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Experimental Determination of Double-K Fracture Parameter for Polypropylene Fibre Reinforced Concrete

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ABSTRACT

Polypropylene fibre reinforced concrete is randomly distributed fibres abate the nucleation, growth of matrix cracks and bridge them after their creations. These reduce the brittleness and provide the strength gain, fracture toughness and ductility. The Double K fracture parameter can describe the cracking process of polypropylene fibre reinforced concrete well since go through three stages: the stage of crack arises, expand stage and break stage. Stress intensity factor caused by bridging stress and the net stress intensity factor were given based on the hypothesis of linear asymptotic superposition. Polypropylene fibre reinforced concrete is short and randomly distributed fibres abate the nucleation and growth of matrix cracks and bridge them after their creations. These reduce the brittleness and provide the strength gain, fracture toughness and ductility. A fibre as reinforcement can be effective in arresting cracks at both micro and macro levels. The effect of varying fibre percentage on initial cracking load, ultimate failure load, initial fracture toughness $K_{IC}^{ini.}$, unstable fracture toughness $K_{IC}^{un.}$ and cohesive fracture toughness K_{IC}^{C} is repeated and studied. Variation in fracture toughness and brittleness index is studied. Closed loop servo controlled equipment has been used in the present work to evaluate optimum Polypropylene fibre percentage for getting maximum fracture toughness is also suggested.

Keywords: Initial fracture toughness, unstable fracture toughness, cohesive fracture toughness, Brittleness index

I. INTRODUCTION

Fibre reinforced concrete (FRC) is widely used in Hydraulic Structures, bridge decks, pavements, slab-on-grade and tunnel linings because of its crack resistance. The structural design for such applications generally requires the constitutive relation in tension or some measure of the critical stress intensity factor. In material science, Fracture Toughness is a property which describes the ability of a material containing a crack to resist the fracture of a material known as fracture toughness. The linear elastic fracture toughness (LEFM) of a material is evaluated from the stress intensity factor (K) at which a thin crack in material begins to grow. Elastic - plastic fracture toughness and is a measurement of the energy required to grow a thin crack. A common basis for the flexural toughness characterization is the bending test of a prism under quasi-static loading. The load-crack mouth opening displacement curve (P-CMOD) obtained from the three-point bending test has also been used to derive the fracture properties of the material. FRC is used in applications where the members have to resist loads ranging from dynamic to sustained loading, it would be useful to incorporate such rate effects in the analysis and design of FRC structures. The concrete structures generally consist of numerous micro-cracks that might result in fracture of the concrete structures under service loads, accidental load and/or exposure to regular environmental conditions. Thus a micro-crack in concrete may become a potential source of crack propagation leading to a probable catastrophic failure. In order to prevent such accidents, it is necessary to predict the failure mechanisms of structures, so that the safety of concrete structures throughout the service life can be assured. Therefore, in this paper our main purpose is to propose a simplified method of determination of the double-K fracture parameters, $K_{IC}^{ini.}$ and $K_{IC}^{un.}$.

There are many research carried on Fracture Mechanics now-a-days. Some of the papers which I found important for my research are reviewed and discussed here. The Double K fracture criterion of steel fiber reinforced concrete was studied by jingcai zhang et. al.[2]. Experimental Analysis of Fracture Properties of Steel Fiber Reinforced Concrete is derived by Li[3]. The

Method recommended by ASTM is one of the most popular fracture toughness measurement methods. This paper focus on Double-K fracture criterion of Polypropylene fibre reinforced concrete.

II. METHODS AND MATERIAL

The procedure used in this work for the three-point bending test on notched beams conforms to ASTM E1820-2003[4]. The dimensions of the specimen are 100×100×500 mm, with a span of 400 mm; a notch is cut at the mid-span (Fig. 1). The beam is loaded such that the direction of casting is perpendicular to the loading direction.

