INFLUENCE OF FLY ASH AND DENSIFIED SILICA FUME AS ADDITIVES ON MECHANICAL PROPERTIES OF COIR FIBER REINFORCED HIGH-STRENGTH CONCRETE

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ABSTRACT

This paper presents the experimental investigation carried out to determine the mechanical properties of coir fibre reinforced high strength concrete of grade M50 incorporating fly ash (FA) and densified silica fume (DSF). Three different compositions of coir fiber reinforced concrete (CFRC) were made. First CFRC without additives, second CFRC made by 10% replacement of cement mass with FA, in the third composition 10% of cement mass was replaced with DSF. In each mentioned admixture, coir was added in its natural length by 0.4% of the binder volume. The mechanical properties viz., compressive strength, flexural tensile strength, density and elasticity modulus of all mixes has been determined. The investigations revealed that adding coir fibres to high strength concrete caused a slight reduction in density and compressive strength of concrete by about 1.5 and 1.2% respectively. However, it improved the flexural tensile strength and dynamic elasticity modulus by 4 and 9%. Improvement of ductility in presence of coir has been proven through direct observation and experiment. Coir fiber reinforced concrete contains FA presented the highest strength compared to other mixes with about 8% higher strength compared to control concrete. It also presented the highest quality through sonic investigation followed by CFRC without additive and CFRC incorporating 10% DSF.

KEYWORDS: *High Strength Concrete; Coir Fibre; Densified Silica Fume; Fly Ash; Compressive Strength; Flexural Strength; Young Modulus*

I. INTRODUCTION

High strength concretes (HSC) has been extensively used in construction industry in recent years since most of the rheological and mechanical characteristics of these materials are better than those of normal strength concretes (NSC). HSC contains chemical admixtures, for water reduction, and having a compressive strength between 50 and 80 MPa.

Almost all these concretes have mineral additives involve for a variety of reasons including strength improvement, reduction of permeability, higher crack resistance and durability factors. Some pozzolans such as silica fume (SF) and fly ash (FA) have a significant potential in this context [1]. Advantageous incorporation of SF through pozzolanic reaction and micro-filler properties in HSC has been reported by some researchers [2-5]. Similarly, FA characteristic as a partial cement replacement has been investigated by different authors [5-7] and it is concluded that in addition to many environmental benefits, it also improves the properties and quality of HSC. However, as strength and softness are inversely proportional, HSC is more brittle than NSC and has some poor performances in case of ductility. As a result, it is essential for this type of concrete to be reinforced [8,9]. Since, steel reinforced concrete has a short lifecycle due to the corrosion of the steel and it requires to be repaired continuously [10], adding fibres in the composite is efficient in order to overcome these problems and improving the toughness, tensile strength and deformation characteristics of the concrete, mainly due to their excellent properties and low cost. Among different types of fibres, natural fibres are renewable, non-hazardous, economic, abundant and are a proper replacement of asbestos [11]. Coir is a kind of natural fibre which is abundantly available in tropical areas, moreover it is tough and durable, provide excellent insulation against temperature and sound and is unaffected by moisture [12,13]. The achieved results of all the researches on the effect of coir on concrete properties [14,15,16,] have presented that coir fibre improves the mechanical properties of concrete. However, the number of these studies is very few [17] and also there are no enough standards and reliable information available about the mechanical properties of HSC incorporating pozzolans and coir fiber in a combination.

Thus, this paper aims to investigate the mechanical behavior of coir fiber reinforced high strength concretes contain FA and DSF. Compressive strength, flexural strength, density and elasticity modulus characteristics of all series will be experiment. Experimental results of different compositions of coir reinforced concretes will be compared to those of plain concrete made by ordinary Portland cement CEM1, to illustrate the effect of coir and pozzolans on concrete properties.
This paper is organized with a brief problem formulation in section 2. Section 3 introduces the material proportion and mix design employed in this investigation. Section 4 and 5 presents the experimental results and comprehensive discussion of the findings obtained from this study and conclusion respectively.

