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Concrete Damage Plasticity Model of Brazilian Tests On Concrete Cylinders With An Effect of Concrete Compressive Strength On The Nature of The Size Dependence

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Abstract

In this research, it has been attempted to investigate the ability of the Concrete damage Plasticity (CDP) material model of the ABAQUS standard software to take into account the size effect phenomenon in simulating the behaviour of concrete structure automatically. To this end, four different grade of concrete and six different size of specimen were used in a standardized split tensile test experiment and were simulated by the ABAQUS software using so-called CDP model for the concrete material. Identification of the parameters used in CDP model used in simulation is done by validating the same. In addition to the material model, the same boundary conditions and finite element attributes were implemented in six different test simulations for four different grades of concrete enabling the author to assess just not only the effects of the size of the specimens on the obtained results but also the effect of concrete compressive strength on nature of size dependence. After comparison of the results obtained from simulation with the corresponding ones extracted from the experiment, it was revealed that in the CDP model of the ABAQUS software can automatically take into account the size effect on tensile strength but is not that prominent.

Keywords: *Concrete Damage Plasticity, Split Cylinder tensile test, Size effect, Concrete*

I. Introduction

In designing a Concrete structure the tensile strength is an important parameter, the size effect of concrete in tensile strength is still a curiosity for the optimum design. One of the tests, Split Cylinder test also called a Brazilian test is used to measure it. In which a cylinder is loaded in a compression diametrically between two platen. According to theory of elasticity, this loading produces a nearly uniform maximum principle tensile stress along the diameter which causes the cylinder to fail by splitting. Although the stress state in not uniaxial(there is significant compressive normal stress in the transverse direction), the tensile stress value in the cylinder at failure has proven to be a useful measure of the tensile strength.

Different researchers experimentally demonstrated that the split-cylinder strength depends on the diameter. However, unique trend is cannot be deduced from available data. They find the following type of behaviour: (a) the test of Sabnis and Mirza [1979] and Kim et al.[1989] show a continuous decrease of strength over the range of sizes of testing (so do the tests of Ross, Thompson and Tedesco[1989]; (b) the test of Chen and Yuan[1980] shows an increase similar to the test reported by.

Hondros [1959]; (c) the tests of Hasegava, Shioya and Okada[1985] covering a broad size range, from 100 to 3000 mm in diameter, reveal a decrease of strength followed by a plateau where the size effect disappears or even a slight increase is discerned(a similar trend was observed in the test of granite by Lundborg [1967]); (d) the tests of square prism reported by Rocco el al.[1995]show a strength constant within a experiment scatter;(e) finally the test by Bazant, He el al.[1991] show first a marked decrease of strength, followed by a slight increase of strength..Different researcher experimentally demonstrated that the split-cylinder tensile strength depends on the diameter. However, there is no agreement on the nature of dependence..Olesen, Ostergaard, and Stang [2006] indicated that when the diameter of the cylinder increases, or width of the loading strip decreases, a better estimate of tensile strength is obtained. Also it was concluded that cylinders perform better than cube for the estimation of the strength. These conclusions are true for intermediate concrete qualities. If the material has deviating ratio between compressive and tensile strength, that is, deviating from the common value of roughly ft=.1fc, different behaviour may emerge. When tensile and compressive strength are more or less equal, crushing of material below the loading strip may prevail. Moreover, for plastic materials, for example, when fibres are added to the cement based matrix, the split-cylinder test is not suited for determining the tensile strength not even in an approximate manner. Tang, Shah and Ouyang [1992] analyzed the split-cylinder test using the two parameter model of Jenq and Shah[1985]. They assumed symmetric crack growth starting from a central notch of various sizes and considered various width of loading strip. With this model they produced the size effect curves for a particular concrete. The splitting of square prism also analyzed using cohesive crack model. This was done by Modeer [1979] using a linear softening function, for a loading strip of width .1D. He assumed a single crack along the loading plane and considered the material to be elastic. He found a small size effect for small dimensions and mild size effect for large dimensions.

II. Description of the Structure and Modeling

The concrete with split cylinder test for different size of cylinders used are modelled by finite elements in a commercial programme environment of ABAQUS. The elements are four node rectangular isoparametric plain stress elements (type C3D8R), and the mesh is shown in Fig. 2.1. It is assumed that a crack may develop in the vertical plane of symmetry. Fixed boundary conditions are specified along the bottom loading strip and the top loading strip is allowed to move vertically constraining other degree of freedom. All vertical displacements of the nodes on the loaded horizontal surface of the loading strip are tied together with cylinder to ensure synchrony. The load applied is displacement controlled so as to know the exact crack pattern in failure of the specimen.

