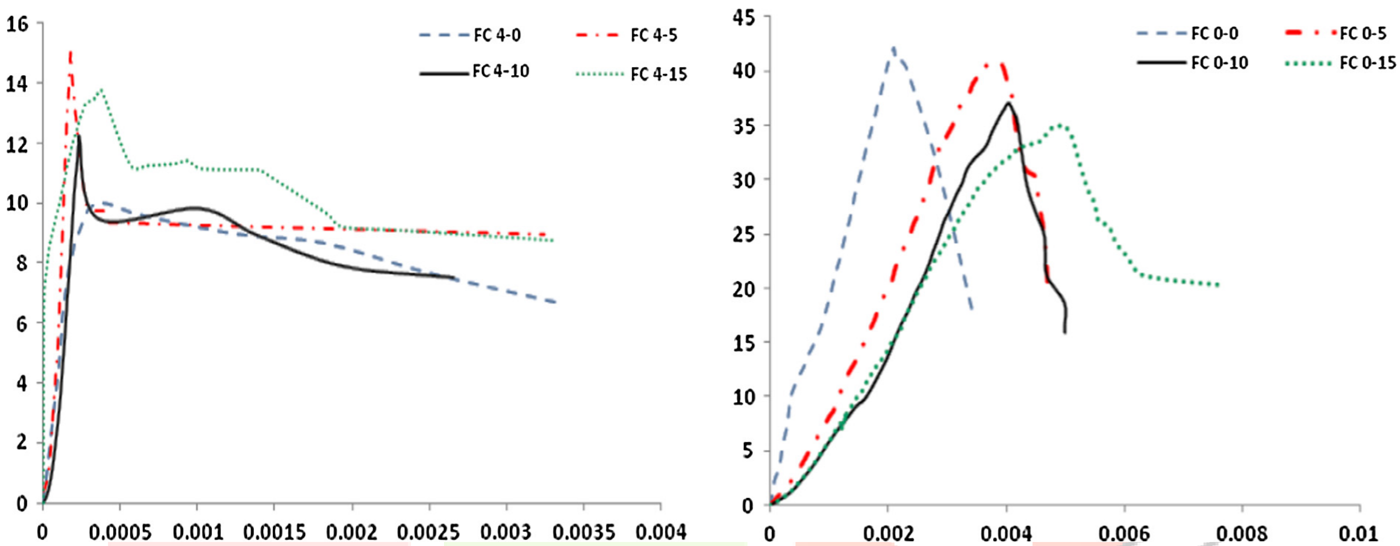

Fig. 8. Stress-strain curve.

The results obtained from investigating the behavior of self-compacting concrete containing glass and fiber showed that the ordinary concrete specimens exhibited the greatest plasticity as well as slump. Addition of plasticizer increased slump. Using a different type of aggregate and substituting it with glass reduced slump due to the reduced weight and the different shape of the aggregate used. In addition, adding fibers reduced concrete slump and increased nesting among concrete particles and aggregates.

4. CONCLUSION

This article attempted to examine the addition of glass as an alternative to aggregates as well as the addition of polypropylene fibers to improve the mechanical properties of the new concrete. As an environmental waste, the recycled glass can be added to concrete so as to reduce the production costs. The replacement of aggregate with glass can curtail the compressive and tensile strengths of the concrete. Moreover, the addition of polypropylene to this type of the concrete can change the tensile strength and even the compressive strength of the concrete. The polypropylene fibers in the concrete enhance the tensile strength and slightly reduce the compressive strength. This study involved 16 mix schemes at various percentages of glass (0, 30, 50, 70 and 100) as replacement of aggregate. Moreover, different percentages of polypropylene fibers (0, 0.5, 1, and 1.5) were used to evaluate the effects of adding these materials to the concrete simultaneously. The use of glass as an aggregate can reduce the concrete slump. The fiber also reduces the grip of aggregates while reducing slump. The fiber-containing glass-free specimens in the concrete (FC0) revealed that the compressive strength lowers by adding fibers. However, the addition of glass to the concrete also minimizes the compressive strength. The results demonstrated that adding fiber to glass-containing concrete can increase the compressive strength. Furthermore, the increase in tensile strength of glass-containing concrete due to addition of fibers tends to be higher than that normal fiber-containing concrete. In fact, the addition of fiber to the concrete, as an alternative to aggregate containing recycled glass, can enhance the mechanical properties of the concrete. The results of this study suggested that 0.5–1% of fiber in the concrete containing glass aggregates can increase the compressive and tensile strengths. The ideal effectiveness ranged from 0.5% to 1% for polypropylene fibers, while it was 30–70% for glass as an alternative to aggregates.

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