HYBRID FIBER REINFORCED CONCRETE: A REVIEW

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ABSTRACT

It is well known that concrete is a brittle material under tensile loading. The mechanicalproperties of concrete can be improved by randomly oriented short discrete fibers whichprevent or control initiation, propagation, or coalescence of cracks.The addition of fibers to concrete in the said amounts has a significant influence on hardened concrete properties;improvement in toughness and energy absorption; achievement of higher resistance to dynamic load andreduction in crack spacing and width. By using hybrid fibers in a concrete mixture the same properties of concrete can be obtained as those exhibited by conventional fiber reinforced concrete but with the addition of a smaller amount of fibers. Moreover, the use of a single type of fiber may improve the properties ofFRC to a limited level. However the concept of hybridization, which is the process ofadding two or more types of fibers into concrete, can offer more attractive engineeringproperties as the presence of one fibers enables the more efficient utilization of thepotential properties of the other fibers.

Keywords: Brittle, cracks, hybrid fiber, mechanical properties, toughness, durability, shrinkage

I. INTRODUCTION

Crack growth due to loading and shrinkage should both be controlled in slab like concrete structures, such as pavements, runways for airports, and continuous slab-type sleeper for high-speed trains. In these types of structures, effective prestressing for crack control purposes will be very difficult, especially in the two principal directions. So, dispersed short fiber reinforcement offers a second approach in this case. [1]The concept of hybridization with two different fibers incorporated in a common cement matrix can offer more attractive engineering properties because the presence of one fibers enables the more effective utilization of the potential properties for the other fibers.Optimization of mechanical and conductivity properties can be achieved by combining different types and sizes of fibers. [2]

By embedding conventional reinforcements into concrete material,only cracks at certain structural sections and at a single scalecan be arrested, although fracturing in concrete is multi-scale. Hybridization means the combination of two or morefibers with different properties in an appropriate manner to takefull advantage of the resultant product. Based on the anticipatedperformance from the final composite material, the fiber propertiesto be considered are length, diameter, strength, elastic modulus,aspect ratio, specific gravity and so on. It can generally be statedthat larger fibers are more effective in bridging macro cracks (providingtoughness) while smaller fibers are effective in bridgingmicro cracks, thus enhancing the behaviour before and/or right aftercrack formation. With a proper combination of large and smallfibers, individual benefits can be collected simultaneously in a singlehybrid cementitious composite. [3]

II. DEVELOPMENT AND APPLICATION OF HYBRID FIBER REINFORCED CONCRETE

Hybrid fiber-reinforced concrete is a type of fiber-reinforced concrete characterised by its composition. It contains at least two or more types of fibers of different sizes, shapes or origins. Considering that fibers of different types have different effects on the properties of fresh and hardened concrete, the use of hybrid fibers allows optimisation of the properties of fiber-reinforced concrete at all levels.Fiber reinforced concrete (FRC) is a type of concrete that contains, including usual components, fibers having high tensile strength. Depending on the amount of fibers added to the concrete mixture, fiber-reinforced concretes can be categorized into two groups: the FRCs containing a small amount (< 2 vol. %) of fibers and the FRCs with a large amount (≥ 2 vol. %) of fibers. [4]

Hybrid fiber-reinforced concrete was applied in construction of concrete pavement for warehouses located in the surrounding area of Zagreb, Croatia. The concrete pavement slab was 22 cm thick; the fields of 5x5 m were placed and reinforced with shear connector at joints. The concrete was delivered to the construction site in a concrete mixer, placed by concrete finishers, and surface finished. [4]

Hybrid fiber-reinforced concrete was used to repair the bridge deck overlay of Rogotin Bridge over the Neretva River on D8 in Croatia. Thickness of the overlay of bridge deck was only 8 cm. [4]

III. LITERATURE REVIEW

Many researchers have investigated the effect of various types of fibers on the properties of concrete. The research on hybrid fiber reinforced concrete is presented below.

3.1 Workability and strength

The contribution of hybrid fibers to the workability, mechanical and shrinkage properties of lightweight concrete (LWC) with high strength and workability was investigated. The results show that adding fiber to the lightweight concrete mixture greatly reduces the sedimentation of aggregates during mixing and improves the uniformity of the mix; however, the slump value is reduced. Compared with single type of fibers, hybrid fibers significantly improve the mechanical properties and brittleness of lightweight concrete, and restrain the long-term shrinkage.The holding effect of different fibers in LWC reduced the surface bleeding of concrete and the sedimentation of the aggregates, and improved the uniformity of the mixture. However, the slump of the mixture reduced somewhat as well. For single fiber types, carbon and steel fibers can both enhance LWC, and provide an increase in compressive and split tensile strengths at different levels. However, for LWC with PP fiber, the compressive strength decreased somewhat. All combinations of different types of fibers resulted in an increase in strength, among which C–S fibers combination provides the best effects, i.e., a 27.6% increase in the compressive strength and a 38.3% of increase in the spit tensile strength. [5]