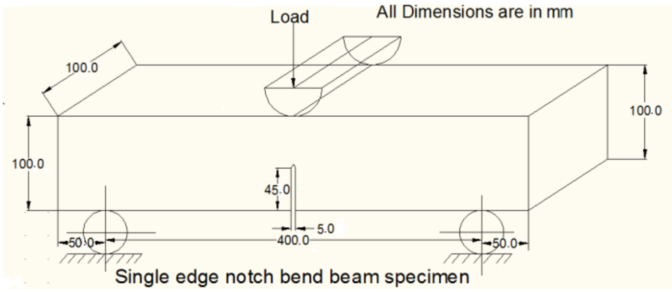

Fig. 1 Testing configuration

For the three-point bending notched beams, beams, initiation toughness were defined as the intensity factor from the initial cracking load P_{ini} at the initial crack tip. The initial crack length or the prefabricated crack length, denote as a_0, can easily and accurately be measured.

Once the initial cracking load is measured, Initial fracture toughness can be calculated can be obtained as follows.

$$K_{IC}^{ini} = \frac{3P_{ini}S}{2w^2b}\sqrt{a_0}\ f_1(a_0/w) \quad \text{. . . (1)}$$

Where,

Assuming A= a_0/w

$$f_1(a_0/w) = f_1(A) = \frac{1.99-A(1-A)\,[2.15-3.93A+2.7A^2]}{(1+2A)(1-A)^{3/2}} \quad \text{. . . (2)}$$

For Single edge notch bend specimens, the value of K_{IC}^{un} can be evaluated as follows

$$K_{IC}^{un} = \frac{3P_{Max.}S}{2w^2b}\sqrt{a_c}\ f_1(a_c/w) \quad \text{. . . (3)}$$

Two ways are available to distinguish the initial cracking load for investigator. One is an effective and simple option you can use. As previously mentioned, the specimen is mainly in elastic state before cracking load reached $P_{ini.}$ With the F-CMOD curve, researcher may pick the inflection point or A in the curve from linearity to nonlinearity as the initial cracking point. The lode correspond to the inflection point is what we want. The other one is the direct method which in the experimental

Techniques, like the laser speckle interferometry, photo elastic coating, strain gauge technique and the acoustic emission method. However, it is not convenient and accurate. Because what these techniques measured is the surface crack rather than the interior of the specimen. In addition, someone may have no access to these measuring instruments.

For three point bend specimen the cohesion toughness K_{IC}^{C} , which is defined as the energy absorbed in the progressive extension of a fictitious crack zone, can be obtained by the following expression:

$$K_{IC}^{C} = K_{IC}^{un} - K_{IC}^{ini} \qquad \ldots (4)$$

The non-dimensional brittleness index, β, proposed by Kumar and Barai[5] (2009), was applied to evaluate the brittleness of concrete by using the ratio of K_{IC}^{ini} to K_{IC}^{un}.

$$\beta = \frac{K_{IC}^{ini}}{K_{IC}^{un}} \qquad \ldots (5)$$

TABLE I. PROPERTIES OF POLYPROPYLENE FIBRE

Material	Polypropylene fibre
Fibre cross-section	Circular
Diameter (denier)	2.5
Cut length (mm)	12
Specific Gravity (gm/cc)	0.91
Color	White

III. RESULTS AND DISCUSSION

In the present work, it was decided to find the fracture toughness of M-30 grade fibre reinforced concrete and compare with that of M30 grade ordinary concrete. For making M30 grade concrete mix design was carried out based on IS 10262:2007[6]. Based on the properties of the aggregates, trials mixes with different proportions were made and compressive strength was determined. The proportion of 1:1.93:3.54 (Cement: Sand: Aggregate) by weight batching with water cement ratio of 0.43 was found to give good results and was adopted for casting the cracked beam specimens to find the fracture toughness. Optimum fibre volume fraction was decided by trying 0.3%, 0.6%, 0.9%, 1.2% volume fractions.