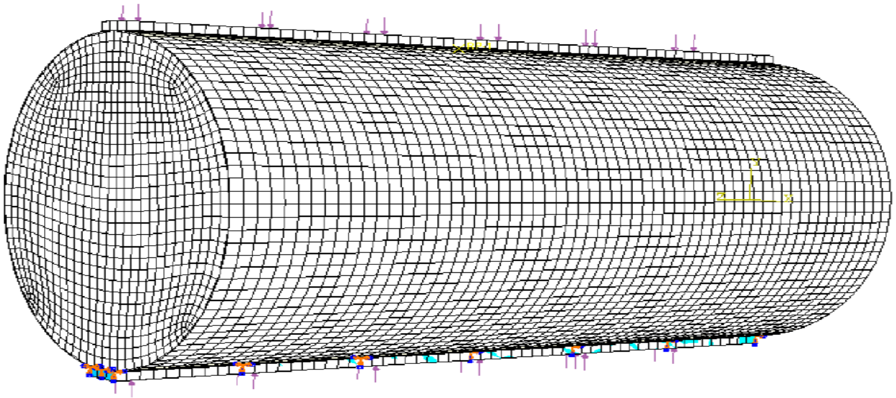


Fig 2.1 Split-cylinder test Numerical model specifying plattens and loading.

For concrete in solid elements the constitutive behaviour is described by Concrete damage Plasticity model. The material of the loading strip elements are modelled as rigid. The problem is solved under an adaptive load step control, and the convergence criterion is based on an energy norm.

A. Convergence Study

The quarter cylinder is used as reference case for conducting the convergence study. Figure 2.2 shows the convergening trend of the predicted load capacity as the mesh element reduces. The difference in the load capacity as the mesh size decreases from 2.5 mm to 1.5 mm is 2.9 percent. On the balance of accuracy and computational economy 2.5 mm mesh is used for all modelling**.**

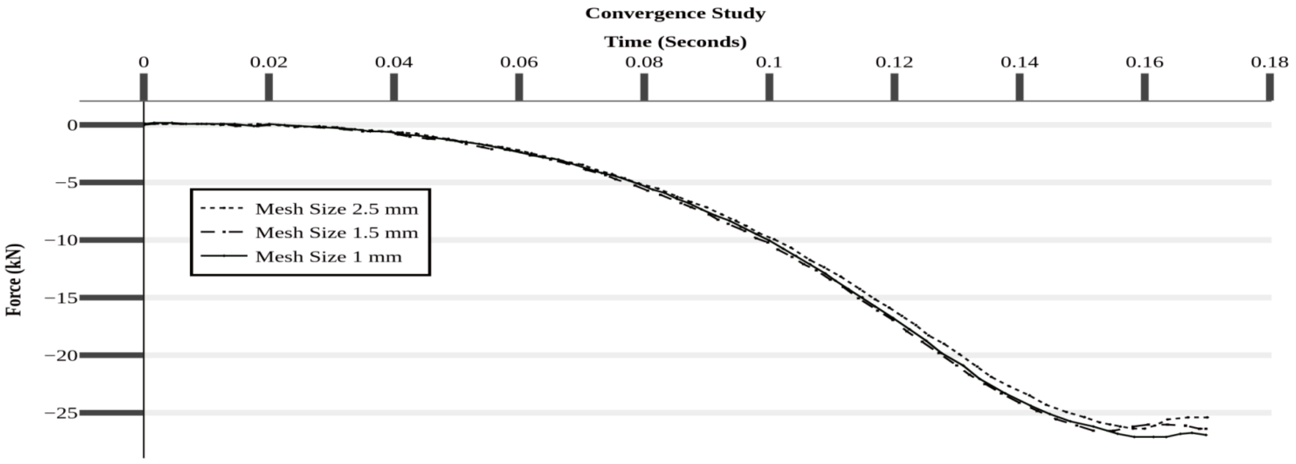


Fig 2.2 Numerical implementation for the size effect study and validation of the model.

The size effect study of split cylinder effect is conducted on the cylinder of sizes 70mm,105mm, 190mm, 300mm, 400mm, 500mm of same thickness 100mm. The study is completed for different grade of concrete 20Mpa, 30Mpa, 40MPa, 50Mpa. The parameters for plasticity part are the default value given by ABAQUS. For different grade of concrete the material parameters which govern the hardening and softening rule and evolution of scalar damage variable are different which are based on the stress-strain curve for compression and bilinear stress-displacement curve for the tension. The damage parameters are not used for compression because at the material point level always the failure happens in tension. To validate the model and the parameters the standard compression test is simulated of cylindrical specimen of size 150 mm diameters, and length 300 mm. The parameters are kept same as given for the split cylinder test for every grade of concrete. The mesh is shown in the Figure 2.3. The loading is applied by coupling the displacement of all the nodes to one center node which is allowed to move vertically restraining all degree of freedom, loading applied is displacement controlled. The comparison of stress-strain graph in compression obtained experimentally and by simulation is done for all grade of concrete. The fracture energy for different grade of concrete in numerical simulation is taken as 34,72,110 and 156 N/m respectively for 20,30,40 and 50MPa grade of concrete.