II. PROBLEM FORMULATION

Conventional reinforced concrete uses steel rebars to increase the strength and ductility. Nevertheless, steel reinforcement is still costly in all countries throughout the world. In order to overcome the complexity, cost-effective but safe constructional material is required. Natural fibres can be one possible material, as they are economical and locally available in many countries. In this work, fly ash (FA) and densified silica fume (DSF) are employed in coir fibre reinforced high-strength concrete.

III. MATERIAL PROPORTION AND MIX DESIGN

Type I ordinary Portland cement, produced by CIMA which is packed under the brand name "Blue Lion Cement" was used. The fine aggregates were locally sourced quartzitic natural river sand in uncrushed form with the fineness modulus of 3.26, specific gravity of 2.83 and a maximum aggregate size of 5 mm and the coarse aggregate was crushed gravel passed through 10 mm sieve. The DSF used was a product of SCANCEM materials in Singapore with the specific gravity of 2.28, a median particle size of 28.21 µm and specific surface area of 0.2170 m²/g. This product complies with ASTM C1240-03a and AS3582.3 1994. Class F fly ash is designated in ASTM C 618 and originates from burning harder, older anthracite and bituminous coal. The medium particle size of used fly ash in this research was 26.68 micrometer with the specific gravity of 2.25. The chemical compositions of CEM1, SF and FA are presented in Table 1.

Table 1. Chemical compositions of Portland cement, FA and DSF.

% by total mass			
Chemical compound	Portland cement	Fly ash	Densified silica fume
Mgo	1.50	2.21	4.60
Al2O3	3.60	26.43	0.27
SiO2	16.00	46.25	84.00
SO3	3.10	1.85	0.44
K2O	0.34	3.07	2.70
CaO	72.00	7.61	0.66
Fe2O3	2.90	10.71	0.54
Na2O	n/d	1.11	4.20

Natural coir fibre without cutting to specific length has been added to all admixtures. The measured average length of the added coir fibre in mixes was 10cm. Type F superplasticizer of sulfonated melamine formaldehyde condensates category was used by 0.2% of binding weights to keep a constant level of workability and to produce the designated slump of 30mm. The potable water from local water supply network was used as the mixing water. Table 2 shows the mixture proportions of concrete mixes. Control concrete (control) mix containing only Portland cement type I as cementitious materials and without coir fiber reinforcement was manufactured. Coir fiber reinforced concrete (CFRC) was also made by ordinary Portland cement CEM1 to specifically present the effect of coir on HSC, in two other mixes coir fibre reinforced high strength concrete made by 10% replacement of cement mass with FA, and DSF respectively.

3.1. Preparation of Samples

The dry constituents were mixed together properly then superplasticizer, water and finally fibres were added to the mix. The concrete samples made by casting fresh concrete into the moulds in three layers and each layer was compacted using a vibrating table for 15 second. 24 hours after casting samples were demoulded and specific code of each admixture was written on the surface of each sample.
Then, samples were immersed in normal potable water continuously until the date of testing. Density, compressive and flexural tensile strength tests of concretes were carried out at the ages of 7 and 28 days and elasticity modulus test and sonic investigation were conducted at 28days.

Table 2. Mixture proportions.

Symbol	Mix proportion (kg/m³)				
	Cement	Sand	Gravel	DSF	FA
Control	495	689.0	1033	-	-
CFRC*	495	689.0	1033	-	-
CFR DSFC*	445.5	689.0	1033	49.5	-
CFR FAC*	445.5	689.0	1033	-	49.5