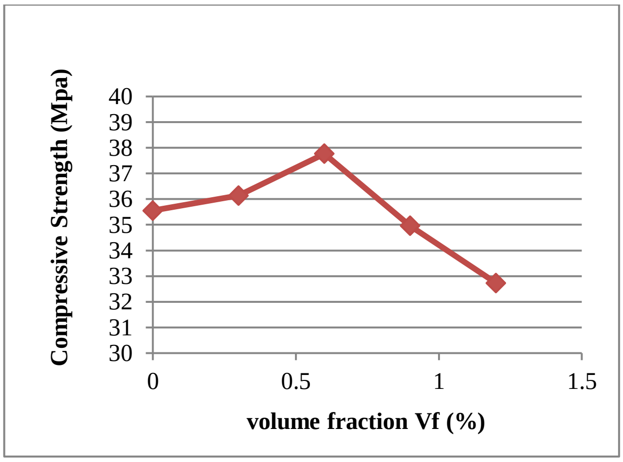

Fig. 2. Compressive strength of concrete VS. Different percentage of Polypropylene fibre volume fraction

From Fig. 2 shows that for 0.6% polypropylene fibre compressive strength obtained is maximum and is 37.77 N/mm².

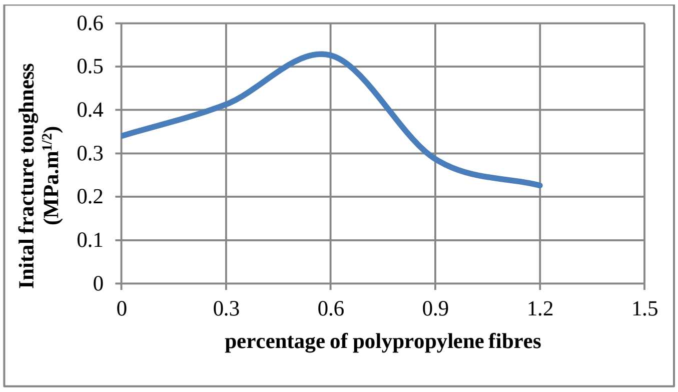

Fig. 3 Initial fracture toughness vs Different percentage of polypropylene fibres volume fraction

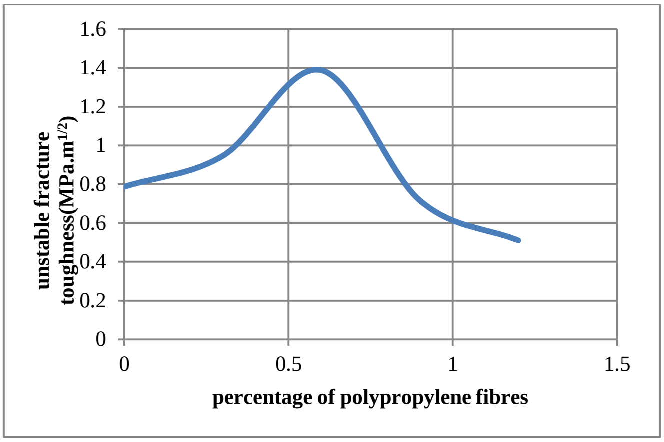

Fig. 4 Unstable fracture toughness vs Different percentage of polypropylene fibres volume fraction

TABLE II. RESULTS OF VARIOUS SPECIMENS

Speci-men no.	P.P fibres (V_f) %	K_{IC}^{ini} (MPa.m$^{1/2}$)	K_{IC}^{un} (MPa.m$^{1/2}$)	K_{IC}^{C} (MPa.m$^{1/2}$)	β
A1	0	0.369	0.835	0.466	0.443
A2	0	0.420	0.761	0.337	0.556
A3	0	0.309	0.765	0.535	0.300
B1	0.3	0.407	0.992	0.720	0.274
B2	0.3	0.496	0.863	0.366	0.576
B3	0.3	0.471	0.983	0.511	0.480
C1	0.6	0.607	1.350	0.742	0.450
C2	0.6	0.486	1.313	0.826	0.371
C3	0.6	0.485	1.501	1.015	0.324
D1	0.9	0.305	0.668	0.362	0.458
D2	0.9	0.398	0.726	0.434	0.402
D3	0.9	0.265	0.759	0.494	0.349
E1	1.2	0.311	0.639	0.327	0.488
E2	1.2	0.136	0.256	0.138	0.460
E3	1.2	0.327	0.637	0.389	0.390

