Effect of Thickness and Fibre Volume Fraction on Impact Resistance of Steel Fibre Reinforced Concrete (SFRC)

Zakaria Che Muda1,2, Fathoni Usman1, Agusril Syamsir1, Chen Shao Yang3, Kamal Nasharuddin Mustapha3, Salmia Beddu1, Sivadass Thiruchelvam4, Nur Liyana Mohd Kamal1, Md Ashraful Alam1, Ahmed H Birima1, Zarina Itam1, O S Zaroog4

1Centre of Sustainable Technology and Environment, Universiti Tenaga Nasional, Malaysia 2Former Student of Universiti Tenaga Nasional 3Centre of Forensic Engineering, Universiti Tenaga Nasional, Malaysia 4Centre of Innovation and Design, Universiti Tenaga Nasional, Malaysia

mzakaria@uniten.edu.my

Abstract. This paper investigates the effect of the thickness and fibre volume fraction (VF) on the impact performance of steel fibre reinforced concrete (SFRC) for the concrete slab of 300mm x 300mm size reinforced subjected to low impact projectile test. A self-fabricated drop-weight impact test rig with a steel ball weight of 1.236 kg drop at 0.57 m height has been used in this research work. The objective of this research is to study the relationship of impact resistance of SFRC against slab thickness and volume fraction. There is a good linear correlation between impact resistances of SFRC against slab thickness. However the impact resistance of SFRC against percentage of volume fraction exhibit a non-linear relationship.

1. Introduction

The impact resistance of a structure is very important to protect the users from being harmed and injured during impact strikes the concrete structure. Important structures such as dams, military defense structure, power plant and so on is very crucial to impact events as if the structure does not have enough impact resistance, it might cause serious loss in property, human life, and economic loss.

Impact resistance represents the ability of concrete to withstand repeated blows and absorb energy without adverse effect to cracking and spalling.

There is lack of research investigation been carried out on the effect of steel fibre distribution on the impact resistance of steel fibre reinforced concrete (SFRC).

Holschemacher et al, it found that increasing of fibre strength will help in increasing the strength, ductility, and post cracking behavior of fibre reinforced concrete because high-strength fibre prevent the fibre from breaking when impact strikes and cracks happened [1]. Xu et al. carried out drop-weight experimental tests on concrete reinforced with 7 types of fibres and study their properties on the impact resistance.[2]. According to A.A. Aliabdo et al, impact resistance of concrete will affected by fibre type and content, shape of steel fibre, coarse aggregate type, and water/cement ratio [3].

The drop weight impact test which is recommended by the ACI Committee 544 [4] is the simplest method. The review paper on impact resistance on concrete target has been published by Z Che Muda et al [5]. Impact resistance of oil palm shells lightweight concrete slab with bamboo fibers has been studied by Z Che Muda et al.[6].

The objective of this research is to study the effect of the steel fibre distribution on the impact resistance SFRC and its mode of failures.
2. Materials and Test Set-up.

The hooked end steel fibre has a fibre length of 50mm with an aspect ratio of 65. The tensile strength of the steel fibre is $1100 \pm 80$ MPa.

Ordinary Portland cement complying to ASTM Type I cement are used with 2% of super plasticizer is used in the design mix to achieved the desired workability.

The basic mix design for the Steel Fibre Reinforced Concrete (SFRC) is shown in Table 1.

**TABLE 1 Mix Design for Steel Fibre Reinforced Concrete (SFRC)**

| Cement (kg/m$^3$) | Fine Aggregates (kg/m$^3$) | Course Aggregates (kg/m$^3$) | Water/cement Ratio | Slump (mm) | Compressive Strength (N/mm$^2$) |
|-------------------|-----------------------------|-----------------------------|--------------------|------------|-------------------------------|
| 440               | 902                         | 889                         | 0.35               | 72         | 39                            |

The study used a self-fabricated low velocity drop-weight impact test rig and its set up are as shown in Figure 1 using a steel ball weighing 1.236 kg with drop height of 570 mm impacting the specimen of size 300mm x 300mm with a thickness of 20 mm, 30 mm, and 40 mm with 1% VF, 2% VF and 3% VF mounted on the steel rack frame. The test sample is 1-way simply supported.

3. Methodology

The potential energy due to the drop body is absorbed as strain energy, generating stresses that causes cracks in the target element. The width, depth, length of the crack developed and its failure mode is associated with the intensity of the energy, the amount of energy absorbed and the properties of concrete. It is assumed that the total computed energy imparted is fully absorbed by the specimens. The relationship of potential energy of a drop-weight projectile and the strain energy dissipated in cracks development is expressed as following formula as proposed by Kankam [7];

$$N*e = R_u * l_c * d_c * w_c$$  \hspace{1cm} (3.1)

Where, $N =$ No. of Blows, $e =$ Energy per blow (Joules), $l_c =$ Total length of all cracks, $d_c =$ Maximum crack depth, $w_c =$ Maximum crack width, $R_u =$ Ultimate crack resistance

A total of 54 sample slabs of size 300mm x 300mm with 30 mm, 40 mm and 50 mm thickness were casted with at control (no fibre), 1%, 2% and 3% steel fibre volume fraction volume (VF). Each of the combination have 3 samples in order increase its accuracy and an average value is obtained.

