FEASIBILITY ANALYSIS - USING RECYCLED CARBON SHORT FIBRES FOR TRC

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Abstract

The short carbon fibers reinforced cementitious matrix composites were prepared. The mechanical properties of the materials were investigated. Recycled Short carbon fiber has recently gained popularity in concrete reinforcing applications due to its excellent mechanical properties. The aim of this research is to evaluate the flexural strength, compression strength and tensile strength in enhancing the mechanical behavior of concrete. Concrete specimens were cast with five different formulations of the same fiber. Interfacial properties were also investigated by scanning electron microscopy. A total of 156 specimens with short carbon fiber volume fraction ranging from 0.0% to 0.5% were tested.

Keywords: Recycled carbon fiber**,** Silica fume suspension, quartz powder, fly ash

1. INTRODUCTION

Carbon fibers show a succession of special properties of high strength, high modulus, high temperature resistance, corrosion resistance, fatigue resistance, creep resistance, light weight, and electric conduction [6]. Carbon fiber reinforced plastics (CFRP) is one of the most common composite material used in industrial fields, mainly the space industry, car industry, architecture and medical sectors etc [1], [2], [3], [9], [10]. The degree of their manufacture is rising. Earth filling of CFRP waste is the main problem. The increased use of carbon fiber reinforced plastics (CFRPs) also has generated an increasing amount of CFRP wastes [1], [2] [3].

According to statistics, the global market value for CFRPs was about 25 billion USD in 2013 and this value is expected to double in 2022, signifying a growth rate of over 7.6% per year [2]. Also, the same thing will happen to current commercial aircraft (the service life of 8500 commercial planes will end by 2025), withal each aircraft bring forth more than 20 tons of CFRPs wastes (Roberts, 2007) [2] [3]. According to the statistics, the world-wide demand for carbon fibers reached approximately 35,000 tons in 2008 and this number is expected to double in 2014, indicating a growth rate of over 12% per year [5]. The increasing requirement of carbon fiber has raised an environmental and economic awareness among researchers for the need to recycle the CFRP waste material in a suitable way [3] Because most of its waste is used as an earth filling, it is essential to conceive novel and useful methods for using recycled carbon fibers. Various techniques have been developed for obtaining recyclable carbon fibers from CFRP [1], [2]. The typical recycling methods could be classification into three systems: mechanical recycling, chemical process and thermal [2]. The main drivers for recycling of carbon fibers are the EU Directive on Landfill of Waste (Directive 99/31/EC). Therefore, land filling of composites is already prohibited in some countries of the European Union. The high price of carbon fiber is another motive to reduce production waste of these [4]. The current method of handling CFRP at their end-of-life has a negative impact on the environment as they are typically disposed of in landfills. With some 6000-8000 commercial planes expected to reach end-of-life dismantlement by 2030 [7], the environmental impact of the increasing use of CFRP will worsen. In an effort to mitigate this, legislation has been put in place [5]. In the CFRC composites, carbon fibers are beneficial in their superior ability to increase the mechanical and electrical properties of cement [6].

There are lots of factors affecting the properties of CFRC composites. Among them, the dispersion of carbon fibers in the cement matrix directly affects the mechanical properties and electrical properties. The improvement of mechanical properties can be observed in higher flexural toughness and strength, and tensile ductility and strength. Carbon-fiber-reinforced cement-based composites (CFRC) possess not only excellent mechanical properties, but also high conductive and electromagnetic performances. In recent years, CFRC have been extensively used as smart civil engineering materials for structural monitors, intelligent buildings and deicing or snow-melting pavements. However, carbon fibers tend to cluster during process of preparing the composites. Nowadays, pre-mixing method (carbon fibers were added before cement) and after-mixing method (carbon fibers were added after cement) are usually adopted to prepare carbon-fiber-reinforced cement-based composites. However, mixing methods of carbon fibers can evidently influence their dispersion in cement matrix.In order to make carbon fibers uniformly dispersed in the cement matrix, an appropriate amount of suitable dispersants and additives should be added in the preparation of CFRC composites. The dispersion is also enhanced by using silica fume (a fine particulate) as an admixture. The improved structural properties rendered by carbon fiber addition pertain to the increased tensile and flexible strengths, the increased tensile ductility and flexural toughness, the enhanced impact resistance, the reduced drying shrinkage and the improved freeze-thaw durability [6,7,8,9].

