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Mechanical Properties of Fiber Reinforced Concrete

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Abstract. This study presents results of an experimental investigation conducted to investigate the mechanical properties of sisal and glass fiber reinforced concrete. Four basic concrete mixes were considered: 1) Plain concrete (PC) containing ordinary natural aggregates without any fibers, 2) sisal fiber reinforced concrete (SFRC), 3) sisal and glass fiber reinforced concrete (SGFRC), 4, glass fiber reinforced concrete (GFRC). Investigated properties were compressive strength, splitting tensile strength, flexural tensile strength and workability. The results of fiber reinforced concrete mixes were compared with plain concrete to investigate the effect of fibers on the mechanical properties of fiber reinforced concrete. It was determined that addition of different kinds of fibers (natural and synthetic) is very useful to produce concrete. The addition of fibers was resulted into higher compressive strength, splitting and tensile strength. However, the workability of the fiber reinforced concrete was found lower than the plain concrete due to the addition of fibers in the concrete.

Introduction

In the past few decades, growing concern over global warming and other significant ecological changes has spurred much debate in all fields of science and engineering. Concrete is the most widely used construction material in the world and steel reinforcement is always required to meet tensile strength and ductility demands of concrete structures. The production of one ton of Portland cement generates approximately one ton of carbon dioxide (CO_2) and requires up to 7000 MJ of electrical power and fuel energy. Therefore, concrete industry has increasingly been considered one of the largest contributors to these ecological changes. The production of concrete and reinforced concrete structures creates lots of environmental issues associated with the significant release of CO_2 and other greenhouse gases Thus, it is urgent to promote sustainable concrete and structures to reduce their negative impact on the environment. The development of new environmentally friendly materials to replace aggregates and steel rebar as reinforcement for concrete structure is a significant step to achieve sustainable concrete and structures. Examples of developments in sustainable philosophies for concrete have been published [1–6]. Much research has been performed on the use of high volumes of fly ash and other supplementary cementitious materials to produce more sustainable and durable concrete [7–10]. Recycled concrete is becoming of increasing interest for use as aggregate in structural concrete and recent research has examined its performance [11, 12].

The primary objective of current study was to evaluate the mechanical properties of sustainable fiber reinforced concrete containing natural and synthetic fibers. To achieve this objective, four basic concrete mixes will be considered: 1) Plain concrete (PC) containing ordinary natural aggregates without any fibers, 2) sisal fiber reinforced concrete (SFRC), 3) sisal and glass fiber reinforced concrete (SGFRC), 4) glass fiber reinforced concrete (GFRC). Investigated properties will be compressive strength, splitting tensile strength, flexural tensile strength and workability. The results of fiber reinforced concrete mixes will be compared with plain concrete to investigate the effect of fibers on the mechanical properties of fiber reinforced concrete.

Experimental Program

Compressive Strength. In this experimental program, the compressive strength tests were carried out with cylindrical sample (ϕ100 x 200 mm) at 21 days, according to ASTM C-39 [1]. The compressive testing machine used is a Universal Testing Machine with a maximum load capacity of 200 Tons. Loading rate is controlled to 1 ton/s in this test until crushing.

Splitting Tensile Strength. In splitting tensile strength test, the cylindrical with size ϕ100x200 mm were tested in accordance with ASTM C469 [1]. The equations provided in the standard to calculate splitting tensile strenght is given below:

$$f_t = 2P/(\pi LD)$$

where, f_t = ultimate splitting tensile strength (MPa), P = ultimate load (N), L = length of cylinderical specimen (mm), D = diameter of cylinderical specimen (mm).