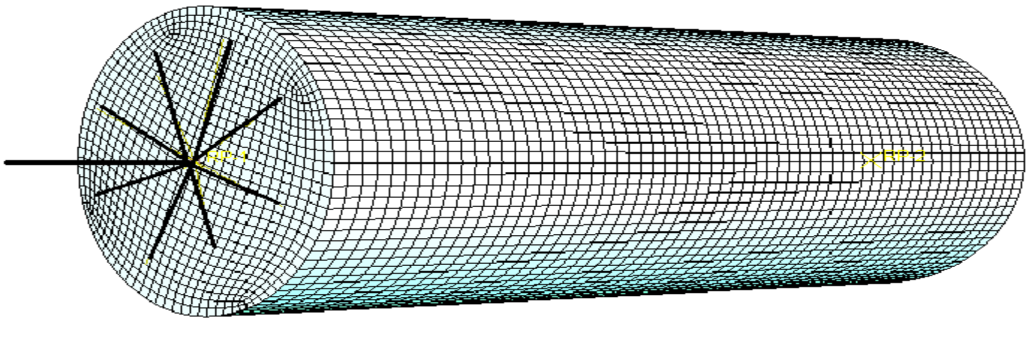


Fig 2.3 Standard compression test with the coupling of nodes to the center node.

III. Material Modeling

A. Concrete damage plasticity

The concrete damage plasticity model is used for the analysis of concrete and other quasi-brittle material. To represent the nonlinear behavior of concrete the concept of isotropic damaged plasticity is used. This

Constitutive theory can capture the irreversible effects of damage that occur in concrete for monotonic, cyclic load under little confining pressure. To describe this behavior the following features are considered:

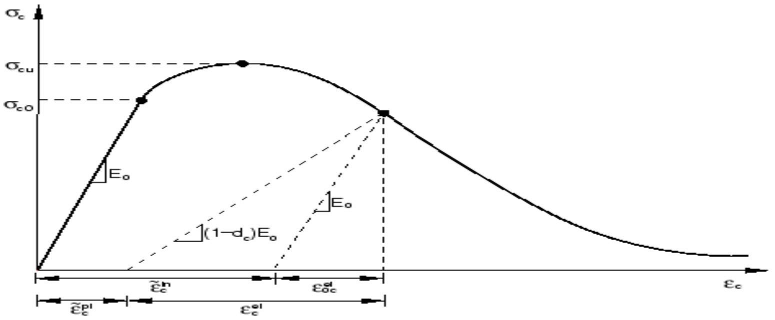
- Different yield strengths in tension and compression softening behavior in tension as opposed to initial

hardening followed by softening in compression

- Different degradation of the elastic stiffness in tension and compression
- Stiffness recovery effects during cyclic loading and
- Rate sensitivity, especially an increase in the peak strength with strain rate.

The stress strain relation is governed by scalar damage plasticity

$$\sigma = (1-d)D_o^{el}:(\varepsilon-\varepsilon^{pl}) = D^{el}:(\varepsilon-\varepsilon^{pl})$$



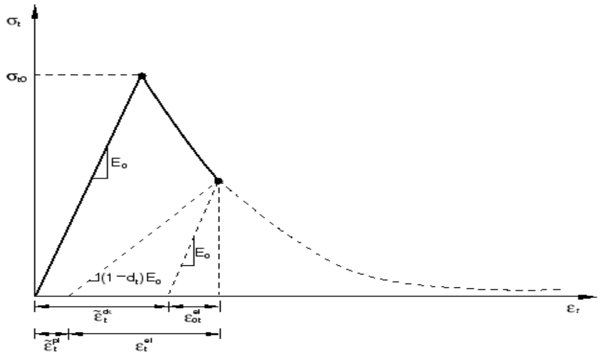


Fig.3.1Response of concrete to uniaxial loading in Compression Fig.3.2. Response of concrete to uniaxial loading in tension.

where, D_o^{el} is the initial (undamaged) elastic stiffness of the material.$D^{el} = D_o^{el}(1-d)$ is the degraded elastic stiffness; and d is the scalar stiffness degradation variable (d_c is the stiffness degradation variable for the compression case and d_t is the stiffness degradation variable for the tensile case), which can take values in the range from zero (undamaged material) to one (fully damaged material). Within the context of the scalar-damage theory, the stiffness degradation is isotropic and characterized by a single degradation variable d. Following the usual notions of continuum damage mechanics, the effective stress is defined (Lubliner, 1989 [3]) as:

$$\bar{\sigma} = D_o^{el}:(\varepsilon-\varepsilon^{pl}) \qquad (2.3)$$

The Cauchy stress is related to the effective stress through the scalar degradation relation:

$$\sigma = (1-d)\bar{\sigma} \qquad (2.4)$$

In the absence of damage d=0, the effective stress is equivalent to the Cauchy stress. It is convenient to formulate the plasticity problem in terms of the effective stress using equation (2.4) to calculate the Cauchy stress.