2. EXPERIMENTAL PROGRAMS

2.1. Materials

Type I Portland cement provided by dyckerhoff weiss Portland Cement, Germany was used in this study. The fine grade fly ash, provided by Blue Circle Company in Australia was used. The fine grade quartz powder, provided by sibelco benelux, Germany was used. Silica Fume provided by Ha-Be Middle East LLC was used in our experiment.The fine aggregate is natural river sand with 0, 2-0, 6 mm in diameter and a fineness modulus of 2.64.

Here only recycled carbon fiber was used which was collected from car industry having length ranges from 200 mm-500 mm and then cut into short form of length was 10 mm-40 mm (**Figure 1a**). The diameter of RCF is about 6-7 µm which was measured through optical microscopy (**Figure 1b**). The mixing content of the RCF was designed as 0%, 0.1%, 0.3% and 0.5% of the total volume of the mix. Physical and mechanical properties of the fibers are summarized in **Table 1**.

Figure 1(a) Short recycled carbon fiber

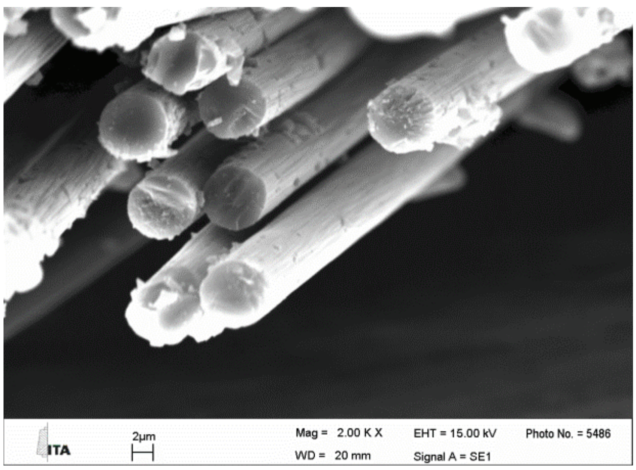

Figure 1(b) SEM of Chopped RCF

Table 1 Properties of recycled carbon fiber

Fibre variety	Length (mm)	Density (g/cm^3)	Modulus of elastic (GPa)	Tensile strength (MPa)	Elongation at break (%)	Water absorption
Recycled carbon fibre	10-40	0.91	4-9	400-700	7-9	<0.1

2.2. Mixing and curing

The mixing process started with the dry mixing of the Portland cement, fly ash, quartz powder and fine aggregates river sand for 5 min in one big bucket. Further, required amount of RCF were added into the dry mixture for another 1 min. Then, the wet mixing of the water, silica fume and super plasticizer Fliβmmitel for 1 min was taken in another bucket (**Figure 2**). At last, wet part was added slowly into dry part. The fresh concrete was mixed for 5 min to make sure still dispersion of fibers in the concrete. The mixture was used as Hand Electric Concrete Mixers Two Muddlers ZY-HM-160 of power 1600W with speed 0-690rpm/min. The fresh concrete was cast in 325 × 100 × 20 mm rectangular molds for flexural strength test and in 50×50×50 mm cubic molds for compressive strength test.

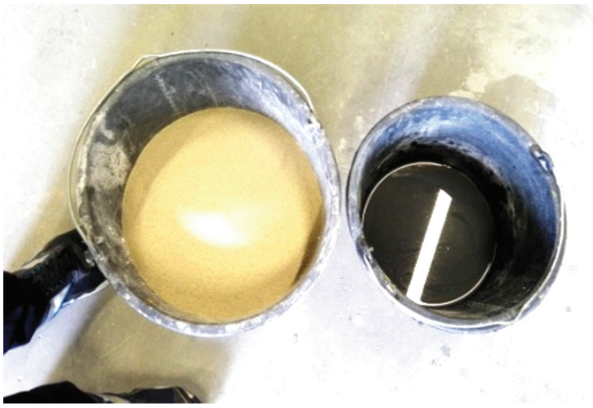

Figure 2 Dry mixture and Wet mixture

Figure 3 Tensile test specimens before cutting

For tensile strength test, the concrete paste was cast in the molds of dimension 275 mm×360 mm×9mm (**Figure 3**) and then each plate were cut into six specimens of exact dimension by sea saw diamond after 14 days of water curing of exact size 275 ×60 × 9 mm. After casting, specimens were cured at 20 °C in molds covered by a polyethylene film to prevent moisture loss. Then, the specimens were de-molded after 24 h and were moved to saturated clean water at 20 °C until the testing (after 14 days).

