Review on Hybrid Fiber Reinforced High Performance High Volume Flyash Concrete

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***Abstract*—This paper presents a review on the high performance high volume flyash concrete reinforced with hybrid fibers. It is well known that manufacturing of one ton of Ordinary Portland Cement (OPC) absorbs about 4GJ energy and produces about 750kg to 1000 kg of CO_2 to the aerosphere and is claimed to affect ozone layers and lead to global warming. Researchers have tried to substitute fly ash for cement which generally leads to lower strength. Fibers in general have been used in recent years, mainly to toughen and strengthen the concrete matrices and to enhance the shrinkage cracking resistance. However, more research is required on the mechanical and durability properties of high performance high volume flyash concrete reinforced with hybrid fibers, as very little research or experimental work is reported in the literature. This paper investigates the provision of three different fibers; steel, polypropylene and basalt in individual and in hybrid form. Analysis shows that performance enhancement can be obtained by using fibers in hybrid form.**

***Index Terms*—high performance high volume flyash concrete, steel fiber, polypropylene fiber, basalt fiber, hybrid fibers, high volume flyash concrete**

I. Introduction

Concrete in general and high performance concrete in particular is quasi brittle. Flyash in Ordinary Portland Cement concrete, it is normally accepted that the lime liberated by the hydrating cement reacts with the finely splitted silica in the flyash to the formation of C-S-H gel with the advantages of concrete workability, reduction in the water demand in concrete.

Fly ash is used as supplementary cementitious materials in concrete not only improves the mechanical properties of concrete and also reduce the cement consumption by replacing part of cement with these pozzolanic materials [1]. As the cement content in the concrete mixture increases, hydration product will also increase and hence the amount of $Ca(OH)_2$ with which the fly ash will enter into reaction will increase, then an increased amount of C–S–H will result, so the flyash will be used more efficiently and as well as acts as a binder in both fresh and hardened concrete [2]. Thomas stated that fibres reinforce a matrix by improving its stiffness or by holding the matrix together after it has cracked, or by a combination of both these mechanisms [3].

Manuscript received June 29, 2015; revised October 24, 2015.

The conception of high performance concrete was formulated in the early 80's. Based on the data of Japanese scientists, the expected life circle of HPC can be up to 500 years. Volume stability, high attrition resistance, high chemical resistance, high strength, low absorption, high durability and good workability are normal features of high performance concrete [4]. High performance fiber reinforced cement composites are more sensitive to the loading rate than conventional concrete as their strength gain is higher for increasing strain rates than for normal concrete [5], [6].

Mechanical behaviors of steel fiber reinforced high-performance concrete with fly ash is significantly improved. The failure mode of concrete considerably changes from brittle to ductile with the addition of steel fibers. Strain rate has great influence on concrete strength and toughness energy is proportional to the fiber content in both static and dynamic compressions [7]. The addition of polypropylene fibres to high-performance concrete is one way to avoid spalling of concrete under fire conditions [8]. Super plasticizer is used to achieve good workability which is used as chemical admixture in high performance high volume ultra-fine flyash concrete [9].

Nowadays, Researchers use steel fibers, polypropylene fibers and basalt fibers in concrete as it improves the strength in concrete. In order to contribute to a reduction of use of cement worldwide, industry wastages like flyash have been initiated by researchers to replace OPC in the concrete, so it is proposed that the flyash could be a potential replacement for ordinary portland cement producing high volume flyash concrete with the use of steel fibers, polypropylene fibers and basalt fibers in hybrid form in order to improve the ultimate strength characteristics of hybrid fiber reinforced high performance high volume flyash concrete.

A. Fibers in Concrete

To make the concrete ductile, different kinds of fibers may be used as secondary reinforcement. As the concrete is weak in tension, to inhibit crack initiation and propagation and to increase the tensile strength and ductility of concrete, fibers are used in concrete.

B. Hybrid Fiber Reinforced Concrete (HFRC)

It is a type of fiber reinforced concrete characterized by its composition and also known to the interaction and/or co-operation of the two or more fibers that acts as a secondary reinforcement in the concrete in which

doi: 10.18178/ijscer.5.1.39-43

synergy effect is implemented to produce a combined effect.

The following section present the review of fibers, flyash used in the concrete.

II. Review of Literature

A. Characteristics of High Volume Flyash Concrete

Class F fly ash may replace 50% of the portland cement and could result in improving resistance to chloride initiated corrosion but such replacement however, may significantly reduce the values of the mechanical properties, such concrete is considered a high performance concrete [10].