A. Material Properties

a) Concrete

Material properties	Values
Density	2400 kg/m3
Dilatation angle	36
Flow potential Eccentricity	0.1
Biaxial to uniaxial stress failure ratio fbo/fc	1.16
Shape of loading surface in deviatory plane	0.667
Viscosity parameter	0

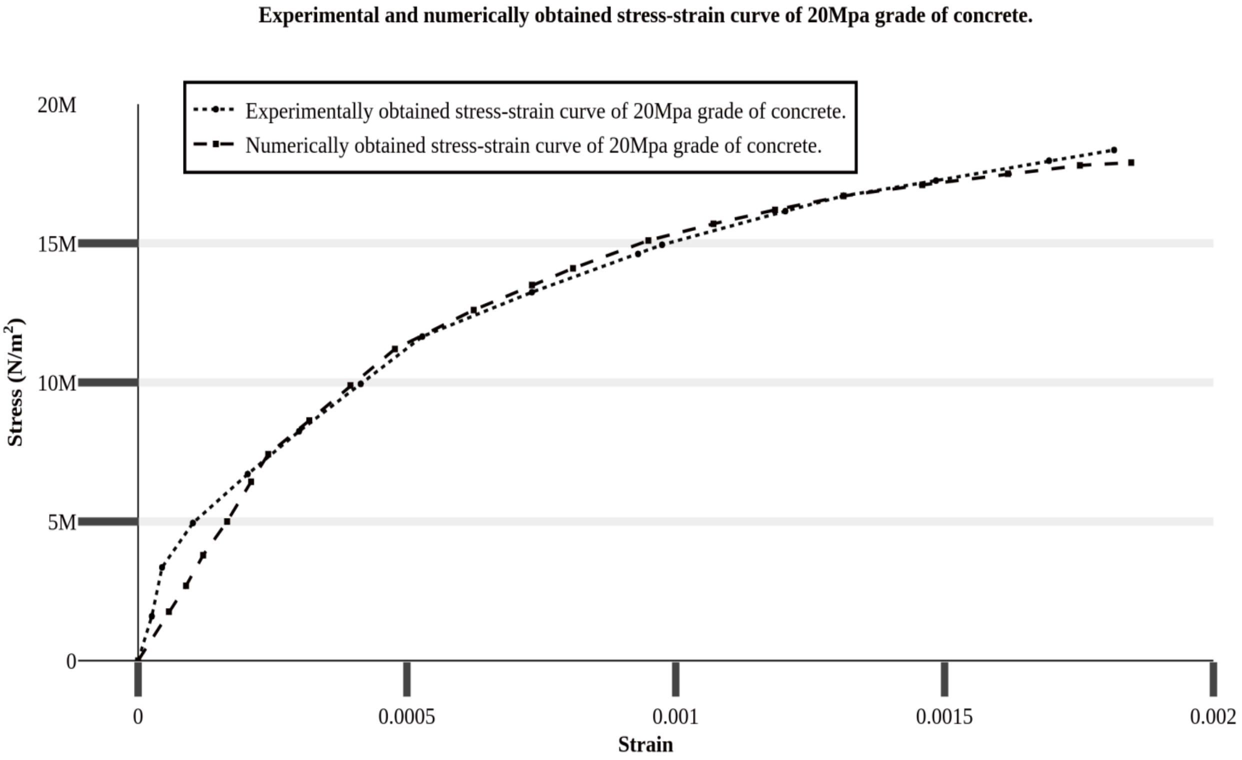


Fig 3.3 Experimental and numerically obtained stress-strain curve of 20Mpa grade of concrete.

