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RESEARCH ARTICLE

NON-LINEAR BEHAVIOR OF FIBER REINFORCED CONCRETE COMPOSITE UNTIL COLLAPSE. A NEW PROCEDURE FOR RANDOM FIBER GENERATION

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ABSTRACT

On this work it was developed a Computational analysis of a Fiber reinforced concrete composite (FRCC), with steel fibers. Composite models are subjected to tensile stresses under quasi-static loads until reach the collapse. Of the great importance was the random fiber distribution inside the composite and their fully integration into the concrete matrix, for this purpose it was developed an algorithm that generates the fibers in three levels of random location by using local spherical coordinate systems. Research was carrying on volumetric composite taking into account 3D random fibers distribution. Composites are analyzed under different percentages of volume fiber highlighting the peculiarities of each case. The analysis involves a charge-discharge process monitoring the nonlinear behavior of the composite as well the evolution of cracks and collapse of the composite. The failure process and collapse was done by using finite elements Birth and Death, who modify their properties when they reach a critic tensile stress inside the concrete matrix.

INTRODUCTION

The study and application of the FRCC is not new, five decades ago began first application of this composite, but mainly used to current years in floors, airport runways, etc. The American Concrete Institute (ACI) has created standards for their use either in case of steel, synthetic or natural fibers. In these decades was carry on a great number of experimental and analytical studies on RFCC specimen, showing its capabilities with respect to the hydraulic concrete without fibers (Zollo,1997), this fact has been made possible the use of thinner floors (Nanni,1989).

Some of the key properties of these composites are their toughness and strength to fatigue, aspects of great importance on impact load and reversal stresses cases (Banthia, 1987). Tests on specimens subjected to compression, tension and bending show significant increases with respect to a plain concrete, however, depends both on the amount of applied fiber and type of fiber: steel, synthetic, or even natural fibers (Alhozaimy,1996). The increased use of steel fibers is by their variably form of fibers allowing extra fixing inside concrete matrix, unlike synthetic fibers which are generally straight.

It has been developed procedures for analyzing a FRCC composite, some are based on the identification of failure mechanisms to identify the fractures and their evolution, and others are based on micromechanical models. Forces on the interface fiber-matrix is of a great importance on the understanding behavior of whole composite, although many developed procedures are based on the assumption of fully bonded between the fiber and the concrete matrix. Finally, it has been developed more complex models that involve all phases of the RFCC composite. In all mentioned models, random distribution fibers inside the concrete matrix emerges as a priority question, because response of the whole composite depends of this matter, at the same time all fibers must be well fixed into the matrix. There are developed procedures, one of which is the fibers generation by means of Voronoi cells (Bolander, 1997). In practice the random distribution of fibers leads to clump as with synthetic fibers, perhaps steel fibers allow better distribution uniformity inside composite. Hence the interest on RFCC research has beginning with a proposed procedure for generating a random fiber distribution within the composite.

MATERIALS AND METHODS

The analysis is performed on a FRCC composite subject to tensile stresses. The goal is to report their behavior under monotonically increasing loads until the collapse. The ACI Standards has not specific procedure for stress testing of these

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RFCC specimens in part because the boundary conditions are affected by fiber inclusions (Olivito, 2010). In this work we analyze the behavior of a prismatic RFCC beam clamped at one end meanwhile tensile loads are applied on the opposite end side, fibers distribution are random located inside the matrix. Applying increasing loads leading to early failure in the concrete matrix, additional stresses will be taken up by fibers located near these cracks. Thus, process continues until the composite collapses. Firstly their behavior is analogous to a composite without fibers but beyond failures appears; its behavior becomes nonlinear and continues until collapse. Distribution of fibers within the concrete matrix requires of the corresponding discrete model. Here, volumetric finite element are used, having three linear degrees of freedom (DOF) per node (Fig.1), meanwhile fibers are modeled using a 3D link finite element. The length of the finite element we chosen as a 1/3 of thickness composite such there exist an adequate vertical distribution of fibers. The so generated nodes were used to generate 3D random fibers. Procedure consists in selecting an arbitrary node random way creating a local spherical system at a distance (radius) equal to the required length fiber, a second node was pointed. The choice of this second node is set to random values based on the two angle parameters of spherical create local coordinate system. The 3D finite link element fibers are subject only to tensile or compressive stresses exclusively (Cook, 1988). Figure 2 shows the procedure for generating the fibers. The resulting random final location of fibers is shown in the next figure. Here the case of a fiber percentage of 0.5% is shown.

