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

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HIGHLIGHTS

- Substitution of glass for aggregates in concrete reduces compressive strength.
- Addition of fibers to glass-containing concrete increases compressive strength.
- Addition of glass to concrete reduces the tensile strength of 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%.

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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 [1]. 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 pozzolan [2–12]. Glass is also used as an aggregate in concrete. The glass particles used in certain studies account for 100% of the aggregate [13–19]. 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 CO_2 and NO_x 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 μm. Studies have also focused on different percentages of glass increase as a replacement powder of cement and aggregates [20–23]. 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 [24–27]. The weight of aggregates in percentages less than 15% enhanced the tensile strength of the concrete [28–30].

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 [31]. The results indicated that glass powder has pozzolanic

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behavior in particles smaller than 38 μm. The compressive strength of the glass used in the experiments was calculated to be 4.1 MPa 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 [32]. 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 [33]. 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 decreases. 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 [34].

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 [35–37]. 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 [38]. The specimens of reinforced concrete beams were in dimensions of $3500 \times 250 \times 180$ 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 [39]. 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 MPa. 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 is 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 [40]. 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 [41]. The amounts of steel fibers used in that study were 1.5, 1, 0.5%. Similarly, Grabois et al. examined the behavior of SCCs containing steel fibers and fly ash [42]. 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 [43]. 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 [44]. 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 [45]. Bosnjak et al. studied the high-strength concrete along with heated polypropylene fibers [46]. 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 [47–48]. 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 [49]. 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

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