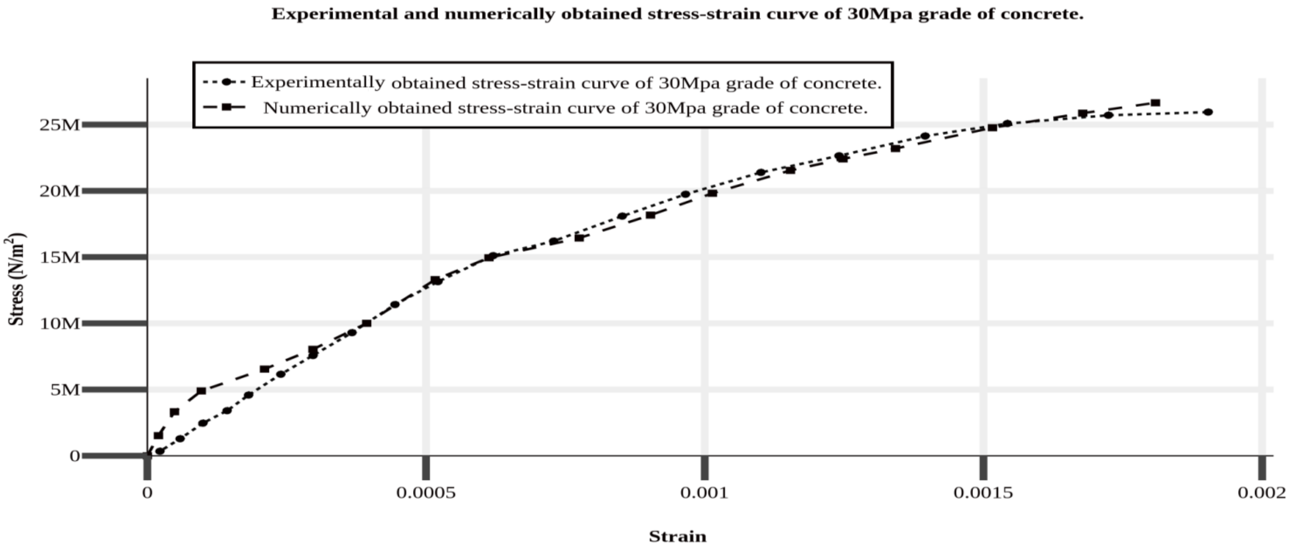


Fig 3.4 Experimental and numerically obtained stress-strain curve of 30Mpa grade of concrete.

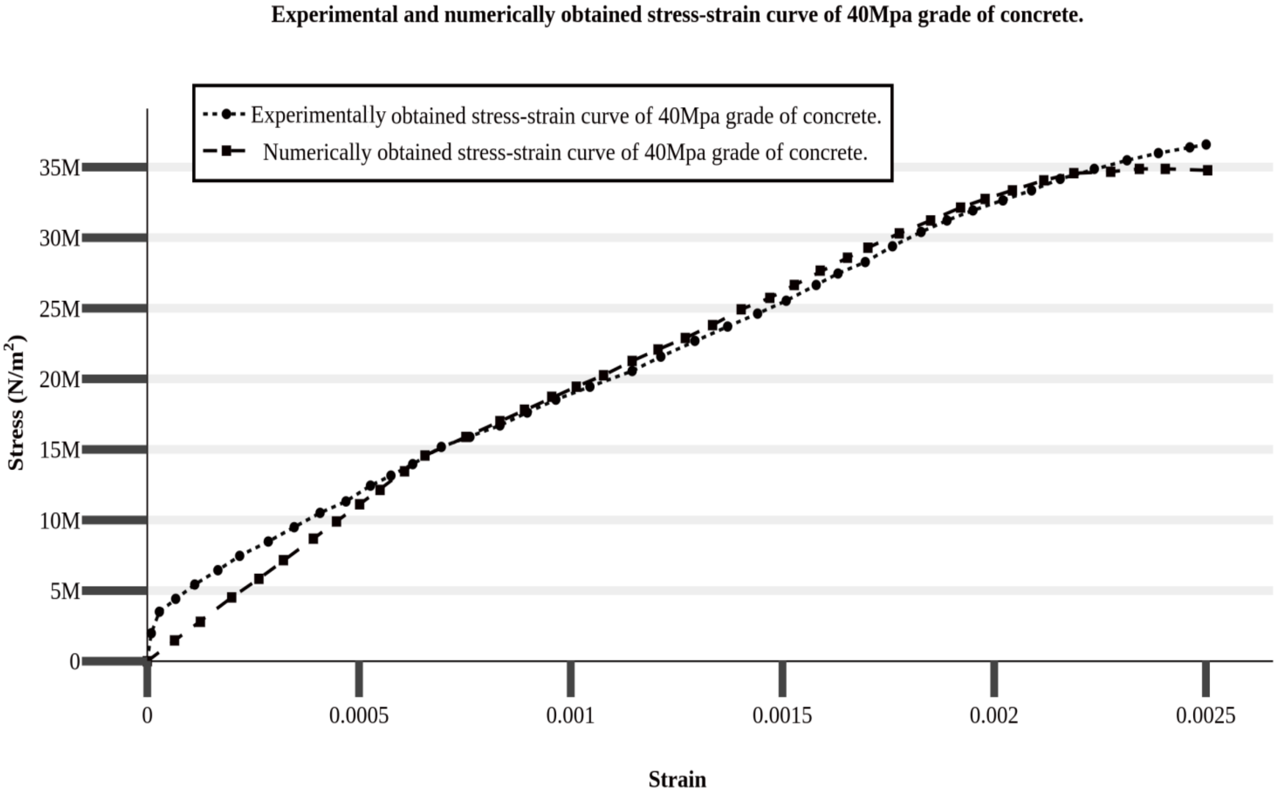


Fig 3.5 Experimental and numerically obtained stress-strain curve of 40Mpa grade of concrete.