**Coir was added by 0.4% of the binder volume.*

3.2. Test Set-up

Each sample was weighted before testing and samples density was recorded in units of grams per cubic centimetre (g/cm^3). Having this information was necessary to find the density of the concrete in different ages in order to determine how compact one substance is compared to another. The balances used, determined the mass of samples to an accuracy of 0.1% suggested by British Standard.
Cubes with 100x100x100 mm³ dimensions were experimented for compression in ages of 7 and 28 days. For each day, three specimens were tested in order to find an accurate average. The specimens were loaded at a rate of 150 kN/min. Flexural strength test performed on prisms of height (h) 100 mm, width (w) 100 mm and length L (l) 500 mm dimensions, according to BS EN 12390-5:2009, using the Universal Testing Machine. The average of two values was taken to define flexural strength of that particular type of specimen.
The dynamic elasticity modulus of concrete was determined non-destructively using resonance tests as prescribed in ASTM C215 and C-666. Two prisms with 100x100x500 mm³ dimensions were tested from each composite at the age of 28days. This testing method was carried out using an E-Meter MK II™ based upon the determination of the fundamental resonant frequency of vibration of a specimen generated by an impact and sensed by an accelerometer. The frequency spectrum was computed and displayed by the meter.
Sonic investigations were carried out in direct method by employing the Portable Ultrasonic Non-destructive Digital Indicating Tester (PUNDIT) to estimate amount of cavities, cracks and defects in CFRCs. The pulse velocity in a concrete depends on its density and its elastic properties which in turn are related to the quality and the compressive strength of the concrete.

Table 3. Test results and characteristics of hardened concrete

No	Mix Reference	Compressive strength (Mpa)		Flexural strength (Mpa)		Density (kN/m³)		28-Day dynamic modulus of elasticity (Gpa)	28-Day ultrasonic pulse velocity (km/s)
		7 Day	28 Day	7 Day	28 Day	7 Day	28 Day		
1	Control	47.3	52.5	5.2	5.8	24.7	25.1	40.8	-
2	CFRC	46.9	51.7	5.7	6.3	24.3	24.8	42.6	43.8
3	CFR DSFC	44.1	50.5	5.5	6.2	23.4	24.1	41.1	42.9
4	CFR FAC	48.3	56.6	5.3	7.1	23.9	24.3	44.4	44.2

IV. RESULTS AND DISCUSSION

The experimental results of all conducted tests on the four composites are presented in Table 3 and are analyzed in following sections.

4.1 Compressive Strength

Figure 1 shows the compressive strength of different mixes at the age of 7-day and 28-day. Considering the results shown in Figure 1, for all series, the compressive strength increased with ages. Incorporation of coir fibers in concrete caused a minor reduction in its compressive strength capability. However, a significant improvement in the strength of coir fiber reinforced concrete with 10% cement replacement with FA could be observed. Compressive strength of coir fiber reinforced concrete incorporating DSF was slightly lower compared to that of coir fiber reinforced concrete without additive.

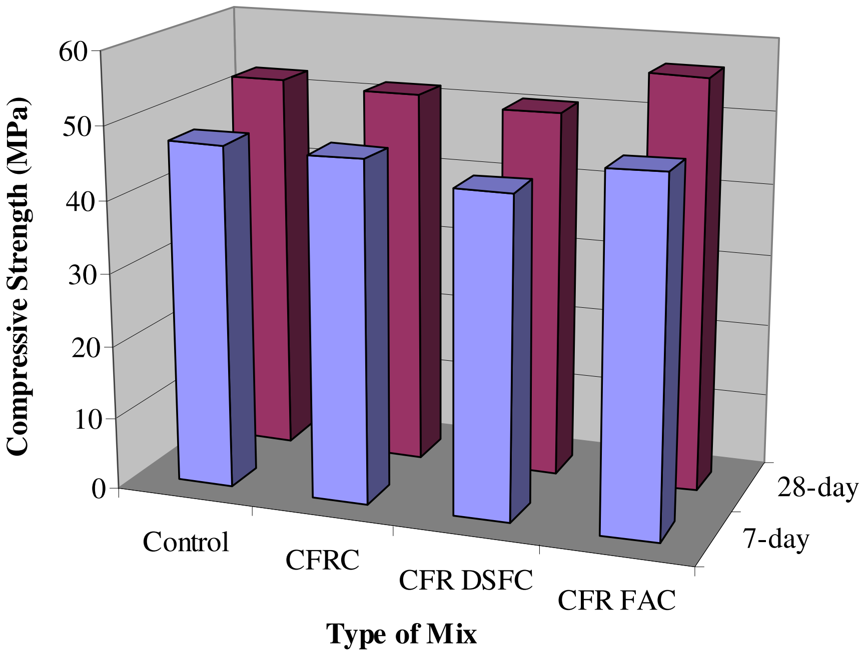

Figure 1. Compressive strength of different mixes at 7-day and 28-day

a. Coir Fibre Reinforced Concrete (CFRC)

