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Fracture Analysis of High Strength Concrete by Using ABAQUS Software

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ABSTRACT— The aim of this research paper is to study about the fractural parameters of high strength concrete by using FEM based nonlinear analysis software ABAQUS and comparing its results with experimentally conducting the fracture test as suggested by the RILEM method. High strength M60 grade concrete blocks were modelled and analysed with displacement controlled loading and appropriate boundary conditions. The fractural parameters such as fracture energy, stress intensity factor, fracture toughness, energy release rate and load displacement relations were evaluated. These parameters form the vary basis of fracture mechanics of concrete. Fracture mechanics plays an important role in studying the propagation of cracks in concrete. Basically fracture mechanics is used for understanding the nature of concrete behaviour. Cracks generally propagate in the direction, which is normal to the greatest tensile stress. In heterogeneous materials, crack initiates in the weakest path in the material. While the shape of the crack is highly irregular, it is expected that the irregularities get smoothed out and the cracks grow in a slow manner forming a simple shape along which the stress intensity factor (SIF) is nearly constant.

Keywords: fracture, concrete, ABAQUS, UTM, SIF.

I. INTRODUCTION

1.1 Fracture in concrete: Concrete is a heterogeneous material mainly composed of hardened cement paste and aggregates. Due to nature of cement hydration shrinkage and creep of concrete takes place. Micro cracks and at times even macro cracks evidently exist, in concrete. Thus, failures of concrete members are usually accompanied by propagation of cracks in the concrete matrix. Understanding and modelling exactly how and at what instance concrete fails is not only critical for designing of concrete structures, but also plays an important role in developing new cement-based materials. Different non-linear fracture models were established for evaluating the different concrete fracture parameters. These models are widely known as the Fictious crack model, the Crack band model, the Size effect model, the effective crack model, Two Parameter Fracture Model, Smeared Crack model, Discrete Crack model etc. The important fracture parameters that can be evaluated from these models are Stress Intensity Factor, Crack Tip Opening Displacement and Strain Energy Release Rate etc.

1.2 Test method and experimental setup: Numerous methods are already been established for the determination of fracture parameters of concrete. Among these methods, RILEM method is widely accepted as a standard method for the determination of fracture toughness. The RILEM method recommends the test beam to be initially notched in the centre of the span by a ratio notch depth to beam depth ranging from 0.1 to 0.5 and span length to beam depth ratio as 4 or 5. The beam is then tested in UTM as three point bending test with appropriate effective span and displacement controlled loading condition.

1.3 Introduction to FEM and ABAQUS: The finite element method is a numerical technique for solving problems of engineering and mathematical models. In this method all the variables of the problem, like shape, boundary conditions and loads are considered as they are in real time but the solutions obtained with this are reasonably approximate. It has been developed by the extension of matrix method of structural analysis. This method is widely used in various fields such as in the analysis of solid mechanics, fluid dynamics, heat flow, electric and magnetic fields and many more. Structural engineers adopt this method extensively for the analysis of beams, frames, folded plates, shells problems and also in seepage analysis of fluid. Both static as well as dynamic problems can be handled conveniently by finite element analysis. The FEM perfectly suits for approximating the solution to the differential equation governing the particular problem. Some known FEM software packages are STAAD, ABAQUS, ANSYS, GT-STRUDL, NASTRAN etc. Using these software packages one can conveniently analyse the complex structures.