The following mesh distribution were investigated to study its impact on service (first) and ultimate (failure) crack resistance.

i. Slab thickness.

ii. Percentage of fibre volume fraction.

At the first crack and ultimate (failure) crack, the total crack length, the crack width and the crack depth measured by filler gauge with its total numbers of blows recorded.
4. Results and Discussion

4.1 Relationship between Crack Resistance and Slab Thickness

There is a good linear correlation with minimum $R^2 = 0.9403$ between the crack resistance and slab thickness as shown in Figure 2. Increase in crack resistance is more substantial as the thickness increases as compared to the increases in the fiber volume fraction. The highest value of first crack and ultimate crack resistance obtain is 15.50 N/mm$^2$ and 86.43 N/mm$^2$ respectively for 50 mm thick slab at 3% VF. The first crack and ultimate crack impact resistance for 50 mm slab are 1.62 times and 1.65 times respectively as against the 30 mm slab at 3% VF steel fibre.

Figure 2(b) shows the ultimate crack resistance without fibre (control slab) is 3.92 N/mm$^2$ for 50 mm thick slab. The ultimate crack resistance for 50 mm slab thickness with 3% FV increased by 22.05 times against its control sample.

4.1 Relationship between Crack Resistance and Fibre Volume Fraction (VF)

There is a non-linear relationship of impact resistance against fibre volume fraction as shown in Figure 3. Generally the first and ultimate crack resistance increases with increasing fibre VF, however the optimum threshold value is with a 3% VF steel fibre. First crack resistance for 50 mm slab increase by 6.03 times and 4.41 times for ultimate crack at 3% VF as compare with 1% VF steel fibre.

There is not much differences in values of first and ultimate crack resistance between 1%VF and 2%VF steel fibre. This indicate that there is no significant gain of first crack and ultimate crack resistance for fibre less than 3% VF.

4.2 Mode of Failures

 Fibres play a very important role in bridging cracks, absorbing energy, transferring loads, and developing micro cracks distribution system. First crack of 0.075mm normally initiate at the bottom surface of the slab due to the limiting tensile strain and propagated upward until neutral axis. When the crack move up and reaches the top part of the concrete, the ultimate crack eventually cause a complete segmental failures. If impact happen continuously, initial crack will subsequently propagate and link up into a larger crack known as a fracture zone. The 50 mm thick slab with 3% VF in Figure 4 (b) has five segmental
failures along the fracture zone and more micro-cracking in the other parts of the slab as compare with 2% VF in Figure 4 (a) has four segmental failures along its fracture zone.

![Figure 4](image)

**Figure 4** Failure Modes at distal surface of 50 mm slab with (a) 2% VF (b) 3% VF.

5. **Conclusion**

The following conclusions can be derived from the experimental results;

- There is a good linear correlation with minimum $R^2=0.9403$ between the crack resistance and slab thickness.
- There is non-linear exponential relationship between the crack resistance and the percentage of VF fibre.
- The first crack and ultimate crack impact resistance at 3%VF steel fibre for 50 mm slab are 1.62 times and 1.65 times respectively as compare with 30 mm slab.
- The ultimate crack resistance for 50 mm slab thickness with 3% VF increased by 22.05 times against its control sample.
- First crack resistance for 50 mm slab increase by 6.03 times and 4.41 times for ultimate crack at 3% VF as compare with 1% VF steel fibre.
- There is no significant gain of first crack and ultimate crack resistance for fibre less than 3% VF.
- The slab with a higher VF has more segmental failures along the fracture zone and micro-cracking in the other parts of the slab as compare with the slab with lower VF fibre.

**References**

[1] Holsthemacher K, Muekker T, Ribakov Y. ‘Effect of steel fibres on mechanical properties of high-strength concrete’. Mater Des 2010;31:2604-15.
[2] Xu Z, Hao H, Li HN. ‘Experimental study of dynamic compressive properties of fibre reinforced concrete materials with different fibres’. Mater Des 2012;33:42-55.
[3] Ali Abd Elhakam Aliabdo, Abd Elmoaty Mohamed Abd Elmoaty, Mohamed Hamdy. ‘Effect of internal short fibres, steel reinforcement, and surface layer on impact and penetration resistance of concrete’. Alexandria Engineering Journal. 2013;52, 407-417.
[4] ACI Committee 544. State-of-the-art report on fiber reinforced concrete. ACI Committee 544 report 544.1R-96. Detroit: American Concrete Institute. 1996.
[5] Zakaria Che Muda, Kong Sih Ying, Salah F A Sharif, Lariyah Bte. Mohd Sidek, Nawfal S. Farhan, A Review - Local Failure On Concrete Target Due To Projectile Impact. International Journal of Science and Engineering Research (IJSER) Volume 4, Issue 1, January 2013.
[6] Zakaria Che Muda, Salah F A Sharif, Lariyah Bte. Mohd Sidek, Nawfal S Farhan, Impact Resistance Of Oil Palm Shells Lightweight Concrete Slab With Bamboo Fibers, International Journal of Science and Engineering Research (IJSER) Volume 4, Issue 1, January 2013.
[7] CK Kankam. Impact Resistance of palm kernel fibre-reinforced concrete pavement slab. J Ferrocement 1999;29(4):279-86. Oct