2.3. Testing methods

The compressive strength was tested according to Australian standard, AS 1012.9-1999 at 14 days, respectively. The splitting tension test was carried out at 28 days according to Australian Standard, AS 1012.10-2000. Flexural strength was carried out according to the Australian Standard, AS1012.11-1985. The flexural toughness of FRC was estimated based on the ASTM: C 1609. Flexural strength at 14 days was respectively tested through the four-point bending experiments conducted on the universal testing machine (Instron Model 8033). The span of flexural experiment was 225 mm. The load was applied by displacement control with a rate of 0.2 mm/min until the specimens failed. The load-displacement curve for each specimen was recorded automatically by data acquirement system

3. RESULT AND DISSCUSSION:

Physical Properties:

Table 2 shows that the water absorption, density and apparent porosity measurements use the immersion technique, based on ASTM C-948-81 (Standard test method for dry and wet bulk density, water absorption and apparent porosity of thin sections of glass-fiber Reinforced concrete) in which the specimens are immersed in water for twenty-four hours at room temperature by weighing the immersed mass Mi (with the sample into the water) and the wet mass Mu (removing Water and gently wipe the surface to remove excess water through a clean, dry cloth). After drying the samples for twenty four hours, carried out in an oven with air circulation, at 105ºC ± 5, the dry mass Ms is weighed. For determination of water absorption, density and apparent porosity, the following equations are used:

Water absorption (%w/w) = (saturated mass - dry mass) x 100 / dry mass

Bulk density (g.cm-3) = dry mass / (saturated mass - immersed mass)

Apparent void volume (%v/v) = (saturated mass - dry mass) x 100 / (saturated mass - immersed mass)

Table 2 Physical properties of TRC specimens

TREATMENTS	Water absorption AA (WA) (%)	Bulk density DA (BD) (g/cm^3)	Apparent void volume AVV (%)
0.0% RCF	9.474 ± 1.501	1.744 ± 0.063	16.447 ± 2.016
0.1% RCF	8.425 ± 0.794	1.814 ± 0.096	15.225 ± 0.835
0.3% RCF	6.423 ± 0.370	1.815 ± 0.054	11.662± 0.865
0.5% RCF	6.145 ± 0.432	1.832 ± 0.077	11.265 ± 0.932

Figure 4 shows that water absorption (%) decreasing with increasing bulk density.Bulk density of 0.1% RCF and 0.3% RCF specimens were not showing significant difference.

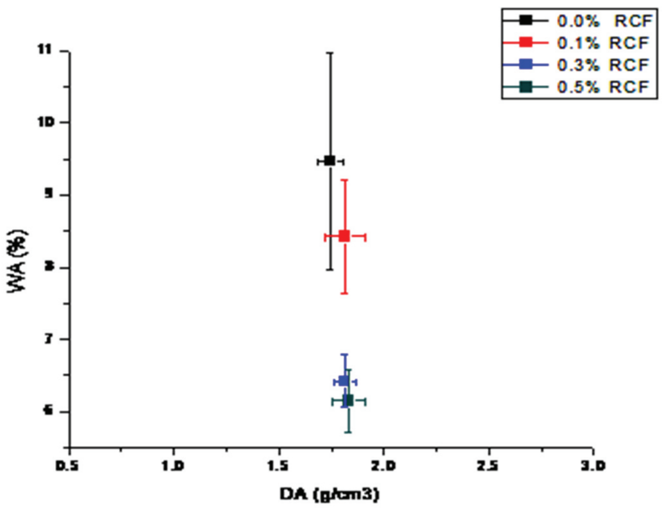

Figure 4 Water absorption(%) vs Bulk density(g/cm^3)