In addition to the low heat of hydration and low cement content which makes it suitable for mass concrete structures, high volume flyash concrete has considerable potential for application in concrete construction and the use of high volume class F flyash together with ordinary portland cement content has produced favorable results as far as strength and durability are concerned [11]. 80% of Class F flyash can be suitably used as cement replacement in concrete by using a rational mixture proportions. The compressive and flexural strength of the high volume flyash concrete mixtures demonstrated continuous and significant improvement at late ages of 91 and 365 days [12].

The use of high volume class F fly ash as a partial replacement of cement in concrete decreased its compressive strength, splitting tensile strength, and flexural strength, modulus of elasticity, and abrasion resistance of the concrete [13]. High-performance concrete with moderate and high strength and low temperature rise could be produced using high volumes of fly ash as cement replacement resulting in a reduction in the maximum temperature rise and increasing the replacement level of fly ash caused lower temperature rise in concrete [14].

Important accomplishment of the use of fly ash through the partial substitution of cement in concrete is the improvement of mechanical properties with enhanced durability performance when compared to the strength of ordinary portland cement concrete.

B. Effect of Fibers in Ordinary Portland Cement Concrete

Fibers can be disruptive to a brittle concrete composite that are of high modulus and relatively stiff [15]. Fiber reinforcement increases the onset of flexural cracking and increasing the post-cracking properties of ductility, tensile strain capability and energy absorption capacity [16].

C. Effect of Steel Fiber in High Performance Concrete

Behaviors of high performance steel fiber reinforced concrete to resist impact was much better than that of reinforced high strength concrete [17]. Addition of crimped steel-fibers to concrete increases the toughness considerably [18] and lead to slight decrease in the compressive strength of concrete [19].

The equivalent bond strength of straight steel fibers, which are commonly used in ultra-high performance fiber reinforced concrete, can be doubled by optimizing the ultra-high performance concrete matrix through composition and particle size distribution, leading to typical pullout load slip hardening behavior which is desirable for high tensile strength, high energy absorbing and strain hardening of concrete [20].

The steel fiber which has the ability to bond well throughout the concrete and can withstand more stiffness.

D. Effect of Polypropylene Fiber in the Concrete

Addition of polypropylene fiber has greatly improved the durability of the concrete composite containing fly ash and silica fume but has a little adverse effect on the workability of concrete composite containing fly ash and silica fume. In addition water permeability, the dry shrinkage strain and the carbonation depth of concrete containing fly ash and silica fume decrease gradually with the increase of fiber volume fraction [21].

Being the member of polymer fibers, polypropylene fiber captivated the most recognition among the academic experimenters and researchers because of its enhanced shrinkage cracking resistance, low cost and its excellent toughness in the concrete [22]-[26]. Polypropylene fibers improves the failure impact resistance of concrete and were observed to have no statistically significant effects on compressive or flexural strength of concrete, while flexural toughness and impact resistance showed an increase in the presence of polypropylene fibers in the concrete [23], [27]. A large number of polypropylene fibers distributing uniformly in the concrete composite can form a grid structure, which has supporting effect on the aggregate and decrease bleeding and segregation of the fresh concrete mixture [28].

Concrete durability is the most significant property, apart from the mechanical properties as the concrete failure is mainly due to durability failures. In initial phase of concrete cracking, polypropylene fiber intercepts the expansion and micro cracks in concrete. When the tensile stress disintegrates the structure, the stress may be carried to the polypropylene fiber, which has high young's modulus and therefore may arrest the propagation of macro cracks and may significantly improve the tensile strength.

E. Effect of Individual Fibers in High Volume Flyash Concrete

Kayali found that fiber reinforced concrete that included high volume fly ash concrete achieved compressive strength and tensile strength values that are more than double those of concrete without fly ash. Polypropylene fibers resulted in gains up to 50% while steel fiber achieved gains up to more than 100% where this enhancement is believed to be due to the microstructural modification and densification in the transition zone between the matrix and the fibers [29].

The use of ultra-fine fly ash and the use of lime water respectively become important factors to increase compressive strength of high volume fly ash concrete. Moreover the use of basalt fibre decreases the

compressive strength of concrete due to its lower volumetric stability in alkali environment [30].

F. Effect of Basalt Fiber in the Concrete

The addition of basalt fiber can significantly improve deformation and energy absorption properties, while there is no notable enhancement in dynamic compressive strength [31]. Addition of basalt fibers up to 2% fiber volume together with mineral admixtures improved the compressive strength and the improvement in the strains corresponding to maximum compressive strength [32]. The basalt fiber significantly improves the tensile strength, flexural strength and toughness index, whereas the compressive strength shows no obvious increase [33].