Theory/calculations

The stress-strain analysis of the RFCC composite under tensile loads is developed based on the following matrix equation (Cook, 1988)

$$\int_V [B]^T\,[D]\,[B]\,dv\,\{U\} = \int_V [N]^T\,\{b\}\,dv + \int_A [N]^T\{s\}dA + \{F\} \qquad \text{........ (1)}$$

Being: [B] = matrix of shape function derivatives, [D] = matrix of elastic constants, [N] = shape function matrix, {U} = displacement vector, {b} = vector of body forces, {s} = vector of surfaces tractions, {F} = vector of nodal external loads.

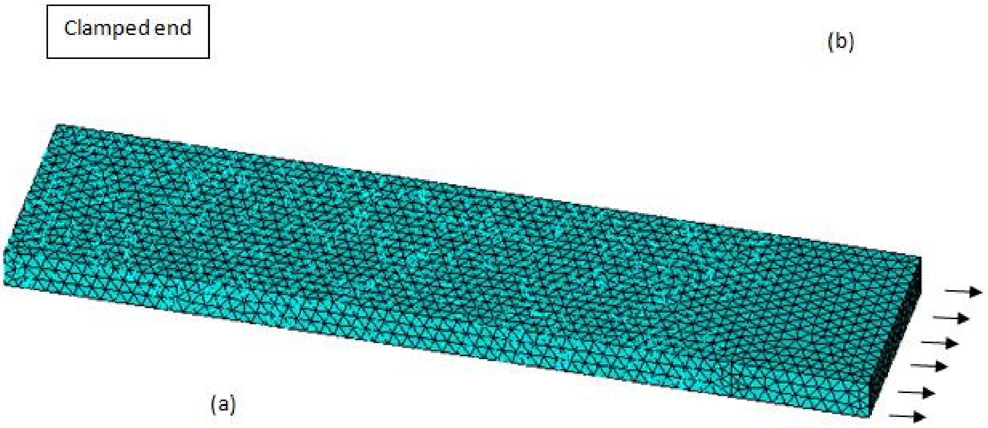

Figure 1. (a) Discrete Model of the RFCC beam, (b) tetrahedral finite element 3 Degree of Freedom per node.

