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Comparison Study on Concretes Containing Fibers to Provide Concrete with High Resistance

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Abstract: This is a study of giving some highlights for inclusion of fibers in terms of using them with concrete. Fiber reinforcement is a traditional and effective method how to improve the toughness and durability of cement based products. This study compared the resistance of concrete containing steel, carbon and glass fibers. The results indicated that the resistance of Steel Fiber Reinforced Concrete was higher than Carbon Fiber Reinforced Concrete and Glass Fiber Reinforced Concrete. It is well known that one of the most significant properties of steel fiber reinforced concrete is its superior resistance to pressure.

Key words: Steel fiber · Glass fiber · Carbon fiber · Concrete · Resistance

INTRODUCTION

Concrete is widely used in domestic, commercial, recreational, rural and educational construction. It is used in such large quantities due to it is, simply, a remarkably good building material for rather more glamorous projects. Despite the common usage of concrete, few people are aware of the considerations involved in designing strong, durable, high quality concrete. In general, concrete is a mixture of cement, water and aggregate material. It is well known that concrete mixed with other matter was applied for resistance purposes.

Civil structures made of concrete and steel bar normally suffer from corrosion of the steel by the salt, which results in the failure of those structures. Constant maintenance and repairing is needed to enhance the life cycle of those civil structures. The admixture added to concrete in order to increases its resistance is fiber. Short fibers are also used as admixtures materials to decrease the drying shrinkage, increasing the flexural toughness and, in some cases, increasing the flexural strength as well [1, 2]. In the case that the fibers are electrically conductive, the fibers may also provide nonstructural functions, such as self-sensing (for sensing the strain, damage, or temperature), self-heating (for deicing) and electromagnetic reflection (for electromagnetic interference shielding).

Plastic shrinkage cracking is one of the most common issues when lying concrete. Although minor cracking is almost expected to happen to any concrete, the severity of the cracks as well as number of cracks can be greatly reduced with the use of fibers. Generally, fiber serves two main purposes (a) reduce shrinkage cracks and (b) provide reinforcement in place of traditional rebar or welded wire mesh [3; 4]. Plain, unreinforced concrete is a brittle material, with a low tensile strength and a low strain capacity. The role of randomly distributes discontinuous fibers is to bridge across the cracks that develop provides some post-cracking “ductility”.

The fibers reinforcement may be used in the form of three-dimensionally randomly distributed fibers throughout the structural member when the added advantages of the fiber to shear resistance and crack control can be further utilized. On the other hand, the fiber concrete may also be used as a tensile skin to cover the steel reinforcement when a more efficient two-dimensional orientation of the fibers could be obtained [5]. The main aim of the presents study is to compare the resistance of concrete containing steel, glass and carbon.

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Background: Over the past decade, concrete has been widely acknowledge as a three-phase material which includes the matrix, aggregates and an interface transition zone, in which the latter is regarded as the weakest link. With the advent of new composites materials of improved mechanical properties and advanced cement matrices the study of the fiber/matrix interface assumes a new interest. Fibers used in cementitious matrices such as concrete are characterized in various ways. Based on the fiber material (natural organic: such as cellulose, sisal, jute and bamboo; natural mineral: such as asbestos, rock and wool; handmade material: such as steel, titanium, glass, carbon and polymers), physicochemical factors (density, surface roughness, chemical stability, non-reactivity with the cement matrix, fire resistance), mechanical properties (such as tensile strength, ductility, elastic modulus, stiffness, elongation to failure and surface adhesion property) [6]. According to Naaman (2003), the cross section of the fiber can be flat, triangular, square, circular, rectangular, diamond and polygonal shape. It is an effective way to increase toughness, shock resistance and resistance to plastic shrinkage cracking of the mortar. In order to develop the bond between fiber and the mixture, the fiber must be modified along its length by roughening its surface and by inducing mechanical deformations.

MATERIALS AND METHODS

Several methods for proportioning SFRC are recognized [3, 6]. To evaluate the influence of fibers on the resistance of concrete, three different mixes and three different fibers were used. The aggregates were siliceous natural sand and crushed limestone. The samples contain different percent of fibers, including 10%, 20% and 25%. The steel fibers were hook-ended of length I_f= 30 mm and diameter d_f = 0.55 mm. Density of steel fiber is 7900 kg/cum. The concrete was mixed using a laboratory pan-mixer, with mixing times ranging from 3 to 6 min. The nominal diameter and length of the glass fiber polymer are 22 mm and 914 mm respectively. The applied method for providing the glass fiber and carbon fiber concrete followed the method described by Liang *et al*. (2002) and Bontea *et al*. (2000) respectively. The samples were kept in water for 3 days (45°C) and then kept in 28°C for 25 days. After that the samples were transferred to test their resistance.