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II. FINITE ELEMENT MODELLING OF CONCRETE BEAMS

2.1 Material property, Geometry and Assembly:

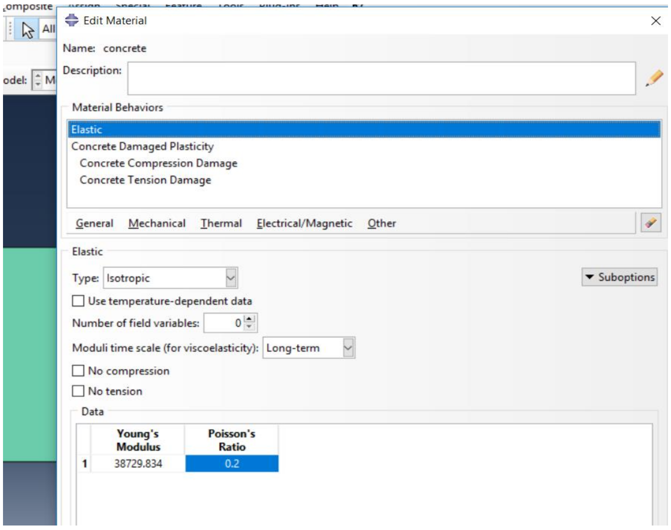

Fig 2.1: Material properties of concrete.

Standard specimen of fracture test as shown in fig 2.1 is developed for the present study. The material properties assigned for the concrete beam resembled to high strength M60 grade concrete. The modulus of elasticity of concrete (E) is taken as 38.7Gpa. The plastic behaviour of concrete was assigned by concrete damage plasticity model appropriately as suggested by the ABAQUS forum. The depth of the beam (D) is taken as equal to 150mm.The specimen length (L) is taken by the ratio L/D equals to 5. The ratio of initial fictious crack depth (a) to beam depth (D) is taken as 0.167 as required for the RILEM method.

2.2 Meshing the Element:

This is an important part of FEA, as it defines the accuracy of analysing any given problem by dividing it into number of sections of regular shapes. Generate the finite element mesh by appropriately choosing the suitable meshing technique that ABAQUS/CAE uses to create the mesh, element shape and its type. While assigning the section we can assign a particular ABAQUS/CAE element type to the given model. Basic meshing requires two stage assignments: first seed the edges of the whole instance, and then mesh the part of the instance. The number of seeds to be assigned is based on the element size or on the number of elements that are present along an edge. In the present study the model is meshed with quadrilateral shape elements with approximate global size as 5 as shown in the figure 2.2.

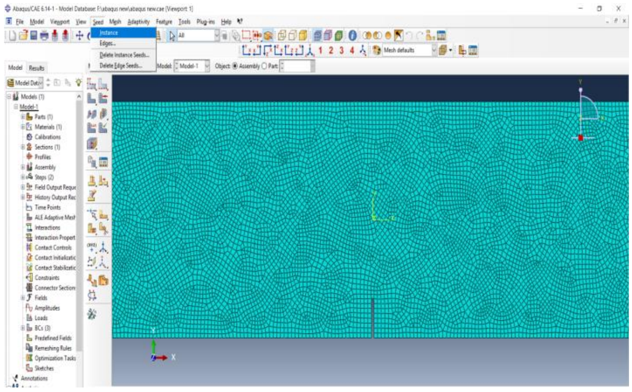

Fig 2.2: Meshed concrete beam.

2.3 Boundary conditions and loading: The supports are assigned as per three point bending test. The vertical roller supports are provided at left and right supports by making the line elements of position 12.5 mm from both the ends as zero displacement. The loading is applied as displacement controlled loading until the fracture of concrete. The loading is given with the help of static riks function as a step loading with final load at the end of 100th step. The boundary condition and loading provided to the model is as shown in figure 2.3.

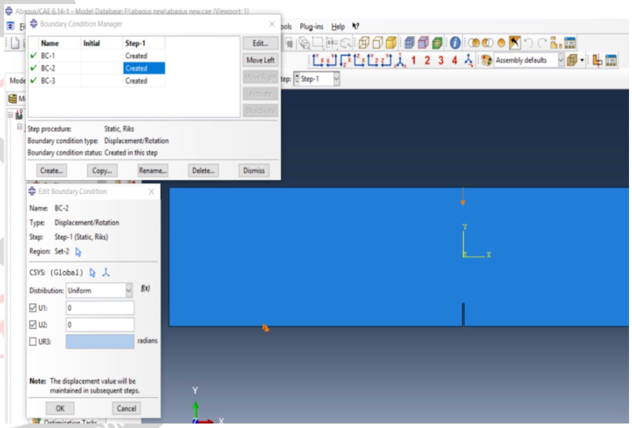

Fig 2.3: Boundary conditions.