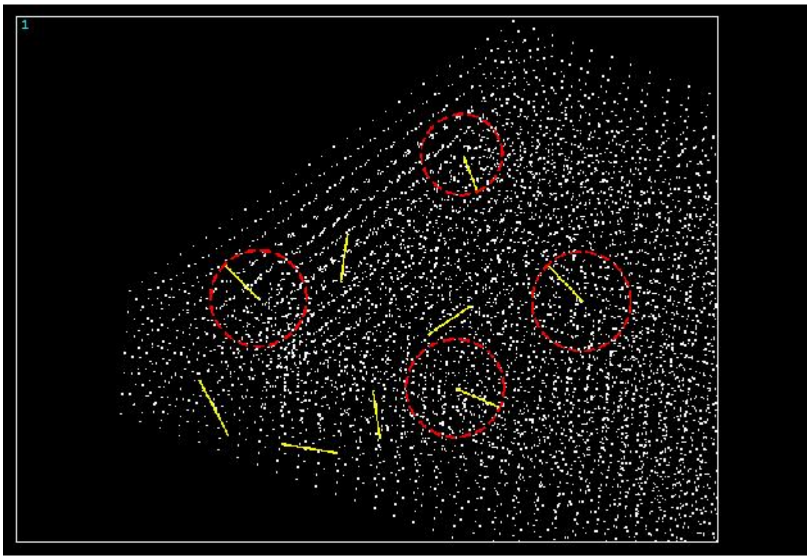

Figure 2. Random generation of Fibers within concrete matrix

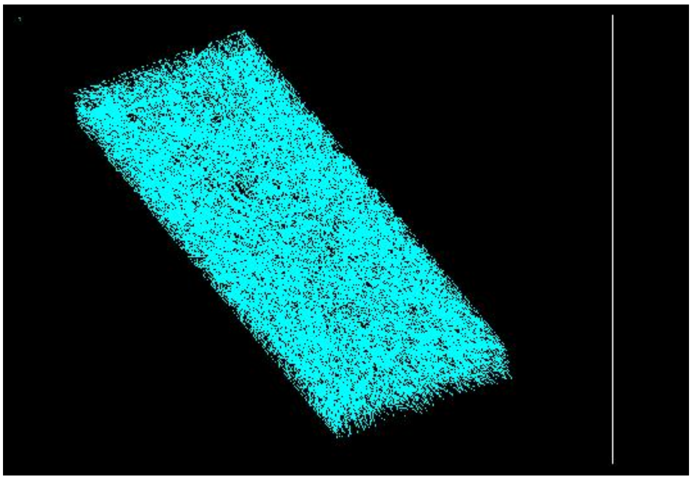

Figure 3. Random fiber distribution corresponding to a 0 5% percentage of fiber in the composite

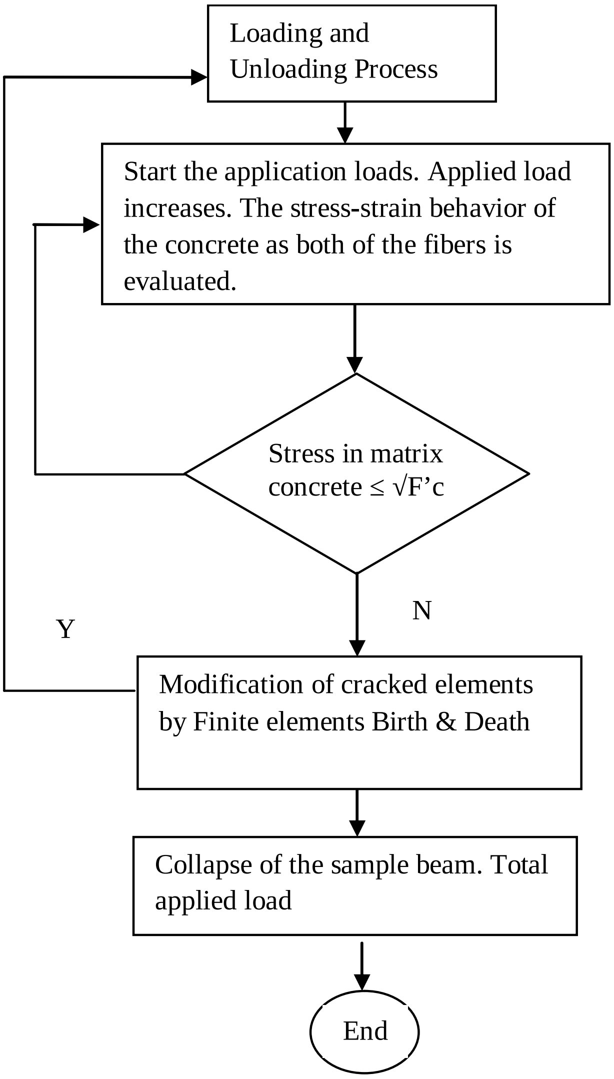

Figure 4. Block diagram of the procedure for the analysis of FRCC composite

Due to slow process of applied loads it can be considered as a quasi-static analysis type; however it requires a charge-discharge iterative procedure to determine the final behavior of composite until collapse. Procedure adopted on this work is described in the Flow-Chart on Figure 4. The increasing loads on the composite generates incipient first cracks commonly when critic elastic range is reached, These fissures can be located in any region within or on the beam surface zones. When a fissure appears within small finite volume element concrete matrix, this element becomes not more able to support and transmit stresses that in turn can spread to adjacent finite elements increasing failure process. At this stage, the behavior of the composite is non-linear, even have become permanent plastic deformations (Stang, 1986; Hillerborg, 1980).