Compressive strength of CFRC was 1.5% lower compared to that of control concrete at the age of 28 days. Coir fibres reduced compressive strength of concrete by increasing voids content due to lower efficiency in concrete compaction. Existence of the polar groups in coir caused inefficient bonding between coir and the hydrophobic matrix, since a dry coir fibre uptakes large amount of moisture content and reduced wettability in concrete mixture. Furthermore, there is possibility for fibres -especially long fibres- to be folded and folded fibres cannot be connected with unfolded fibres properly [18] and a weak bond between those portions of fibre will eventually lead to reduction in composite strength. Interconnected of these fibres may also reduce the strength of concrete. Thus, since there is no attachment exists among fibres and they are not bonded with matrix sufficiently, failure occurs before reaching the designated strength of composite.

b. Coir Fibre Reinforced Fly Ash Concrete(CFR FAC)

Compressive strength of CFR FAC was about 8% higher compared to control concrete. As mentioned earlier, addition of coir increased voids content in concrete leading to reduction of compressive strength. FA used in this research consists of particles with 2.2 kg/m³ relative density which is a more efficient void-filler than Portland cement with relative density of 3.15 kg/m³. Spherical shape of FA particles also, allowed them to flow freely in mixtures and fill the forms more completely during vibration.

Furthermore, in alumino-siliceous pozzolans such as fly ash, both silica and alumina react with calcium hydroxide -which is a potential site of weakness in the cement paste- and produces additional calcium silicate hydrate and various calcium-aluminate hydrates and calcium alumino- silicate hydrates leading to an additional reduction in capillary porosity during hydration [19-21]. This reaction leads to higher rate of strength gain in time, enabling coir reinforced fly ash concrete to produce considerably higher ultimate strength compared to control plain concrete.

c. Coir Fibre Reinforced Densified Silica Fume Concrete (CFR DSFC)

Compressive strength of CFR DSFC at the age of 28 days was about 3.8% and 2.3% lower compared to control concrete and CFRC respectively. Normally, a fresh un-densified SF has particle in the size range of about 0.03-0.3 µm. However, in densification process of SF progressive entanglement of clusters of SF particles occurs during tumbling action, which results in formation of dense agglomerates [22] so that the median particle size of DSF used in this research was 28.21 µm which is much coarser than cement particles with median particle size of 3.19 µm. Such alteration in particle size of SF has adverse effects on its micro filler action in concrete and rate of secondary hydration between SF particles with portlandite produced from primary hydration of cement [23].

In hydration process, presence of the relatively big pozzolanic particles (>10 µm) decelerate the reaction between lime and silica and most of the gels will be produced after the hardening of the cement, resulting in possible disastrous pressure build-up and a slow destruction of the concrete. As a result, the proper measures should be taken to disperse SF agglomeration to make it more effective on improving the properties of materials.

4.2 Flexural tensile strength

Figure 2 demonstrates the flexural strength of different mixes at the age of 7-day and 28-day. Comparing to control concrete, the flexural tensile strength of CFRC, CFR DSFC, CFR FAC improved by about 9%, 7%, and 23% respectively. Cement matrix has the important function of transferring applied load to the fibres along with keeping the fibres together. The capability of a fibre reinforced concrete depends on the fibre-matrix interface and the ability to transfer stress from the matrix to the fibre. Discontinuous fibres are randomly distributed throughout the cement paste to delay and control the tensile cracking of concrete. Fibres transform inherent unstable tensile crack propagation to a slow controlled crack growth. This crack controlling property of fibre reinforcement delays the initiation of flexural and shears cracking and increase the flexural strength. Fibres get hold of giving additional tensile strength and extensibility in concrete under flexural loading so that the matrix will no longer lose its load-carrying capacity at first crack.