Flexural Tensile Strength. Concrete prism with dimension of 100x100x500 mm were tested in accordance with ASTM C 293 [1]. The prisms were tested using third point loading. The loads and central deflection were measured. The flexural strength, expressed in terms of modulus of rupture can be determined using following formula;

$$R = 3PL/(2bd^2)$$

where, R = modulus of rupture, P = ultimate load, L = beam span between supports, d = depth of beam, b = width of beam

Material Properties. Ordinary Portland Cement (OPC) conforming to ASTM classification Type I, manufactured by Siam Cement Public Company Limited was used throughout this experiment. The natural river sand passing through sieve No.4 (4.75 mm) according to ASTM C33-02 [16] was used in the mixing of concrete for all tests. The coarse aggregate was crushed limestone aggregate with the maximum size of 19 mm (3/4"). In this study, ordinary tap water available in the laboratory was used for mixing. Two main types of fibers: natural sisal fibers and synthetic glass fibers were used. Natural sisal fibers were obtained from local farms in the form of long fibers. Further, long fibers were cut into 45 to 50 mm length. Synthetic glass fibers were obtained from local supplier. Properties of both fibers are listed in Table 1.

(a) Sisal fibers

(b) Glass fibers

Fig. 1 Sisal and glass fibers.

Table 1 Properties of fibers.

Fiber type	Length (mm)	Diameter (mm)
Sisal	45-50	0.25
Glass	35-40	0.013

Mix Proportions. The mix proportions of concrete used in this experiment are given in Table 2. The mix being to obtain a strength of 20 MPa at 21 days strength. Water to cement ratio of 0.78 was kept constant in all mixes.

Table 2 Mix proportions.

Mix	Cement (kg/m^3)	Sand (kg/m^3)	Aggregates (kg/m^3)	Fiber type	Fiber (kg/m^3)
PC	280	720	1182	-	-
SFRC	280	720	1182	Sisal	6.0
SGFRC	280	720	1182	Sisal+Glass	3.0+3.0
GFRC	280	720	1182	Glass	6.0

Mixing Procedure of Concrete. The concrete was mixed by a conventional pan mixer. A consistent mixing procedure was used to avoid segregation and fiber balling problem during mixing. At first, coarse aggregate and sand were mixed in the mixer. Second, cement was then added into the mixer. After that, all materials were mixed for 1 min. And then, water was gradually poured the mixing drum and mixed for 2 min to reach uniform consistency. Subsequently, fibers were gradually sprinkled by hand, rotating at total speed for 5 min, and care was taken to obtain homogeneous and workable mixture. Slump test was carried out after fiber addition. Fig. 2 shows the mixing process.

Fig. 2 Mixing procedure of sisal fiber reinforced concrete.

Test results and Discussion

Workability of Fiber Reinforced Concrete. It was found that use of natural and synthetic fibers resulted in low workability as compared with plain concrete containing natural aggregates. 25%, 11% and 5% reduction in workability were observed for SFRC, SGFRC and GFRC, respectively, compared with plain concrete (Table 3). Although the fibers clearly reduced the workability of the concrete, most of the other mechanical properties were improved.

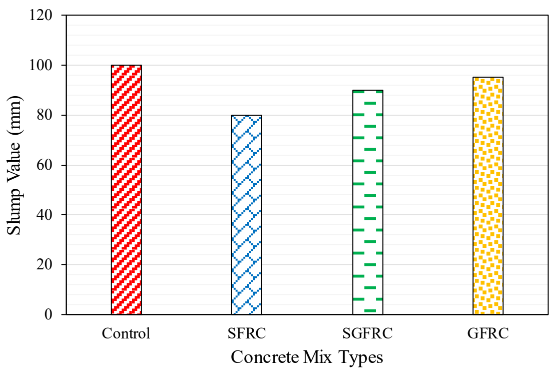

Fig. 3 Slump values of FR concretre.

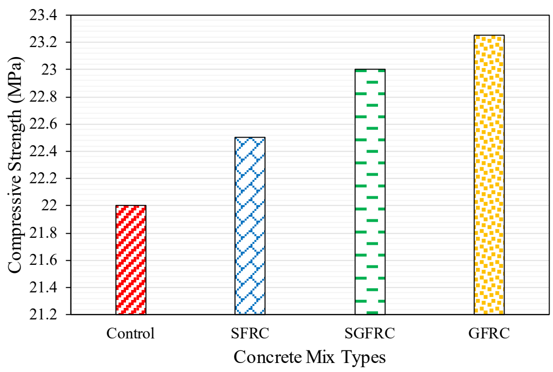

Fig. 4 Compressive Strength of FR concretre.