Microstructural Analysis

The fracture surface of the RCFRC samples after mechanical test was observed under a scanning electron microscope (JSM-6460) as shown in **Figure 5**. Clearly, carbon fibers were well distributed in the cement matrix as seen in **Figure 5. Figure 5** supplies another SEM image of the fracture surface of a RCFRC sample of good fiber dispersion. Clearly, both the bending strength and the tensile strength increase with the increasing fiber content as shown in **Figure 5**. Good fiber dispersion is not only beneficial to the mechanical properties of the composites, but to the electrical conductivity owing to the formation of conductive networks caused by the contact of carbon fibers one another [11]. Good dispersion of carbon fibers is not only beneficial to the mechanical properties but also to the electrical performances owing to the possible contact of carbon fibers one another, whereas the poor dispersion may exert negative influences on the mechanical and electrical properties of the composites. It is known that the rupture of the composites is closely related with the development of micro-cracks inside it. Adding carbon fibers into cement can stop the free expansion of cracks, which not enhances the compressive strength. So, it is essential for uniform dispersion of carbon fibers to achieve homogenized RCFRC composites [12,13].

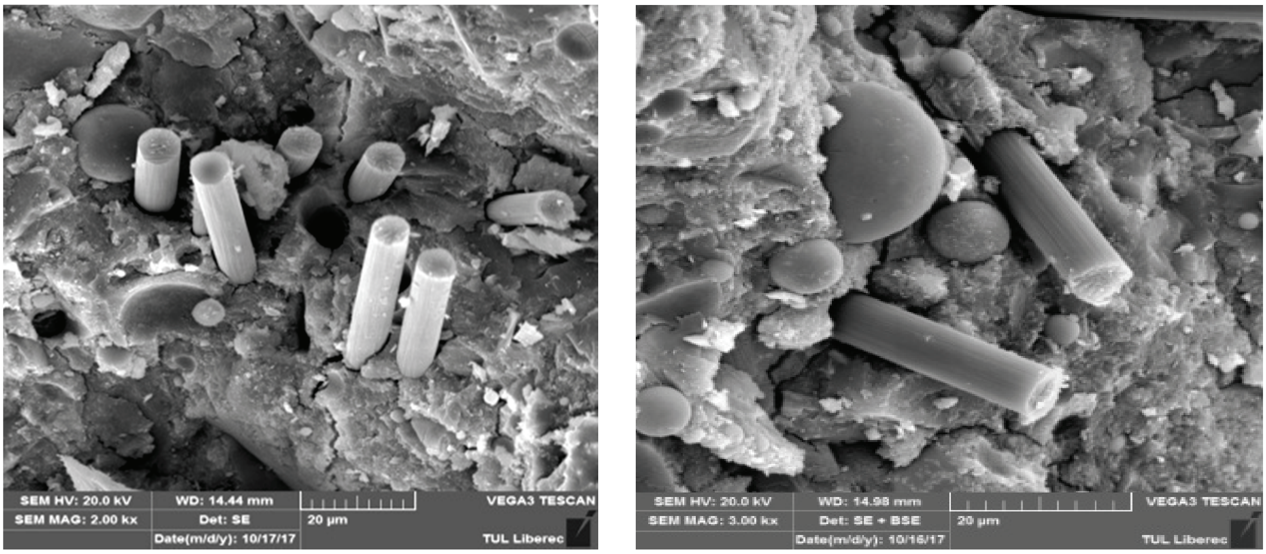

Figure 5 Microstructural analysis of fractured specimen

Mechanical Properties:

Figure 6 shows stress-strain curve. The flexural strength as a function of fiber mass fractions when carbon fibers are well dispersed in the cement matrix. Obviously, the flexural strength increased linearly with the increasing of mass fractions of carbon fibers. This is because carbon fibers have the function of strengthening and toughening, namely, reinforcement, which can prevent the formation and propagation of micro cracks in the cement matrix.

In **Figure 7**, the effect of carbon fibres on the tensile strength of concrete can be seen from stress-strain curve. The increased carbon fibres increased the tensile strength. For example, the 14 days tensile strength for Mixture M1 (0% carbon fibres), Mixture M2 (0.1% carbon fibres), Mixture M3 (0.3% carbon fibres) and Mixture M4 (0.5% carbon fibres) was 394.61N, 431.72 N, 490.47 N and 595.18N respectively.The increase in the tensile strength of concrete occurred because the increased percentage of carbon fibres reduced the crack growth and thus resulted in the failure at a higher load. Furthermore, the brittleness decreased significantly with the higher amount of carbon fibres, as noticed from the failure mode of the concrete specimens.