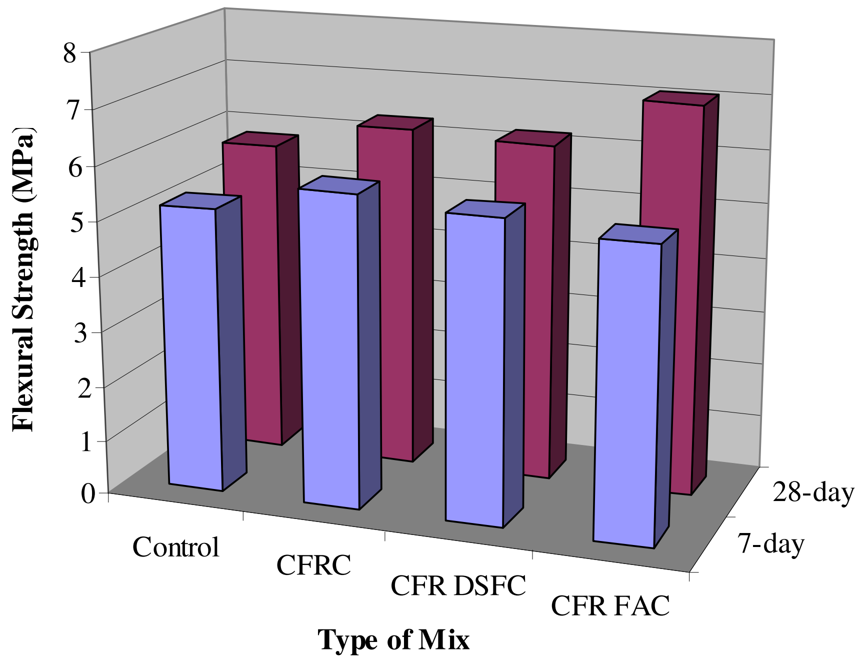

Figure 2. Flexural strength of different mixes at 7-day and 28-day

4.3 Modulus of Elasticity

Figure 3 illustrates the modulus of elasticity of different mixes at the age of 28-day. Comparing to the PHSC, the dynamic elasticity modulus of CFRC, CFR DSFC and CFR FAC improved by about 4%, 1%, and 9% respectively. Among the factors affecting modulus of elasticity of concrete, moisture condition plays an important role.

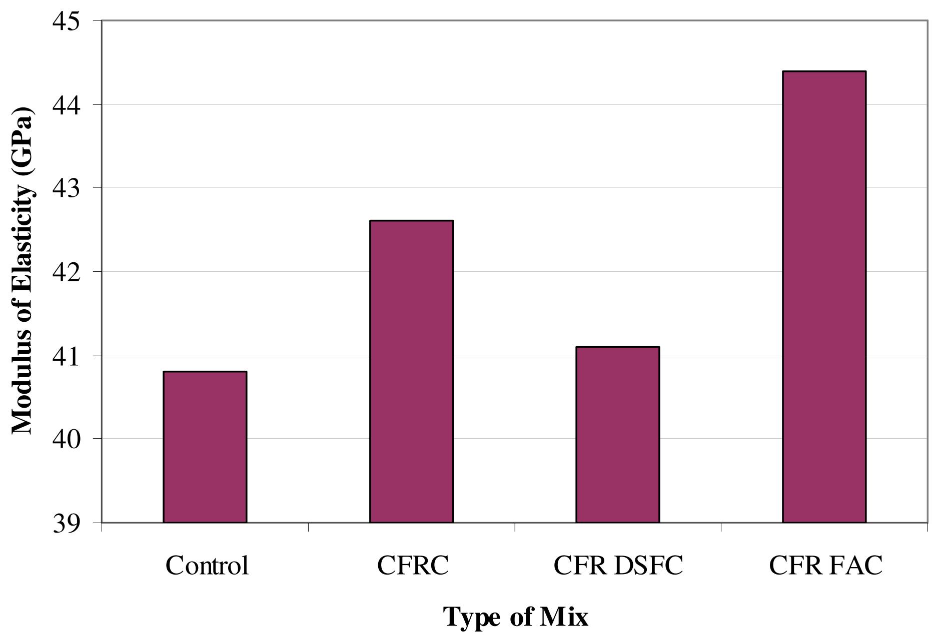

Figure 3. Flexural strength of different mixes at 7-day and 28-day

Moist curing of the specimen until testing time reduced drying and increased elasticity modulus of concretes as drying produces more micro cracks in the transition zone, which affects the stress-strain behavior of the concrete. Coir fibre also decrease the micro cracks in the transition and plays a major role in affecting the stress-strain behavior of concrete since the transition zone characteristics affect the elastic modulus more than it affects the compressive strength of concrete.