RESULTS AND DISCUSSION

Table 1 shows the obtained results for the resistance of each sample. According to the results, the resistance of the samples highly depends on the applied fibers. The samples containing steel fibers exhibit the highest resistance and were followed by samples containing carbon and glass fibers. The results also indicated that concrete with higher percentage of fiber had higher resistance to pressure.

Steel Fiber Reinforced Concrete (SFRC): Steel fiber reinforced concrete (SFRC) is a composite material made of hydraulic cements, water, fine and coarse aggregate and a dispersion of discontinuous, small fibers. It may also contain pozzolans and admixtures commonly used with conventional concrete. These fibers are distributed uniformly throughout the concrete matrix. The primary function of steel fibers is to modify micro and macro cracking. By intercepting cracks at their origin, the steel fibers inhibit crack growth.

The application of steel fiber concrete in civil construction are the most popular due to its improvement resistance to cracking, fatigue, abrasion, impact and conventional reinforced concrete. There are a number of different types of steel fibers with various commercial names. Steel fibers can be categorized into four groups based on the manufacturing process, including cut wire, slit sheet, melt extract and mill cut. FRC composite properties, such as crack resistance, reinforcement and increase in toughness are dependent on the mechanical properties of the fiber, bonding properties of the fiber and matrix, as well as the quantity and distribution within the matrix of the fibers [7]. FRC have different effects on concrete. In general, fibers do not increase the flexural strength of concrete and so cannot replace moment resisting or structural steel reinforcement. Some fibers

Table 1: Comparison between concrete containing steel, carbon and glass fibers.

Percentage	Weight	Fiber	Resistance (pressure = Mpa)
10	308	Steel	108
		Carbon	103
		Glass	102
20	308	Steel	231
		Carbon	224
		Glass	220
25	308	Steel	279
		Carbon	274
		Glass	271

actually reduce the strength of concrete. The quantity of fibers added to the concrete mix is expressed as a percentage of total volume of the composite, termed volume fraction (Vf), which ranges from 0.1 to 3% [7].

The advantages of steel fiber reinforced concrete are (a) fast and perfect mixable fibers and High performance (b) optimize costs with lower fiber dosages (c) steel fibers reinforced concrete against impact forces, thereby improving the toughness characteristics of hardened concrete and crack resistance (d) steel fibers reduce the permeability and water migration in concrete, which ensures protection of concrete due to the ill effects of moisture. Materials used in SFRC usually are cement (Ordinary Portland cement), fine aggregates, coarse aggregates, water (water should be free from acids, oils, alkalis, vegetables or other organic impurities), admixture, super plasticizers and steel fibers.

Carbon Fibers Reinforced Concrete (CFRC): Carbon fiber is formed by long chains of carbon atoms, created from precursor chemical compounds modified by chemical engineers for efficiency. Due to high useful property, carbon fibers find its way to concrete and civil engineering. One property, in particular, is its unparalleled strength to weight ratio. This strength comes from the very nature of the crystalline chemical bonds formed in the hot stretching process [8]. These patterns highlight the properties of the chemical bonds, making a super rigid, super light structure. Carbon fiber is, also, relatively flexible due to alignment of the composition of the atoms. This flexibility is, yet another, key property found crucial in the application of carbon fiber. Carbon fiber reinforced concrete, through the parts used to constitute the mixture, has certain properties that make it extremely useful to its use in construction [9].

The two processes for producing carbon fibers are based on different starting materials; either PAN (polyacrylonitrite) carbon fibers or petroleum and coal tar pitch. Both processes apply heat treatments and various grades of carbon fibers can be achieved with each, based on the combination of heat treatment, stretching and oxidation (Table 2). Concrete in itself is a highly sturdy material known for its ability to even strengthen over time. In addition to the permanence of concrete, it is extremely popular to add extra reinforcement throughout the relative center of structures in the form of reinforcing steel bars often referred to as rebar.

