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Study on Fracture Parameters of Fiber Reinforced RC Hollow Beam

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ABSTRACT

Pipe networks and ducts are necessary in modern buildings to support various services, including AC, telephone, electricity, water supply, computer networks, and sewage. Typically, these systems are situated below the beam and covered by the ceiling for aesthetic reasons, which results in dead space. To decrease the dead space in the floor area, ducts and pipes can be passed through the longitudinal and transverse openings in beams. The concrete located near the neutral axis of reinforced concrete beams is frequently underutilized, and this concrete can be substituted with lightweight material to decrease the weight of concrete. Incorporating a GI pipe to create a hollow section in the beam is another way to reduce the weight of the structure. This study examines the flexural behavior of reinforced concrete hollow beams under a two-point load and evaluates the suitability and flexural strength of these beam structures. Steel fibers improve the fracture behavior of members, and the further studies compare the fracture parameters of fiber reinforced hollow beams with solid beams.

Keywords – Flexural behavior, Fracture parameters, Hollow beam, Light weight, Steel fiber

1. Introduction

Hollow structural sections are widely used for various practical purposes, including improving architectural aesthetics and enhancing the total thickness in the column-supporting area to ensure services. RC beams, which are commonly utilized for water and sewage drainage services, power transfers, communications, and water transfers, are one of the most frequently used types of hollow sections. The benefits of a hollow cross-section include reduced weight, which particularly affects the cost of transportation, handling, and precast cross-section erection, as well as a significant reduction in material quantities. Previous studies have shown that single-hole GI pipes exhibit better flexural strength than other types of pipes [1], and that the flexural behavior of fibrous beams is superior to that of non-fibrous beams [2].

In this experimental study, we investigated the effect of a reduction in the concrete area, as well as the impact of steel fiber on the fracture parameters of Fibre Reinforced RC Hollow Beam. The addition of steel fiber to concrete helps reinforce the material by providing additional tensile strength and toughness. This makes the concrete more resistant to cracking and other types of damage, particularly under dynamic loading conditions such as those experienced by bridges, tunnels, and floors.

These are the main objective of the study:

- Study the effect of reduction in area of concrete in tension zone and compression zone.
- Study the effect of steel fibre in RC hollow beam.
- Compare the fracture behaviour of Fibre Reinforced RC Hollow Beam.

2. Methodology

2.1 Experimental study

Reinforced concrete beams with dimensions of 850×150×150 mm^3 tested for this study. The beams were provided with 2 No.s of 8mm diameter bars on top and bottom, with stirrups of 8mm diameter at 125mm c/c distance. A solid RC beam with the same specifications was taken as control beam(CB) for reference. Additionally, hollow beams with different percentages of reduction in area were also tested to determine the ultimate load, as shown in Table 1.

The results indicate that the first crack and ultimate load values of the control beam increased for the hollow beam with a 5% reduction in area (HB1) with the incorporation of GI pipe. However, from HB2 to

HB5, the values decreased due to increase in the reduction of the area of concrete. HB2 carried a load greater than CB, while the others carried a load lower than CB. Therefore, HB3 was selected for further study, which was steel fiber reinforced hollow beam (SRHB). End hooked steel fibers with an aspect ratio of 50 and a density of 7800kg/m^3 were used to cast SRHB with different percentages of steel fiber, and tests were conducted to determine the first crack load and ultimate load, as shown in Table 2.

Table 1. Hollow Beams

DESIGNATION	CB	HB1	HB2	HB3	HB4	HB5
Hole Diameter (Inch)	0	1.5	2.0	2.5	3.0	3.25
Hole Diameter (mm)	0	38.1	50.8	63.5	76.2	82.5
Area Reduction (%)	0	5	9	14	20	24
First Crack Load (kN)	66.8	71.9	70.5	63.8	55.8	43.9
Ultimate Load (kN)	73.6	83.0	80.8	72.0	65.2	50.1

Table 2. Steel Fibre Reinforced Hollow Beam

DESIGNATION	HB3	HB3 -0.5	HB3 -1.0	HB3 -1.5	HB3 -2.0
Percentage of Steel Fibre (%)	0	0.5	1	1.5	2
First Crack Load (kN)	63.8	64.1	65.9	67.1	67.2
Ultimate Load (kN)	72.0	72.8	75.5	77.8	75.8

2.2 Fracture Behavior of Steel Fibre Reinforced RC Hollow Beam

Stress intensity factor, Crack mouth opening displacement, Energy release rate and Fracture energy are the four fracture parameters used to study the fracture behavior of steel fiber reinforced RC hollow beam.

