Effect of Steel Fibres Distribution on Impact Resistance Performance of Steel Fibre Reinforced Concrete (SFRC)

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Abstract. This paper investigates the effect of the mesh distribution on the impact performance of steel fibre reinforced concrete (SFRC) for the concrete slab of 300mm x 300mm size reinforced with varied thickness and fraction volume 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 effect of the mesh distribution on the impact resistance SFRC for various slab thickness and fraction volume. Random fibre distribution is the more effective than the top and bottom fibre distribution in terms of absorption of impact energy, crack resistance, the ability to control crack formation and propagation against impact energy.

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 lost in property, human life, and economic lost.

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 \cite{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.\cite{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 \cite{3}.

The drop weight impact test which is recommended by the ACI Committee 544 \cite{4} is the simplest method. The review paper on impact resistance on concrete target has been published by Z Che Muda et al \cite{5}. Impact resistance of oil palm shells lightweight concrete slab with bamboo fibers has been studied by Z Che Muda et al,\cite{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 ± 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/m³)  | Fine Aggregates (kg/m³) | Course Aggregates (kg/m³) | Water/cement Ratio | Slump (mm) | Compressive Strength (N/mm²) |
| 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.

![Low-velocity Drop-weight Impact Test Rig and Test Set-up](image)

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];

\[ N \times e = R_u \times l_c \times d_c \times w_c \]  \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 fraction volume (FV). 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. Random fibres distribution.

ii. Top and bottom fibres distribution.

The random fibres distribution are uniformly distributed throughout the depth of the slab. The top and bottom fibres distribution has the fibres distributed within 10mm depth at the top and bottom of the slab.
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 Steel Fibres Distribution

In Figure 2 and Figure 3 indicate that random fibre distribution has a better crack resistance values than the top and bottom fibre distribution as the volume fraction increases. Random fibre is generally more efficient arrangement in its ability to control crack formation and propagation against impact energy as compared with the top & bottom fibre distribution.

The fibre distribution arrangement is insignificant against crack resistance when the FV is below 3%. The significant fibre distribution arrangement between random and top & bottom can only be seen at 3% FV for the first and ultimate crack resistance.

The highest values of the first crack for random distribution is 15.5 N/mm² and the top & bottom fibre distribution is 5.7 N/mm². The first crack resistance for random distribution increases by 2.7 times as compare with the top & bottom fibre distribution.

The random distribution with 3% FV steel fibres has the better ability of transferring stresses across a cracked section uniformly, bridging and provide more resistance to the cracks formation and propagation, transferring impact loads, absorbing more impact energy and developing more micro cracks distribution in the slab. In top and bottom fibre distribution, the crack bridging is absence due to the missing fibres in the mid-depth of the slab, thus providing lower impact energy and resistance for the first and ultimate cracks.

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 random distribution in Figure 4 (a) has five segmental failures along the fracture zone with more micro-cracking in the other parts of the slab as compare with the top and bottom distribution in Figure 4 (b) has only three segmental failures along the fracture zone for ultimate crack of 3% FV fibers and 50 mm thick slab.

![Figure 4](image)

**Figure 4** Ultimate Crack Resistance Failure Modes for fibers with 3% FV and 50 mm thick slab.

(a) Random Fibres Distribution (b) Top & Bottom Fibres Distribution.

5. Conclusion

The following conclusions can be derived from the experimental results:

- Random fibre is generally more efficient arrangement in its the ability to control crack formation and propagation against impact energy as compared with the top & bottom fibre distribution.
- The fibre distribution arrangement is insignificant against crack resistance when the fraction volume is below 3%.
- The first crack resistance for random distribution increases up to 2.7 times as compare with the top & bottom fibre distribution.
- In top and bottom fibre distribution, the crack bridging is absence due to the missing fibres in the mid-depth of the slab, thus providing lower impact energy and resistance for the first and ultimate cracks.
- The random distribution with higher fraction volume has more segmental failures along the fracture zone with more micro-cracking in the other parts of the slab as compare with the lower fraction volume.

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