Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 49(1) (2017) 33-34
DOI: 10.22060/ceej.2016.865

Study of the Effects of Type and Amount of Steel Fibers and Diameter of Projectile on Behavior of UHPSFRC

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ABSTRACT: There are many structures subjected to impact and projectile penetration loading due to accidental, military and/or sabotage threats. Thus, assessment of behavior and vulnerability of materials, structural members and non-structural members is important to provide suitable materials having minimal vulnerability and better behavior. Ultra-high performance concrete reinforced by steel fibers has much better performance against these loads than ordinary concrete. The fiber specifications are the main parameters influencing the performance. This study mainly aims to find the effects of steel fiber density on impact behavior of ultra-high performance steel fiber reinforced concrete (UHPSFRC), which also considers economic aspects. Here, low velocity impact is studied by experiments, while high velocity impact is studied by numerical simulations. The simulations are verified by experimental results. Also, some tests are conducted to determine mechanical properties of concrete for the simulations. The effects of projectile diameter and specifications of steel fibers are investigated, too.

Review History:

Received: 14 August 2013
Revised: 13 August 2016
Accepted: 27 August 2016
Available Online: 18 February 2017

Keywords:

Ultra High Performance Concrete
Steel Fiber
Impact
Projectile
Numerical Simulation

1- Introduction

One of the recent innovations in concrete technology is ultra-high performance concrete (UHPC). Based on the recommendations of the AFGC (Association Francaise de Genie Civil, 2002), the ultra-high performance concrete is a cement based material with the compressive strength more than 150 MPa, in addition sufficient fibers contain to having a ductile behavior. In general the specific properties of UHPC is as follows:

- Compressive strength more than 150 MPa
- Sufficient fibers contain to having a ductile behavior
- Much more cement and specific type of aggregate (hard minerals sand with specific size)

This type of concrete durability compared to conventional concrete, has increased, as well as the conventional cracking weaknesses of concrete at the grain boundary between aggregate and mortar are removed [1].

Bindiganavile and Banthia have shown that the addition of polymers and steel fibers increase absorb energy and flexural strength of concrete under impact loading [2]. Furthermore Bindiganavile et al. introduced a new type of ultra-high performance concrete, compact reinforced composite (CRC) is called, with the higher impact strength than the other concrete types [3]. In 2001 Marar et al. evaluated the effect of the fibers type, amount and percentage, on the absorption, compressive stiffness and impact resistance of HSFRC. According to their conclusions, toughness impact and compressive stiffness increase with any increase in the volume of steel fibers and a logarithmic function dominates between compressive stiffness and impact energy of HSFRC [4].

Farnam was evaluated a kind of Fiber-Reinforced SCC with two percent by volume of the fibers by the fall hammer test. To view the effect of steel fiber reinforced, he also provided control specimens without fibers with the same mix design [5].

Nili and Afroughsabet examined the effect of fiber and silica fume on concrete with 48, 33 MPa compressive strength samples, separately and combined by the fall hammer test. Authors reported the results of study in terms of number of impacts for the first visible cracks and ultimate failure [6].

In this research, the effects of steel fiber density on impact behavior of ultra-high performance steel fiber reinforced concrete (UHPSFRC) is studied. The low velocity impact is studied by experiments and high velocity impact is studied by numerical simulations. The effects of projectile diameter and specifications of steel fibers are investigated by numerical and experimental methods, respectively.

2- Materials and methods

Cubic samples with dimension of 10 cm, 150 MPa strength, 1% fiber density (U1) and 2% fiber density (U2), are constructed. For this purpose, microfiber with length of 13 mm, diameter of 0.175 mm (i.e., ratio of length to diameter is 74) and tension strength of 2000 MPa is utilized.

In order to evaluate impact strength of the UHPSFRC under low speed impact, square panels with 30 cm width and 23 mm thickness are designed. Impact loading test is conducted by free fall of 8.5 kg mass from 1 m height. Support conditions (simple and fixed cases) are provided by bolt constraints at up and bottom sides of each panel. In hammer fall test, each

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panel is subjected to impact loading until its failure. Crack initiation, ultimate failure, opening diameter and ultimate displacement are recorded.