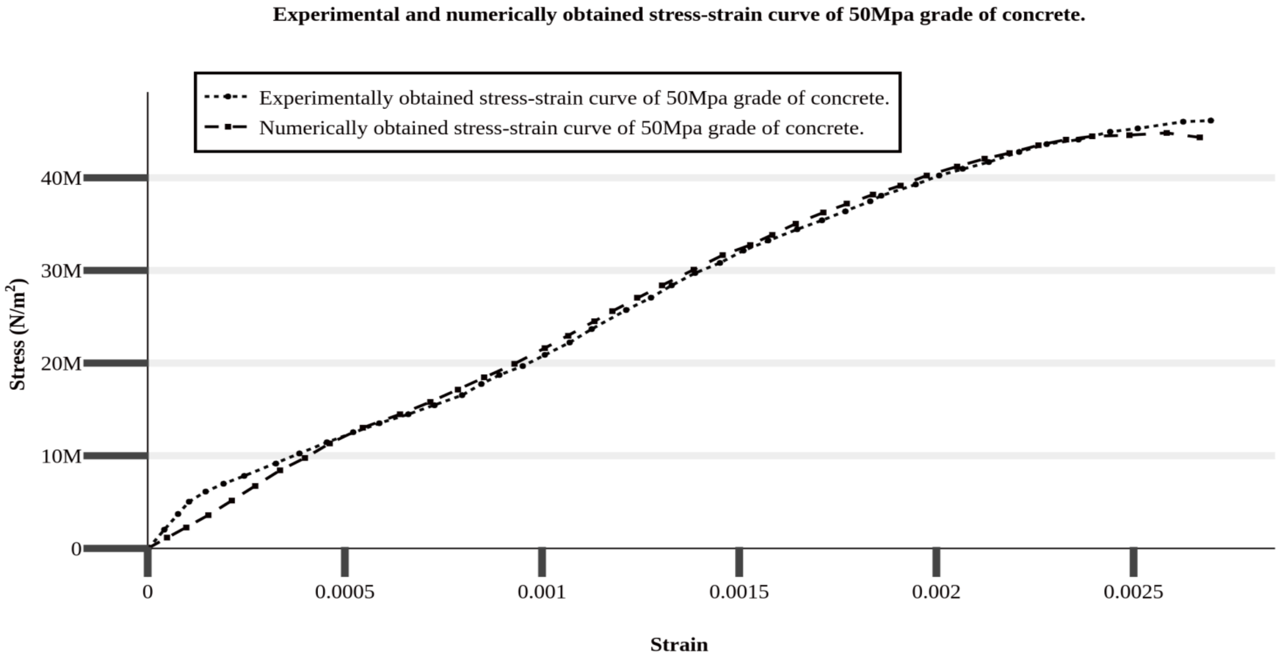


Fig 3.6 Experimental and numerically obtained stress-strain curve of 50Mpa grade of concrete.

Fig 3.3 to Fig. 3.6 shows thecomparison of stress-strain graph in compression obtained experimentally and by simulation is done for all grade of concrete.

IV. Experimental results for the split cylinder test

To study the size effect, tests of very broad size range 1:7, were conducted on cylinders of diameters d=70,105,190,300,400 and 500 mm. The thickness of all specimen (i.e., the cylinder length) was b=100 mm. all the specimen were cast from one and the same batch of concrete. The maximum aggregate size was of 20 mm. The four different grades (20, 30, 40 and 50MPa) of specimens are casted in the experimental investigation. The specimen was cast with the cylinder axes being vertical. The moulds were stripped after one day, after which the specimen were cured for 28 days in a moist room of approximate 95 percentage relative humidity. At the age of 28 days, the specimen was tested in closed-loop testing machine.

A. Analysis and Results for size effect

The nominal stress values obtained from the experiment are plotted in Fig.4.1 in linear scale of σ_N vs d. The nominal values from numerical simulation are platted in Fig 4.2. The comparison of different grades are shown in the curve. The best fit for the values obtained from experiment shows that the values first deceases upto a diameter of 400 mm after that there is a slight increase in the values the same is reported by the Bazant, He elal.[1991]. The values obtained also shows that as the strength increases the deviation is more prominent. In the numerically obtained strength values by the Concrete Damage Plasticity Model for the concrete the Strength values decreases with the size and the deviation as shown in the experiment is not seen. Moreover the prediction of the values is also not that prominent