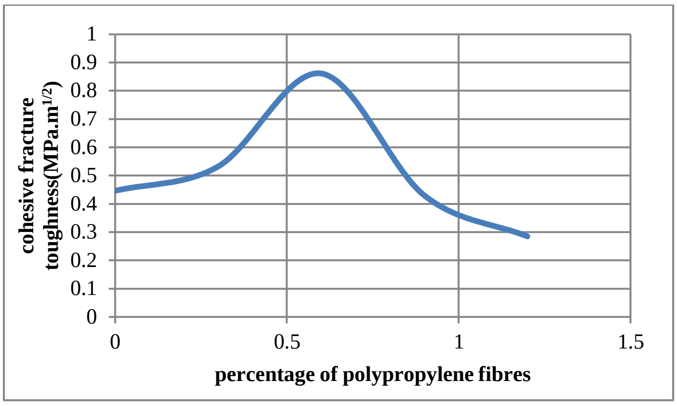

Fig. 5 Cohesive fracture toughness vs Different percentage of polypropylene fibres volume fraction

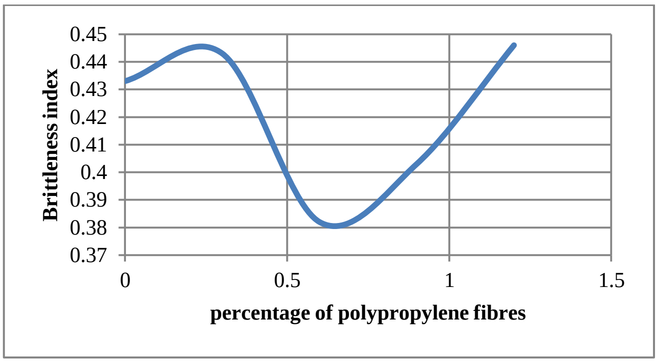

Fig. 6 Brittleness index vs Different percentage of polypropylene fibres volume fraction

Fig. 6 shows that non-dimensional brittleness index decreases up to 0.6% volume fraction of polypropylene fibres. So it can be said that ductility of fibre reinforced concrete is maximum at 0.6% fibre volume fraction. The value of brittleness index decreases with increase in fracture toughness.

IV.CONCLUSION

- ✓ Double-K fracture parameters can describe the crack propagation of Polypropylene fibre reinforced concrete well. The maximum gain in fracture toughness was achieved for 0.6% polypropylene. Thereafter increasing the fibre content has marginally reduced the fracture toughness. The values of fracture toughness for polypropylene fibres in MPa.m$^{1/2}$ are 0.946, 1.388, 0.718, and 0.511 for 0.3, 0.6, 0.9, and 1.2% of fibres respectively.

- ✓ The initial cracking load, ultimate failure load, initial fracture toughness $K_{IC}^{ini.}$, unstable fracture toughness K_{IC}^{un}, and the cohesive toughness K_{IC}^{C} increase with increase in the volume fraction of synthetic fibre up to 0.6%.
- ✓ The value of non-dimensional brittleness index decreases with increase in fracture toughness.
- ✓ The Double-K fracture parameters and the brittleness index are good indicators for assessment of fracture behaviour of concrete materials.
- ✓ From the present study it is observed that the optimum dosage of polypropylene fibres volume fraction is 0.6%.
- ✓ The application of this method can be made to large size concrete structures like dam, nuclear reactor vessels, and liquid retaining structures where crack initiation may be one of design criterion including final failure condition.

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