In this study, nonlinear softening behavior of fiber concrete is considered by stress-strain curve in hydrodynamic elasto-plastic material of LS-DYANA for numerical analysis of a sample under high speed impact. In numerical simulations, hydrodynamic elasto-plastic and plastic-kinematic material models are used, respectively. Also, an equation of state (EOS) describes volumetric stress and strain of shock responses for high speed impact. Therefore, material response due to projectile is modeled by the EOS and the hydrodynamic elasto-plastic material. Furthermore, an element erosion algorithm is applied for Lagrange finite element model for damage simulation of projectile and the concrete target.

In these simulations, in order to find penetration depth and diameter in concrete targets, vertical contact of projectile with ogive nose to UHPSFRC is considered. This projectile has length, diameter, weight, warhead radius and velocity of 25 mm, 15.5 mm, 11.68 gr, 2.87 mm and 800 m/s, respectively. Each concrete target has dimensions of 400×400×250 mm with specific fiber density. In order to evaluate the effects of projectile diameter on penetration depth and hole's diameter of a sample, numerical simulations are performed for three other diameters of projectile, too.

For constructing UHPSFRC, fibers with diameters ranging from 0.1 to 0.2 mm and lengths ranging from 3 to 20 mm are utilized. Elasticity modulus of 200 GPa and tension strength between 1000 MPa and 3000 MPa are defined for steel fibers with failure deformation of 3 to 4 %. In order to determine the effects of using nationally produced macro-fibers on strength and ductility of UHPSFRC, eight concrete mixtures are considered for UHPSFRC which consists of two types of steel fibers (1% and 2%) and two types of aggregates. These effects are studied by some experiments including compressive strength, bending strength, tension strength, shear strength, elasticity modulus and stress-strain curves tests.

3- Conclusions

Results show that UHPSFRC samples with 2% fibers have the maximum impact strength for every support condition, among others. However, simply supported cases are better to withstand against impact loads. With neglecting support conditions, number of required impacts for ultimate failure increases when fiber density increases, which shows the importance of selected fiber density in UHPSFRC behavior. Fibers can restrict crack growth. Thus, there are many narrow cracks in samples with larger fiber density, and integrity of panels are maintained with increasing the number of impacts until failure of the panels.

Both UHPSFRC samples have similar mixture details, but they have different fiber density. Results show that the both samples have similar compressive strength. Thus, fiber density has negligible effects on ultimate compressive strength. However, fiber density is effective for tension strength and residual compressive strength and straining, leading to toughness and large energy absorption. Based on the results obtained from numerical simulations and the technical literature, toughness of the target, that is more important than tension strength, is effective for reduction of hole's diameter and projectile penetration.

When fiber density is increased, toughness and ductility and residual strength of the concrete is increased in stress-strain curves. Therefore, the concrete can sustain more damages before failure. Similar loading for the both UHPSFRC samples shows that numerical strain contours of 2% fiber density has smaller damage zone than those of 1% fiber density. According to economic aspects of a favorable design, UHPSFRC with 2% may be more cost-effective than the 1% case.

When macro-fibers are used rather than micro-fibers, although strength and energy absorption of concrete is slightly reduced (12% to 20%), total cost is significantly reduced. But due to crushing of concrete consisting of macro-fiber and departing of the fibers, these fibers are not suitable for impact loads considering economic and technical viewpoints.

When diameter of projectile is increased, its mass and impact force are also increased with constant contact velocity. Therefore, penetration depth and hole's diameter is increased in UHPSFRC for the both fiber density. However, this increment is significantly larger for the concrete with 1% fiber density with respect to 2% fiber density.

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Please cite this article using:

G., Dehghani Ashkezari, "Study of the Effects of Type and Amount of Steel Fibers and Diameter of Projectile on Behavior of UHPSFRC". *Amirkabir J. Civil Eng.*, 49(1) (2017) 101-117.

DOI: 10.22060/ceej.2016.865