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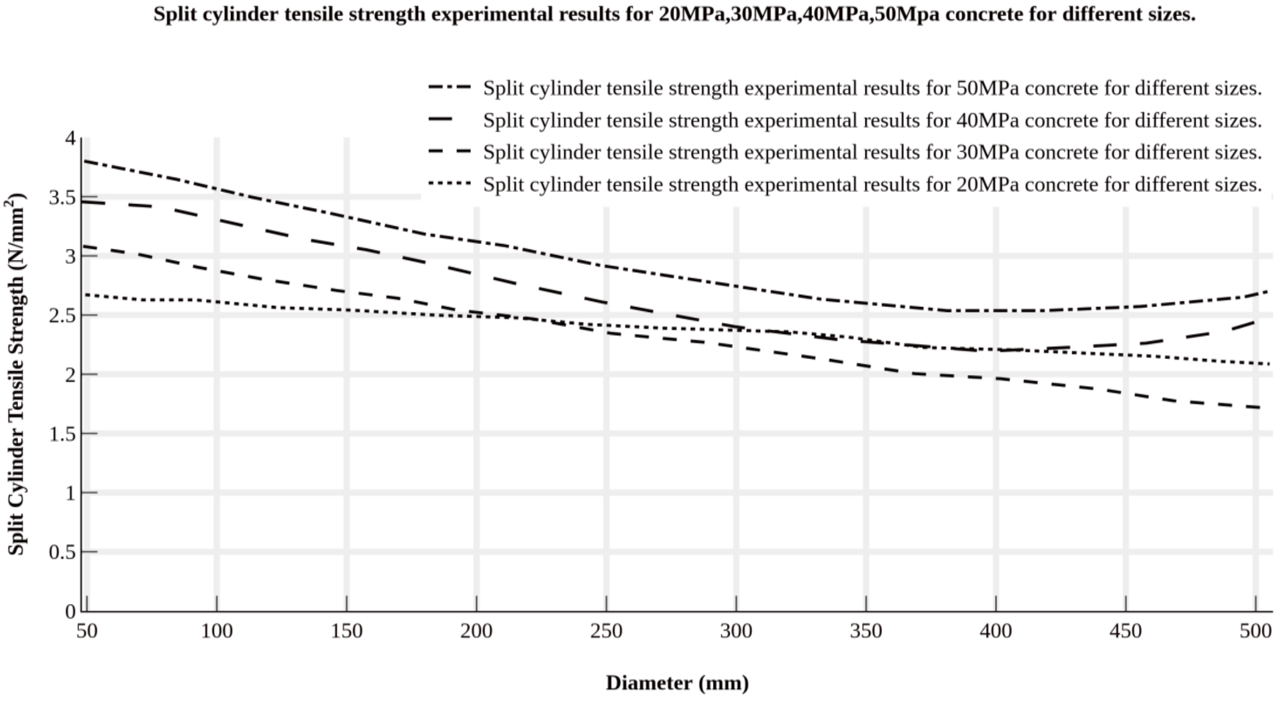

Fig 4.1 Results of experiment for size effect in split cylinder strength.

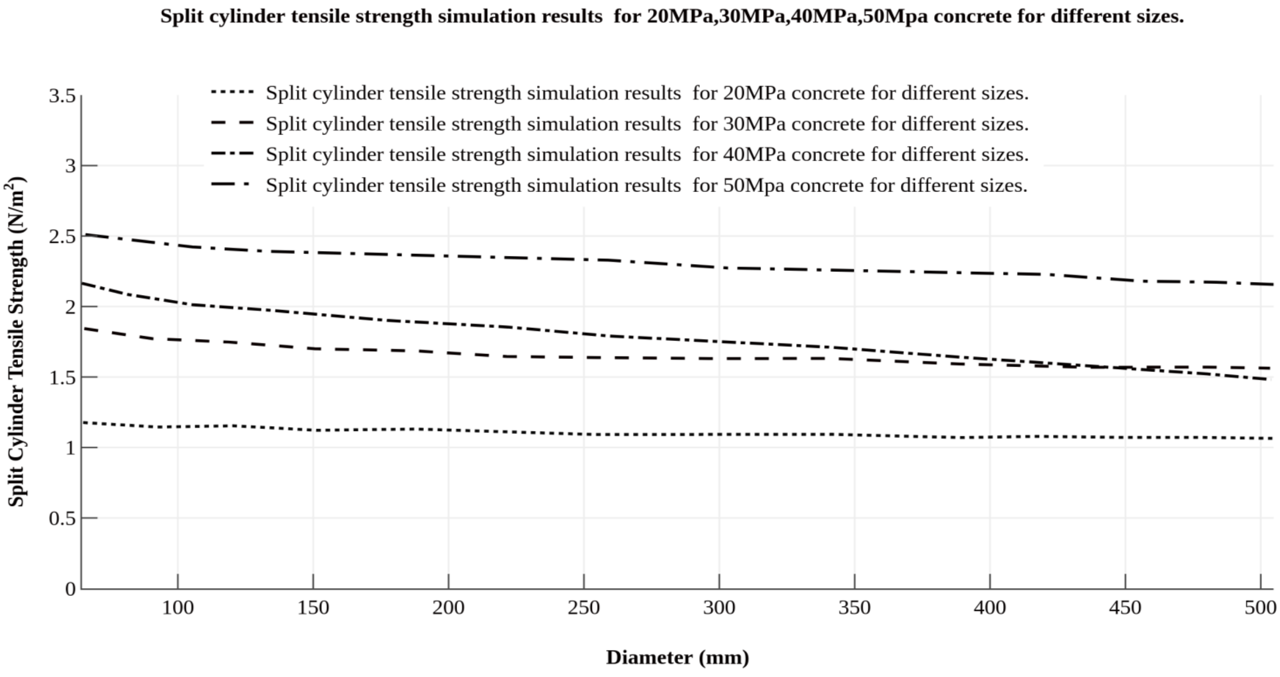

Fig 4.2 Results of numerical simulation for size effect in split cylinder strength.