4.4 Density

Density measurements of 7, 14 and 28 days of four admixtures are presented in Table 4.7 which are achieved by weighting cubes and prisms before compression and flexural testing. For all series it was observed that, density of concrete was slightly increased over the age. Densities of the four admixtures are in the range of 2400-2600 kg/m³ which are above the considered range for conventional concrete. It is vital to achieve a maximum possible density because a high density stops the water vapor inside the concrete from escaping out of the concrete mass.
There was a slight reduction in the density of CFR FAC and CFR DSFC compared to CFRC because FA and DSF have a lower specific gravity compared to cement. Specific gravity of FA and DSF are 2.25 and 2.2 respectively, which are somewhat lighter than Portland cement with a specific gravity of 3.15. Thus, adding this pozzolans to a concrete mixture will not densify the concrete. Contribution of coir fibre also decreased concrete density by about 1.2% since presence of voids in concrete reduces the density and strength. This needs an adequate workability for a perfect compaction offer a reasonable amount of work under the given conditions.

4.5 Ductility

When plain concrete cubes were subjected to compressive strength, small initial cracks formed on the surface of samples. Cracks progress fast and extend followed by crashing and blasting to failure. Failure occurs suddenly once the ultimate compressive load was achieved. However, when CFRC samples were subjected to the compressive loads specimen seems still unbroken even when ultimate loading and failure occurred. Figure 4 shows the test specimens after compression test. This observation proves that brittle failure of control was transformed to relatively ductile failure with the presence of coir fibre.

(a) PHSC Sample (b) CFRC Sample

Figure 4. Samples shape after failure

4.6 Ultrasonic pulse velocity (UPV)

Among all specimens, CFR FAC obtained the highest UPV at 28 days. It was higher than UPV of the CFRC about 1% and the lowest UPV was attained by CFR DSFC that was lower than that of CFR HSC about 2%. It signified that the FA series specimens might have more compacted microstructures than DSF series specimens. Concrete with less porosity has higher strength and higher UPV since the presence of void on the path will increase the path length as it goes around the void. UPV of CFRC, CFR DSFC and CFR FAC were between 4.2 and 4.5 km/s. Therefore, according to IS: 13311 Part 1, they were classified as sound concrete with desirable quality.

V. CONCLUSIONS

When coir fiber is added to concrete and part of the Portland cement is replaced by fly ash or densified silica fume, each of these additives acts in a different but co-operative way, depends upon their chemical or physical characteristic. Incorporation of natural coir fibers causes about 1-2% reduction in ultimate compressive strength of high strength concrete, this may be due to lowering the quality of compaction in presence of coir and increasing the porosity. Compressive strength of CFR FAC was about 8% higher compared to control concrete as FA with its spherical particle shape and its lower relative density than ordinary Portland cement is a better void filler. It also reduces concrete voids and porosity through contribution of both silica and alumina in hydration process and improve concrete strength additionally. Besides, introduction of coir in mix, improves the flexural tensile strength of CFRC, CFR DSFC, CFR FAC by about 9%, 7%, and 23% respectively. It should be pointed out that reduction of micro cracks, significantly affects the stress-strain characteristic of concrete so that comparing to the control concrete, the dynamic elasticity modulus of CFRC, CFR DSFC and CFR FAC improved by about 4%, 1%, and 9% respectively. Densities of CFR FAC and CFR DSFC are slightly lower compared to CFRC because FA and DSF have a lower specific gravity compared to cement. Coir also causes reduction in concrete density by increasing concrete voids content.

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