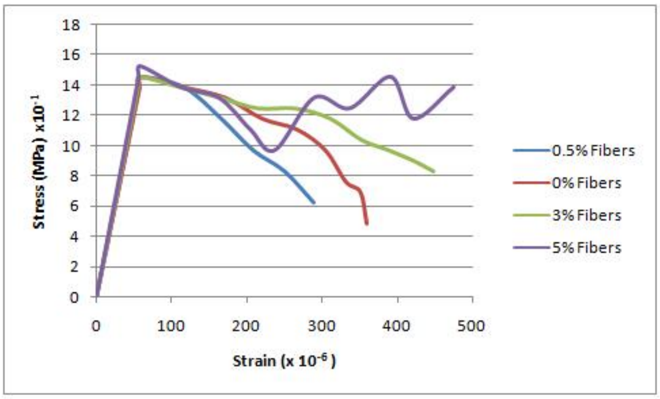

Figure 5. Stress-strain relationship of the RFCC composite with steel fibers . Aspect ratio of fibers= 60

There are treatments for analyzing non-linear behavior of the RFCC composite, some of them referred to fracture mechanics that evaluates the energy generated at each stage of the fracture, the problem here is the difficulty to include all possible fractures. The process presented here identifies a failure as concrete somewhere has exceeded its capacity in tension and monitors the cracks assuming that it has been disabled all finite volume elements where such failure has occurred. The computer developed procedure is written in APDL language and runs on the ANSYS modeling program (Ansys software, 2012). General data are entered including general dimensions of the sample, material properties, amount of fibers and their aspect ratio. Also it is requested the elasticity module of fibers and the suggested number of charge-discharge cycles. Table 1 shows the data used in this work, four types of material are included.

Beginning load-unloading cycles and according load increases, are reviewed the stresses on the concrete matrix, if exceed the critical limit in tension this finite element migrates to material 3: Element Birth and Death (Ansys documentation, 2012), so ends the load cycle, now it proceeds to download the beam sample and restart the load-unload process to determine when and where the fracture newly occurs. The load-unload process is accompanied by the pre-deformation (previous strain stage) that are added to the new load cycle. As the load increases the stresses and strains will also increase, composite will support more stresses due to the fiber capacity to take more deformation than concrete matrix. Described procedure is valid as long as the dimension of the finite volume element is small, the process continues until the composite is no longer able to support additional loads and collapse.

Table 1. Material Properties of RFCC Composite

Properties	Material No. 1 Concrete	Material No. 2:Fibers Case : Steel	Material No. 3 Elements Birth and Death	Material No. 4 Material clamped end
Elasticity Module	24.24 GPa	210 GPa	1E-04 GPa	2.1E+05 GPa
Poisson ratio	0.10	0.25	0.46	0.01
Fiber Length	-----	0.6 cm	------	------
Fiber diameter	------	0.01 cm	------	------