The optimization of fiber size, fiber content, and fly ash content in hybrid polypropylene-steel fiber concrete with low fiber content based on general mechanical properties. The research results show that a certain content of fine particles such as fly ash is necessary to evenly disperse fibers. The different sizes of steel fibers contributed to different mechanical properties, at least to a different degree. Additions of a small fiber type had a significant influence on the compressive strength, but the splitting tensile strength was only slightly affected. A

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large fiber type gave rise to opposite mechanical effects, which were further fortified by optimization of the aspect ratio. High performance hybrid fiber concrete should first possess good capacity on compaction and static properties, such as compressive strength, MOR, and splitting strength. Therefore, this research first investigates the optimization of cementitious matrix, fiber type, and fiber content based on previously mentioned properties. [1]

Three types of hybrid composites were constructed using fiber combinations of polypropylene (PP) and carbon, carbon and steel, and steel and PP fibers. Test results showed that the fibers, when used in a hybrid form, could result in superior composite performance compared to their individual fiber-reinforced concretes. Among the three types of hybrids, the carbon–steel combination gave concrete of the highest strength and flexural toughness because of the similar modulus and the synergistic interaction between the two reinforcing fibers. [6]

3.2 Flexural Behaviour

The flexural performance of four Hybrid (H-) Ultra High Performance Fiber Reinforced Concretes (UHPFRCs) with different macro fibers was investigated. Four macro fibers were long smooth (LS-) steel fiber, two types of hooked (HA- and HB-) steel fibers, and twisted (T-) steel fibers while one type of micro fiber, short smooth (SS-) steel fiber, were blended. The enhancements in modulus of rupture, deflection capacity and energy absorption capacity were different according to the types of macro fiber as the amount of micro fiber blended increased. The order of flexural performance of H-UHPFRC according to the types of macro fiber was as follows: HB- > T- > LS- > HA-fiber. The influence of strain capacity in tension on the flexural performance of H-UHPFRC was also examined. The deflection capacity and the ratio between flexural strength and tensile strength were dependent upon the strain capacity of H-UHPFRC. In a hybrid system, the improvement of equivalent bending strength (f), deflection capacity (d), and toughness (Tough) are sensitive to the types of macro fiber as the amount of micro fibers blended increases. [7]

The fracture behaviour of all single and hybrid FRC under tensile and fracture stresses was remarkably stable and, in the case of flexural tests, met the structural requirements of the standards. The fracture toughness and ductility, as well as residual strength, were increased if compared with the same proportions of fibers added separately and subsequently combined. This synergy in the fracture results led to a high-performance concrete capable of bearing loads close to the peak-load for deflections of span/60. This improving effect was observed on the fracture surface of the specimens that showed the same preferential orientation for both types of fibers and an improved orientation and distribution of the polyolefin fibers. In addition, this synergy was found in both flexural and uniaxial fracture tests. Moreover, the low degree of scatter found due the meticulous testing procedures permit the conclusion that simultaneous use of these two fiber types can be used to increase the properties of FRC. [8]

K. Ramadevi and D. L. Venkatesh Babu, analyzed the behaviour of RC beam structures strengthened by using hybrid fiber reinforced concrete (HFRC). The concrete beams are casted for a grade of M25 as per IS 10262:2009. The fibers used are polyolefin and steel (crimped) fibers in various volume fractions. The main reasons for adding steel fibers to concrete matrix is to improve the post-cracking response of the concrete i,e., to improve its energy absorption capacity and apparent ductility, and to provide crack resistance and crack control. The base polyolefin is highly resistant to the majority of aggressive agents and will never oxidize when exposed to the conditions which cause steel to rust. The ultimate deflection for the HFRC beams was found to be

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increasing when compared to the control specimen, which is due to the increase in ductility of the beams by the introduction of fibers. [9]

The size effect on the flexural behaviour of ultra-high-performance hybrid fiber-reinforced concrete (UHPHFRC) was investigated. Three different sizes of specimens were tested using four-point bending in a three-dimensional scale: 50 x 50 x 150 mm3 (small), 100 x 100 x 300 mm3 (medium), and 150 x150 x 450 mm3 (large). As the size of the specimen decreased, the flexural strength, normalized deflection, and normalized energy absorption capacity of UHP-HFRC increased significantly, while the average crack spacing on the bottom surface of the specimen was noticeably decreased. [10]