The crack patterns in experimental results and numerical analysis are similar. The definition of anisotropy of concrete in compression and tension eventually leads to correct crack patterns.

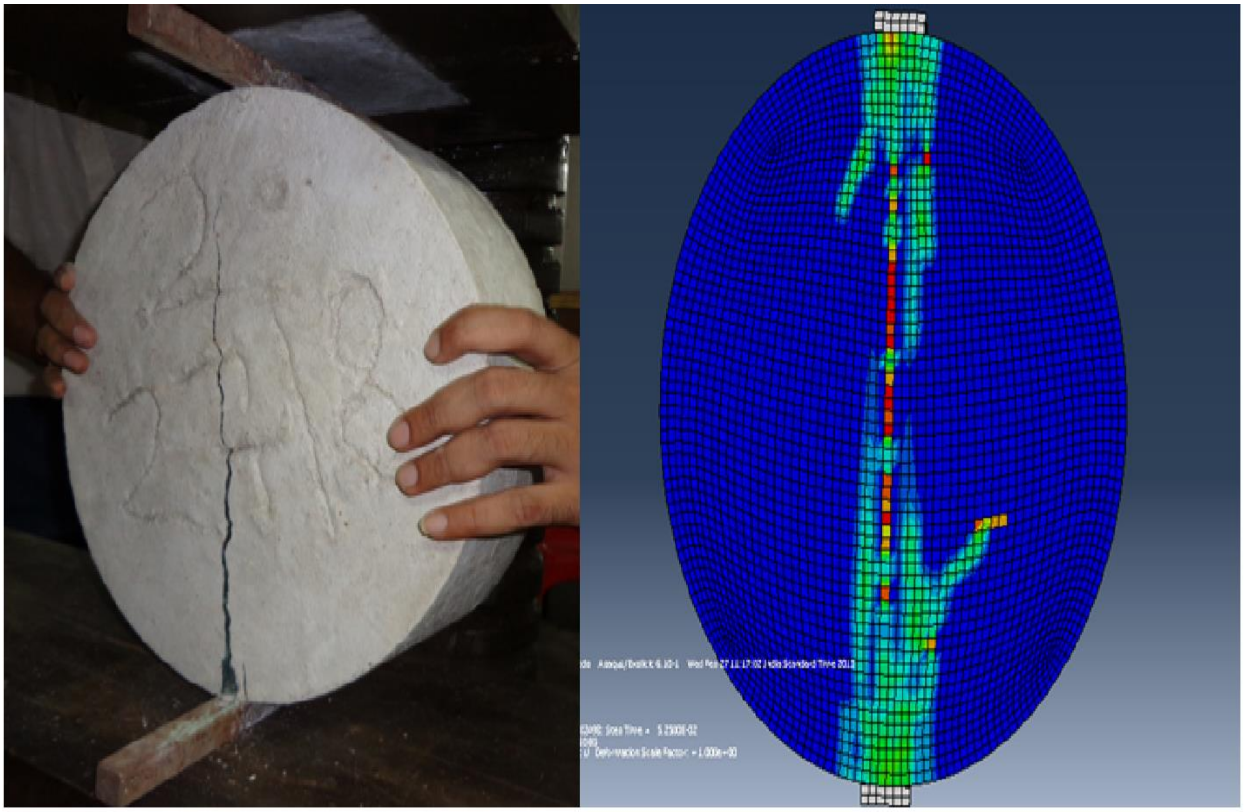

Fig 4.3 Comparison of crack pattern in experimental and numerical results.

V. Conclusion

The experimental and numerical results confirm the size effect in the split-cylinder test for every grade of concrete. However there is a reversal of size effect in higher grade of concrete which also reported by Bazant. The numerical study conducted for size effect show the size effect but the effect is not that prominent.

The present model gives the crack propagation from center of the specimen then the crack propagate towards the both end, in experimental investigation the load applied is force controlled and the failure is abrupt. In those condition the crack propagation and crack pattern is difficult to achieve.The numerical results are done by validation of parameters by standard compression test and the parameters which are used in the study of size effect are kept same for every grade of concrete. The experimental results give the insight to the effect of grade of concrete in size dependency. The results shows that the grade of concrete increases the size effect become more prominent, also as the grade of concrete increases more the concrete got brittle and the fracture process zone size decreases.

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