The supplement of small, lightweight carbon fibers adds increased electrical conductivity to the concrete. The fibers, with their small density and lightweight properties, will also make the weight of the entire structure that much lighter [10]. With the increased levels of conductivity of concrete structures, damage detection will be made much less invasive as previous methods. Carbon fiber reinforced cement composites have been considered as intrinsically stress/strain sensor for damage assessment [11]. This is due to the effect of strain on the electrical resistivity. The resistance in both stress direction and transverse direction increases on tension, because of slight fiber pull-out that accompanies crack opening and decreases upon compression, due to slight fiber push-in that accompanies crack closing [11]. This electromechanical phenomenon, called piezoresistivity (i.e. change of the electrical resistivity with strain), allows the use of electrical resistance measurement to monitor the strain of the cement-based material [11].

Table 2: Some properties of carbon fibers [12]

	PAN		
Property	Type 1	Type 2	Pitch
Diameter (μm)	7-9.7	7.6-8.6	18
Density (kg/m^3)	1950	1750	1600
Modulus of elasticity (GPa)	390	250	30-32
Tensile strength (MPa)	2200	2700	600-750
Elongation at break (%)	0.5	1	2-2.4
Coefficient of thermal expansion (10^{-6} / C°)	-0.5- -1.2 (parallel) 7-12 (radial)	-0.1- -0.5 (parallel) 7-12 (radial)	

According to the structural properties, carbon fibers compete with glass, polymer and steel fibers [11]. Carbon fibers (isotropic pitch based) are advantageous in their superior ability to increase the tensile strength of concrete, even though the tensile strength, modulus and ductility of the isotropic pitch based carbon fibers are low compared to most other fibers. Carbon fibers are also advantageous in the relative chemical inertness [10, 11]. According to functional properties, carbon fibers are electrically conducting, in contrast to glass and polymer fibers, which are not conducting. Steel fibers are conducting, but their typical diameter is much larger than the diameter of a typical carbon fiber. The combination of electrical conductivity and small diameter makes carbon fibers superior to the other fiber types in the area of strain sensing and electrical conduction. But, for providing thermoelectric composites, due to the high electron concentration in steel and the low hole concentration in carbon, carbon fibers are inferior to steel fibers.

Table 3: Some properties of glass fibers [15]

PROPERTY	GFRC Spray-Up	GFRC Premix
Dry density, kN/m^3 (pci)	19-21 (108-120)	19-20 (108-114)
Compression strength, MPa (psi)	50-80 (7252-11603)	40-60 (5802-8702)
Young's modulus (compression), GPa (psi)	10-20 (1450 $\times 10^{-3}$ to 2901 $\times 10^{-3}$)	
Impact strength, Nmm/mm^2 (pound inch/inch^2)	10-25 (57.1-1-1428)	8-14 (45.7-79.9)
Poisson ratio	0.24	0.24

Glass Fiber Reinforced Concrete (GFRC): Glass fiber-reinforced concrete (GFRC) consists basically of a cementitious matrix composed of cement, sand, water and admixtures, in which short length glass fibers are dispersed. Glass-fiber reinforced cement composites (GFRC) are produced by incorporating a small amount of alkali-resistant glass fiber in cement mortar to overcome the traditional weakness of inorganic cements, namely poor tensile strength and brittleness. The length and content of the glass fiber reinforcement can be chosen to meet the strength and toughness requirements of the product. Also, the type of aggregates can be varied in order to control thermal properties The effect of the fibers in this composite leads to an increase in the tension and impact strength of the material [13]. The lightweight characteristics and improved tensile strength of GFRC as compared with concrete led to its use as a structural material (Table 3). One advantage of these bars over steel is their resistance to corrosion. Although the bars do not corrode in contact with deicing chemicals, they can deteriorate rapidly in an alkaline environment [14].

Spray-up and premix are two main production techniques of GFRC [13]. In the first technique (spray-up), the mortar is produced separately from the fibers, which are mixed only at the jet of the spray gun. The glass fiber strands are cut within the spray gun to the required size, typically between 25 mm and 40 mm and are about 5% of the GFRC total weight [14]. The subsequent compressing with a cylindrical roll guarantees the adaptation of GFRC to the form, the impregnation of the fibers within the mortar, the removal of the air retained within the mix and an adequate density.

CONCLUSION

The applications of fiber reinforced concrete appear with an increasing frequency in the last decades because of their favorable properties compared to the cement based composites without any reinforcement. Therefore, the requirements to the exact knowledge of the properties of FRC are increasing rapidly.

Each type of fiber (steel, carbon and glass) has its special ability and property to be used for reinforcement of concrete. In this study the resistance of SFRC was higher than the CFRC and GFRC.

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