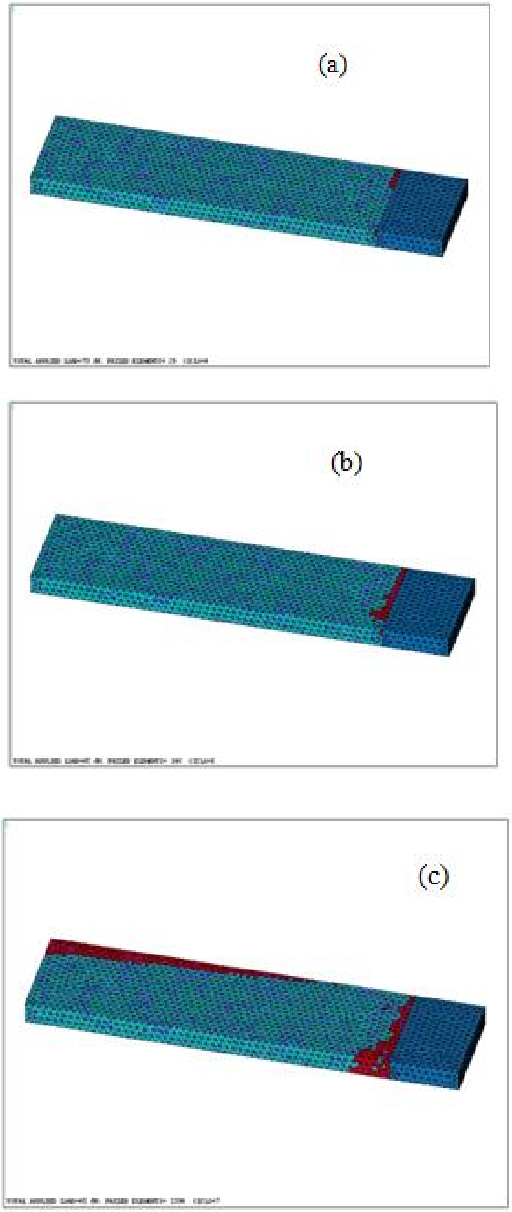

Figure 6. Evolution of the collapse of the steel fiber composite under loads

RESULTS

The analysis on the composite was applied for different percentages of steel fibers; one of the first results concerns the stress-deformation behavior of the composite including the case without fibers. Figure 5 shows the stress-strain behavior. On next Figure 6 is shown the evolution of the steel fibers concrete composite collapse, under a random fiber distribution. The observing case has 5% of fiber volume.

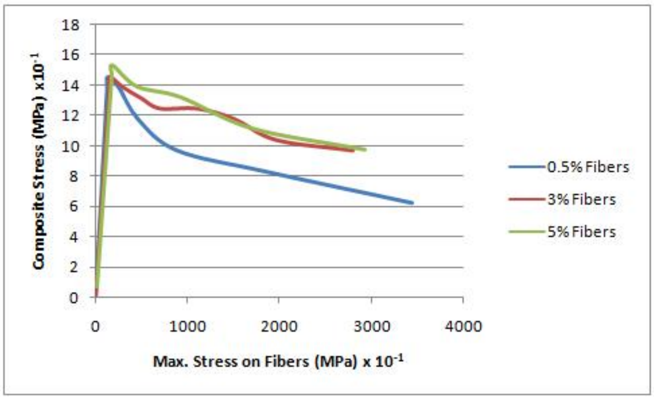

Figure 7. Relationship between the maximum stresses in the steel fibers and total stress in the composite. Aspect Ratio of fibers= 60

The Figure 6 shows some stages of the evolution of failure process for particular steel random fiber distribution. Failure process takes place on non-linear range. On stage (a) Total Applied Load = 70 dN, while Failed elements = 29, Number of Load-unload cycles = 4. On stage (b): Total Applied Load = 45 dN, Failed elements = 140, Load-unload cycles = 6. Stage (d): Total Applied Load = 45 dN, Failed elements = 1394, Load-unload cycles = 7.

DISCUSSION

Random distribution of fibers is a critical aspect in the analysis of the RFCC composite, proposed procedure has the advantage that fibers remain fully integrated to matrix concrete. Applying elements Birth and Death is another noteworthy aspect because unlike treatments requiring a non-linear law (elastic-plastic, trilinear elastic, and so on) here the introduction of these finite elements modify the materials properties as is requested according failure process within matrix. Obtained are comparable with those obtained from experimental solutions (Olivitto, 2010), in addition our results also allow monitoring stress behavior within volume composite as well in every fibers of the composite (see Fig.7). Described procedure is also valid for the composite made of synthetic or natural fibers, however these fibers are more susceptible to create clumps or "nests birds" that decrease the homogeneity in the distribution of fibers (Vondran,1990).

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