2.2.1 Stress Intensity Factor (K)

Stress intensity factor in the crack region should be known to estimate the crack growth rate. It represents the resistance to failure and can be calculate by (1):

$$K = \sigma_N \times \sqrt{\pi a} \times f_1(\propto) \quad \ldots (1)$$

where

σ_N = nominal failure stress $=\frac{6P}{bd}$,

$$f_1(\propto) = \frac{[1.99 - \propto(1-\propto)(2.15 - 3.93\propto + 2.7\propto^2)]}{[\sqrt{\pi} \times (1+2\propto)(1-\alpha)^{\frac{3}{2}}]}$$

$$\propto = \frac{a}{d}$$

P = ultimate load

a = crack width

2.2.2 Crack Mouth Opening Displacement (CMOD)

Crack mouth opening displacement gives the width of crack while loading. It can be calculate by (2):

$$\text{CMOD} = \frac{4 \propto \times \sigma_N \times U(\propto)}{E} \quad \ldots (2)$$

where,

$$U(\propto) = \frac{1.021 - (0.760 \propto)}{(1 - 2.149 \propto + 1.162 \propto^2)}$$

2.2.3 Energy Release rate (G)

Energy release rate represents the amount of work associated with a crack opening or closure and can be calculate by (3):

$$G = \frac{K^2}{E} \quad \ldots (3)$$

where, E= Young's modulus

2.2.4 Fracture Energy (G_f)

Fracture energy is the amount of energy required cracking one unit of area of a continuous crack and can be calculate by (4):

$$G_f = \frac{W}{A_S} \quad \ldots (4)$$

where,

$W = P \times l$

$A_S = a \times d$

3. Result and analysis

3.1 Comparison of ultimate load

As in Fig 1, when fibre is added to hollow beam with 14% area reduction (HB3), the ultimate load value increases from HB3 to HB3-1.5 by 8% and then decreases for HB3-2.0 by 2.5%.

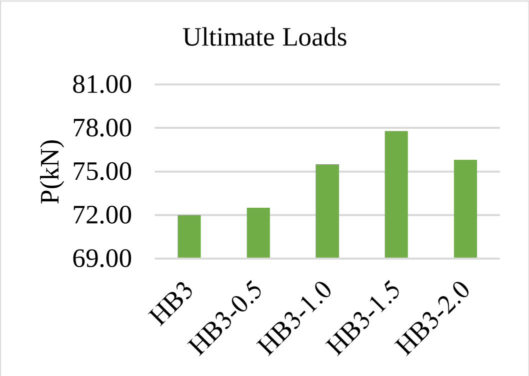

Figure 1. Comparison of ultimate loads

The addition of steel fibres to concrete can improve its strength and durability, but excessive steel fibre content can negatively impact the quality of the concrete mix. When the steel fibre content exceeds 1.5%, the fibres can start to clump together, resulting in decreased workability of the concrete and the formation of voids or gaps, ultimately reducing its overall strength. Moreover, densely packed steel fibers can hinder proper bonding of the concrete, further decreasing its strength. Another important consideration is the orientation of the fibres, which becomes more random with increasing fibre content. This randomness can impede the fibres' ability to effectively reinforce the concrete in the direction of applied load, causing a reduction in flexural strength, particularly when the fibres are unevenly distributed. Therefore, proper attention should be given to the steel fibre content, distribution, and orientation to optimize the strength and quality of the concrete.

3.2 Comparison of fracture parameters

In this study, the fracture parameters Stress Intrinsic Factor, Energy Release Rate, Fracture Energy, and Crack Mouth Opening Displacement were investigated for concrete reinforced with steel fibers. The results indicated that the values of these fracture parameters increased by approximately 27%, 63%, 13%, and 39%, respectively, from HB3 to HB3-1.5, as shown in Fig. 2 to Fig. 5. However, these values decreased for HB3-2.0 by approximately 16%, 29%, 2%, and 22%, respectively.