III. RESULTS AND COMPARISON WITH RILEM TEST

3.1 ABAQUS Results: Job analysis was performed on the model and the load and displacement data were obtained from the history output tab in the result visualisation section. the peak load sustained by the concrete before fracture is obtained as 17.37KN. The midpoint deflection of the concrete model attained a value of 2mm. The following fig 3.1 refers to the result visualisation and load and deflection values.

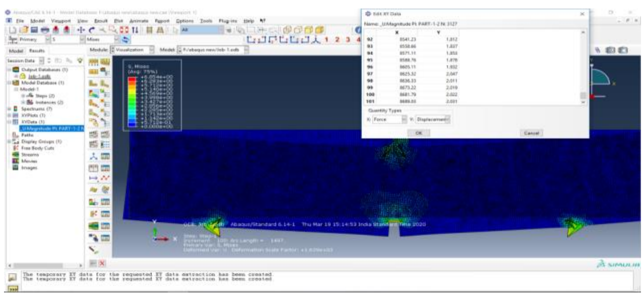

Fig 3.1: Result and visualisation of fractured beam.

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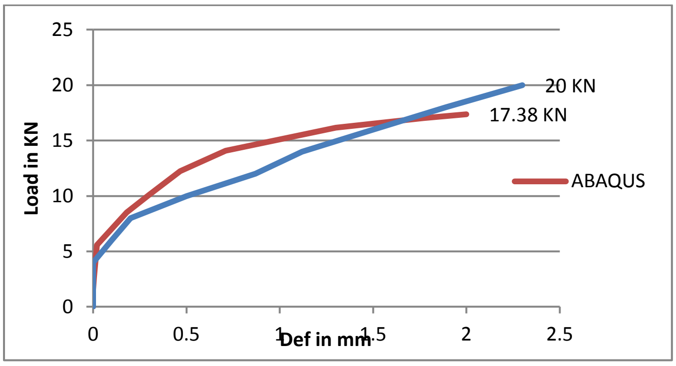
3.2 RILEM test results: The important observations from the RILEM test are as follows ; the peak load achieved by the concrete before fracture was observed as 20KN. The mid point deflection of beam was observed as 2.3mm.

3.3 Load deflection graph: the load and deflection data obtained from the ABAQUS and RILEM test were interpreted in the following chart with load on y-axis and deflection on the x-axis.



Graph 1: Load versus deflection comparison.

3.4 Fracture energy: The fracture energy of any material is considered as the area under the load deflection curve. The fracture energy evaluated from the ABAQUS result data came out to be 26.437KN-mm whilst the fracture energy computed from RILEM test method is obtained as 29.04KN-mm.

3.5 fracture toughness or stress intensity factor: SIF is the ratio of fracture energy and c/s area of fracture i.e. SIF comes out to be 1.175 N/mm2 as per the ABAQUS software and 1.29 N/mm2 as per RILEM test method.

3.5 Energy release rate: The energy release rate as per Griffith energy criterion is given by G=SIF2/E where G= Energy release rate, SIF= Stress intensity factor, E= young's modulus of concrete. The Energy release rate computed as per ABAQUS is 0.0356KN/mm2 and that as per RILEM test is 0.042KN/mm2.

IV. SUMMARY AND CONCLUSION

In this paper fractural parameters of high strength concrete have been evaluated using non-linear FEM based ABAQUS software and compared the results with RILEM fracture test method. From the obtained results following conclusions can be summarised.

1. The peak load and the deflection values obtained from FEM software ABAQUS and RILEM test shown a similar trend with a slight variation ABAQUS being marginalised to lesser values.

2. Similarly the fracture energy, fracture toughness and energy release rate obtained shown a slight variation.

3. Despite concrete being a heterogeneous material and diverse casting and working conditions the RILEM test results and ABAQUS results are reasonably relatable.

4. Fractural parameters of concrete for required notch to depth ratio and grade of concrete can be conveniently evaluated from ABAQUS software without compromising the accuracy of the results.

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