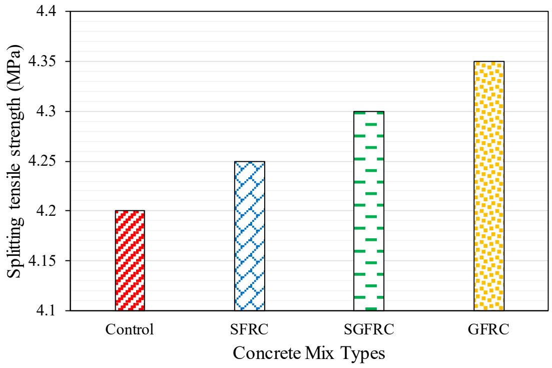

Fig. 5 Splitting tensile strenght of FR concrete mixes.

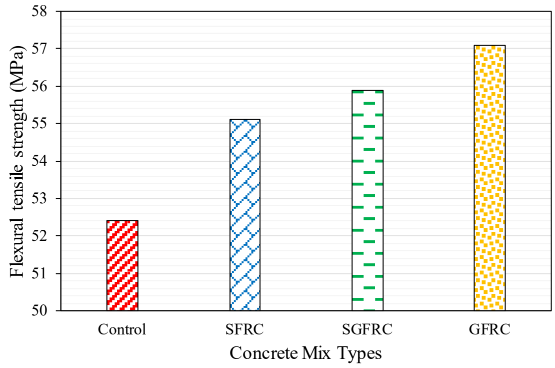

Fig. 6 Flexural tensile strength of FR concrete mixes.

Compressive Strength. It was noted that the addition of natural and synthetic fibers increases the compressive strength of concrete (Fig. 4). As for sisal fiber reinforced concrete (SFRC), the compressive strength was increased by 2.25% compared to the control beam. This indicated that the natural fibers contributed a minor increase in compressive strength. Further it can be seen concretes with the mixture of sisal and glass and only glass fibers also resulted in increased compressive strength. It can be seen that SGFRC and GFRC attained 4% and 6% increase in compressive strength compared to the plain concrete without fibers (Table 3).
Splitting Tensile Strength. In this study, splitting tensile strength increased by 10%, 12% and 15% for SFRC, SGFRC and GFRC, respectively, as compared to the plain concrete without fibers (Fig. 5 and Table 3).

It was observed for the case of plain concrete with natural aggregates, the cylindrical specimens were suddenly split into two parts, but for the case of fiber reinforced concrete (SFRC, SGFRC and GFRC), there was no sudden failure after cracking. Only cracks line occurred at the center of the specimens due to the effect of fibers.
Flexural Tensile Strength. In this testing, the flexural strength increased by 5%, 7% and 9% for SFRC, SGFRC and GFCR, respectively in comparison to plain concrete without fibers. Addition of fibers seems to change the failure mode from brittle to ductile and improve post cracking load and energy absorption capacity in comparison to plain concrete. Addition of fibers may bridge the cracks, transmitting the force and control crack propagation. This is drastically different to plain concrete beam where immediate collapse occurred at the onset cracking within tension zone (Fig. 6 and Table 3).

Table 3 Experimental test results.

Concrete Mix	Slump Values (mm)	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Flexural Tensile Strength (MPa)
PC (Control)	100	22.00	4.20	52.40
SFRC	80	22.50	4.25	55.10
SGFRC	90	23.00	4.30	55.90
GFRC	95	23.25	4.35	57.10

Conclusions

This study presents an experimental investigation on the mechanical properties of fiber reinforced concrete. Based on experimental results, following conclusions can be draw; 1) Use of different fibers such as sisal and glass is very useful to alter mechanical properties of concrete, 2) Workability of fiber reinforced concrete is found lower than plain concrete (control concrete) to the addition of fibers, 3) Compressive strength, spitting and flexural tensile strength properties of fiber reinforced concrete can be greatly enhanced by adding different kinds of fibers into the concrete, 4) Comparatively glass fibers are proved most effective to alter or enhance mechanical properties of concrete than sisal fibers.

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