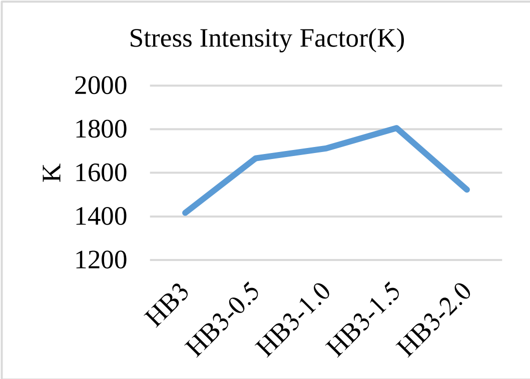

Figure 2. Stress Intensity Factor

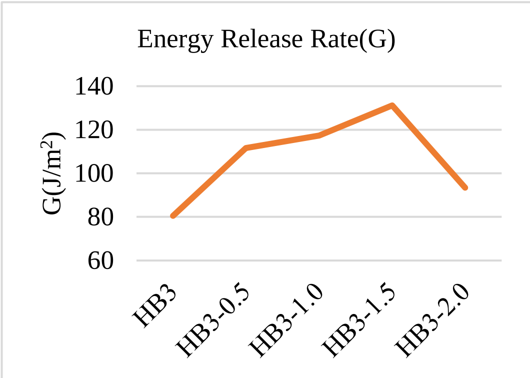

Figure 3. Energy Release Rate

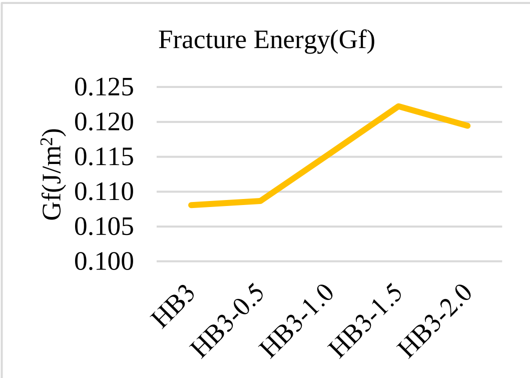

Figure 4. Fracture Energy

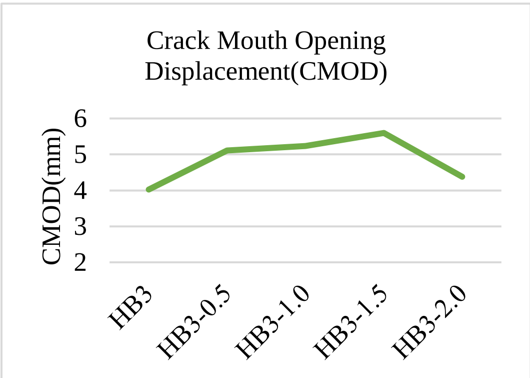

Figure 5. Fracture Energy

The addition of steel fibers to concrete can improve its tensile strength and toughness by bridging micro-cracks that occur during loading, resulting in the formation of multiple micro-cracks that distribute the load more evenly throughout the material, thereby increasing the fracture parameters. However, the decrease in fracture parameters observed in the case of a 2% steel fiber added RC hollow beam can be attributed to the formation of clusters of steel fibers in the concrete matrix, which can lead to a non-uniform distribution of load during loading. This non-uniform distribution can cause premature failure of the material, resulting in a decrease in the fracture parameters.

4. Conclusion

In this study, the effect of reducing the area of concrete in a hollow beam was investigated, with the goal of determining the maximum percentage of area reduction that could be achieved using GI pipe without compromising the ultimate load carrying capacity. The results showed that a maximum percentage area reduction of 9% was achievable without negatively impacting the ultimate load carrying capacity.

Next, the effect of steel fibre on the strength of an RC hollow beam was examined. The study determined that the maximum percentage of steel fibre that could be used to improve the strength of the hollow beam was 1.5%. The results further showed that a hollow beam with a 14% reduction in area and 1.5% steel fibre could withstand a load greater than that of the control beam.

To support the experimental findings, fracture parameters were also analyzed, including Stress Intrinsic Factor, Energy Release Rate, Fracture Energy, and Crack Mouth Opening Displacement. Peak values for these parameters were observed in the 1.5% steel fibre reinforced hollow beam. These results suggest that the addition of steel fibre can improve the fracture toughness and ductility of the hollow beam. Overall, the findings of this study suggest that a combination of area reduction and steel fibre reinforcement can be effective in enhancing the strength and fracture resistance of hollow beams.

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