3.3 Toughness

The hybrid fibers can be considered as a promising concept and the replacement of a portion of steel fibers with palm fibers can significantly reduce the density, enhance the flexural strength and toughness. The results also indicates that the use of hybrid fibers (1.5 steel fibers + 0.5% palm fibers) in specimens increases significantly the toughness indices and thus the use of hybrid fibers combinations in reinforced concrete would enhance their flexural toughness & rigidity and enhance their overall performances. The results show that the use of hybrid fibers (1.5 % steel fibers + 0.5% palm fibers) in specimens has increased the toughness indices in the matrix significantly compared with mix of 2% when the single steel fibers was used. Thus indicates that the use of hybrid fibers combinations in reinforced concrete would enhance their flexural toughness & rigidity and enhance their overall performances. [2]

3.4 Rheological Properties

The influences of fiber types, size, dosages, and fiber combinations (used in hybrid mixes) on fresh (slump flow, L-box passing ability, V-funnel flow time, and segregation index—a measure of workability) and rheological (viscosity and yield stress at various time intervals ranging from 10 to 70 min) properties are critically analyzed on the basis of experimental results. The workability/ rheological properties of concrete mixtures are found to depend on types, dosages, geometry of fiber, and in cases of hybrid mixtures, interaction and synergic properties between different fiber types also play a critical role. Generally, the plastic viscosity/yield stress increases with the increase of PVA/metallic/hybrid fiber volume and elapsed time. [11]

3.5 Fracture Behaviour

Three different types of steel fibers with and/or without hooked-ends were added to the mixtures in two different volume fractions (0.75 and 1.5% of the total volume of concrete). The fracture energy test results show that the concretes with high strength long steel fibers display behaviour of enhanced toughness and ductility when compared to the concretes with normal strength steel fibers. The results of image analyses show that even when high volume of fibers are used fibers in the self-compacting concrete can be dispersed homogeneously without clumping, which results in enhancement in toughness of concretes. [12]

The HFRC composite was produced using three types of fibers namely steel, Kevlar and polypropylene. The increase in SF fiber volume results in increase in the fracture properties of HFRC mixes. The replacement of SF fibers by KF fibers causes either almost no change or small decrease in the values of fracture properties of HFRC. The replacement of SF fibers by equal volume of PF fibers causes either no change or small increase in the fracture properties of HFRC composites. [13]

3.6 Impact resistance

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The flowability, static mechanical properties and impact resistance capacity of UHPHFRC are measured and analysed. The dynamic impact test results show that the long steel fiber plays a dominating role in improving the impact resistance capacity of UHPHFRC. With a constant total steel fiber amount, the addition of short fibers can cause a decrease of the impact resistance capacity of UHPHFRC. [14]

3.7 Corrosion damage reduction

A self- consolidated hybrid fiber reinforced concrete mixture is tested under a chloride-induced corrosive environment to determine the role of crack suppression in both the initiation and the propagation phases of corrosion damage. Transverse crack suppression by means of fiber reinforcement inclusion is important for extending the duration of the initiation phase but it is the suppression of splitting cracks (both mechanically and corrosion-induced) that provides significant durability enhancement in the propagation phase.[15]

3.8 Fire Resistance

The contribution focuses on observing the behaviour of hybrid fiber reinforced concrete under ambient and elevated temperature with the aim to determine the mechanical properties of the material. The obtained findings contribute to improving the knowledge in the field of both concrete structures exposed to high temperature and structural behaviour of fiber reinforced concrete. The presence of fibrous reinforcement ceases to have effect on the residual tensile strength of material as the temperature increases.[16]

IV. CONCLUSION

From the review of research articles mentioned in this paper, the HFRC is aninnovative engineering material.

1) With a simultaneous utilization of Nano-silica and hybrid fibers (steel and polypropylene fibers), the negative influence from the WBA (waste bottom ash) can be effectively minimized and the flexural strength of the UHPFRC (Ultra-High Performance Fiber Reinforced Concrete) can be improved.

2) Both the tensile and compressive strength of hybrid fiber reinforced concrete decreases with increasing temperature.

3) The workability/ rheological properties of concrete mixtures are found to depend on types, dosages, geometry of fiber, and in cases of hybrid mixtures, interaction and synergic properties between different fiber types also play a critical role.

4) The enhancements in modulus of rupture, deflection capacity and energy absorption capacity were different according to the types of macro fiber as the amount of micro fiber blended increased.

5) High performance hybrid fiber concrete should first possess good capacity on compaction and static properties, such as compressive strength, MOR, and splitting strength.

6) The main reasons for adding steel fibers to concrete matrix is to improve the post-cracking response of the concrete i,e., to improve its energy absorption capacity and apparent ductility, and to provide crack resistance and crack control.

7) Use of hybrid fibers in specimens increases significantly the toughness indices and thus the use of hybrid fibers combinations in reinforced concrete would enhance their flexural toughness & rigidity and enhance their overall performances.

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