Figure 8 and 9 shows carbon fibers are not well dispersed in the cement matrix, the compressive strength decreases with the increasing fiber contents gradually. However, the strength does not always keep increasing as the fiber content rises. When carbon fibers are used in excessive amount (over 0.5 wt% by mass of cement in this work), they are likely to fasciculate.

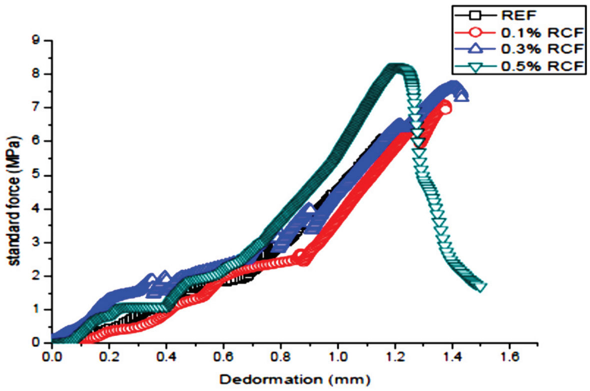

Figure 6 Standars force vs Spesific deformation(mm)

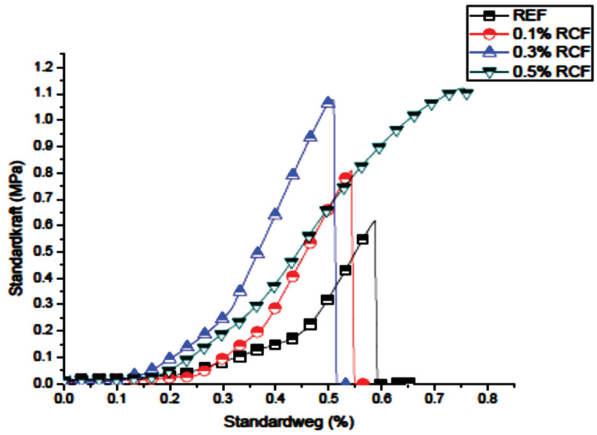

Figure 7 Tensile stress(MPa) vs Strain(%)

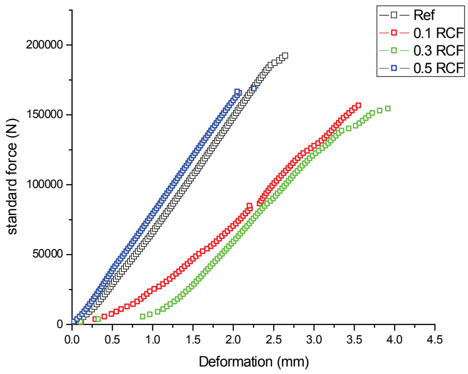

Figure 8 Standard Force (N) vs Deformation(mm)

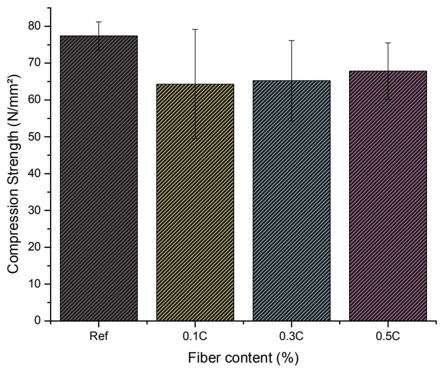

Figure 9 Compression strength v Fiber content (%)

CONCLUSION

- The mechanical properties of the RCFRC composites increase with the increasing fiber contents.The compressive strength has been decreased by addition with fiber.
- Recycled Carbon fibres increased the tensile strength because they bridged the crack opening and thus contributed to take additional load until failure.
- Scanning electron micrographs of the fractured concrete specimens revealed that recycled carbon fibres were distributed in FRC. However, many carbon fibres came very close to each other and the congestion of fibres occurred for the concretes with high fibre content
- From physical tests confirmed that WA(%) are decreased when Bulk densities of FRC are increased.

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