Nihat stated that degradation of basalt fiber in concrete can be found under microstructure analysis showing that basalt fiber changes into small parts which are different from its original form. Steel fiber is better as a strengthening material in high volume flyash concrete but the addition of basalt fiber resulted in decrease in compressive strength as the fracture energy and flexural strength on the other hand improved with the addition of basalt fiber. As the basalt fiber content increased, the concretes showed higher ultimate loads, larger deflections before failure and higher fracture energy values [34].

The basalt fiber strengthening improved both the yielding and the ultimate strength up to 27% and the basalt fiber strengthening will be a good alternative methodology among other fiber reinforced polymer strengthening systems [35] and these fibers are more efficient in strengthening and toughening the geo-polymeric concretes than ordinary portland cement concretes only for higher fiber CONCENTRATIONS and this difference in behavior is probably related to the nature of the bond between fiber and matrix [36]. So the basalt fiber can improve the energy absorption properties, toughness index and flexural strength in the concrete.

G. Effect of Polypropylene Fiber and Flyash in the Concrete

A certain content of fine particles such as fly ash is necessary to evenly disperse the hybrid fibers containing polypropylene fibers. The micromechanical feature of crack bridging is operative from early stages of damage evolution to beyond ultimate loading [22].

Presence of fly ash and polypropylene fiber in concrete regardless of separately or together reduces drying shrinkage. The influence of polypropylene fiber in flyash concrete is found to be insignificant on compressive strength. Polypropylene fiber decreases the workability of the concrete but, polypropylene fiber addition, either into portland cement concrete or fly ash CONCRETE, did not improve the compressive strength but the positive interactions between polypropylene fibers and fly ash lead to the lowest drying shrinkage of fibrous concrete with fly ash as it increased the freeze–thaw resistance more than only the polypropylene fibers did [37].

H. Effect of Hybrid Fibers in the Concrete

Cement-based composites can be produced using a mixture of organic and inorganic fibres which exhibit the advantages of both. The high impact strength derived from nylon and polypropylene will remain stable over very long periods of time in normal use. Improved behavior in bending may be obtainable with organic fibres by improving the stress transfer to the fibres and by using higher volume fractions [38].

Hybrid fibres are to control cracks at different size levels, in different zones of concrete at different curing ages and at different loading stages. The large and the strong fibres control large cracks. The small and soft fibres control crack initiation and propagation of small cracks [39].

The performance under impact loads in hybrid fiber reinforced concrete in which polypropylene fiber was more effective than glass fiber in the hybrid fiber reinforced concrete. [40]. Hybrid combination of steel fiber and polypropylene fiber enhances the resistance to both nucleation and growth of cracks, and that such fundamental fracture tests are very useful in developing high performance hybrid fiber composites [41].

The presence of hybrid fibers in the concrete can resist tensile stress in the tensile zone below the neutral axis as it incorporates more destructive energy in the hybrid fiber-reinforced concrete, as it has more amount of the fiber content in it.

III. CONCLUSIONS AND DISCUSSIONS

From the above literature review, it is clear that steel fiber (high modulus fiber) which is stronger and stiffer, improves the concrete strength, while polypropylene fiber (low modulus fiber), has the capacity to strengthen brittle cementitious materials and is more flexible and has the property to retain heat for a prolonged time which leads to improved toughness, and strain capacity in the post-cracking section and retard early cracks. Basalt fiber which is high in oxidation resistance and radiation resistance, fracture energy and abrasion resistance leads to increase in the flexural strength.

So considering the advantages of steel fiber, polypropylene fiber and basalt fiber individually and in hybrid form, it is suggested by combining the hybrid fiber system in which the presence of three fibers (steel fiber, polypropylene fiber and basalt fiber) together in high performance high volume flyash concrete may increase and exhibit excellent mechanical properties including compressive strength, split tensile strength, flexural strength and may with-hold the toughness property of the concrete after ages, may increase the deformation capability and load-bearing capacity, may improve the micromechanical characteristics of bridging the crack from initial stages, may improve the impact, fatigue and wear strength, may improve the carrying capacity of the structure and structural stiffness.

It is suggested that the hybrid fibers can be proportioned by high volume fraction, i.e. greater than 2% to improve the mechanical properties but may affect the workability of concrete.

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