Development of tool for estimating the diagram Residual Stress versus CMOD for the SFRC under 3BPT assay based on experimental results

Felipe Marques Queiroz[1], Pedro Paulo Martins De Carvalho[2]

[1]*Undergraduate in Civil Engineering , Federal University of Western Bahia*
Rua Professor José Seabra de Lemos, 316, 47808-021, Barreiras/BA, Brazil
f@elipe.queirozufob.edu.br
[2]*Center for Exact Sciences and Technologies , Federal University of Western Bahia*
Rua Professor José Seabra de Lemos, 316, 47808-021, Barreiras/BA, Brazil
pedropaulomdc@gmail.com

Abstract. The three-point bending test, commonly used for the experimental analysis of a steel fiber reinforced concrete beam (SFRC) involves difficulties, such as its cost of operation and mainly by the values of steel fibers and test equipment. However, relatively few studies are done, especially in Brazil, and much remains to be done for more accurate analyses of the results that corroborate each other. This study deals with the developing of a practical algorithm that is easy to understand the user to provide expected results of a three-point bending test based on experiments conducted by [1], [2] and [3]. The program was developed with the aid of the *Matlab* software and stores the results obtained from the literature in the form of a database and returns to the user a graph of Characteristic Residual Resistance (MPa) versus CMOD (mm).

Keywords: computational tool; reinforced concrete with steel fibers; three-point bending test.

1 Introduction

The high compressive strength of concrete has the consequence, the increase in fragility, so it is necessary to complement composites collaborator to the concrete matrix, such as the fibers generated from different materials, which alleviated this deficiency of concrete behavior, with the formation of an element capable of supporting greater requests and exhibit better behaviors in the presence of deformations. The existence of a dubious material with high strength would allow the realization of slender structures that would lead to a reduction of the overall weight of the structure, which consequently would increase the range of possibilities in the use of concrete.

The development of SFRC (reinforced concrete with steel fibers) occurs through the many researches that are produced to investigate its mechanical properties. The main contributions of steel fiber are: - the increase of the ductility of concrete, since the fibers help in the control of cracking due to its ability to transfer stresses through the cracks, and thus minimizethe concentrations of cracks that cause the sudden rupture of a fragile concrete; - and the increase in the tenacity of the concrete, since the transfer of stresses, causes in the matrix a high post-rupture deformation capacity, which may be, with the increase in compressive strength (stiffening) or without (softening), which will depend on the fiber content present in the matrix.

1.1 Purpose

Assist future experimental assays by providing and estimative diagrams of residual *versus* CMOD of a given sample with established characteristics of matrix resistance, fiber volume and fiber shape index submitted to the three-point bending test by means of a tool that presents low computational cost.

1.2 Limitations

There are limitations in the application of the software due to:

1) The number of experimental studies for steel fiber reinforced concrete, especially in Brazil, is very diverse, with the existence of types of tests submitted to simple flexion, plate puncture, four-point bending, etc., requiring a correlation between the various types of tests;

2)The unpredictability of the orientation of steel fibers in hardened concrete results in different experimental results for specimens of the same characteristics;

2 Bibliographic Review

2.1 Steel Fibers and Shape Index

One of the characteristics of the reinforcement provided by the fibers is the fact that they are randomly distributed in the material, reinforcing the entire part, and not a certain position, as with conventional reinforcements [4]. One and everything indicates [3] that the fiber content is fundamental in controlling the tenacity of the concrete matrix, the higher the fiber content, to a certain extent not to affect the plasticity of the matrix, the better the characteristics of the fiber-reinforced concrete. As the efficiency of the fiber depends on the transfer of stresses between the cracks, it is deduced that the higher the fiber content, the greater the ability to transfer stresses, further increasing the stiffness of the post-cracking part.

In addition to mechanical resistance, one of the main contributions to the behavior of fiber post-cracking is the form factor. This has vital importance in the behavior of concrete after the beginning of the first fissure. The form factor is the relationship from the division of the fiber length (l), not elongated, by the diameter of the equivalent area of its cross section (d), where for each class type, there is a specific equation dictated in norm for the definition of the value of the equivalent diameter.

2.2 The effect of fibre content

A study by [3], presents results of 3-point tests on 69 concrete beams reinforced with steel fibers with different steel contents and matrix strength. It was concluded that the fiber content is the most impacting in the results present in the samples among the influences of compressive strength, fiber yield strength and the effect of fiber size.

2.3 SFRC post-cracking behavior

Depending on the content and type of fiber used in the concrete matrix, it may present two distinct post-cracking characteristics called: hardening, for-high fiber content with high performance and softening, for low fiber content. Both being a contribution in the deformation capacity of concrete before rupture.

According to [5], unlike a simple concrete, the SFRC exhibits a significant residual tensile strength due to the contribution of the fibers embedded in the hardened concrete, although its first resistance to cracking is almost the same as that of a simple concrete. Also according to the author, the SFRC member, however, during the loading process suffers considerable deformations and cracks before the failure, is everything occurs due to the fibers present uniformly in the volume of concrete, in almost all possible directions, which cross the fissure surfaces of the concrete element, although, this improved response displayed by the SFRC is greatly influenced by the amount of fibers that cross the crack, its pullout behavior and the resistance properties.

2.4 Three-Point Bending Test

The three-point notch test, which will be adopted as the main data parameter in this work, follows the standardization of fib Model [6] and the European standard EN 14651:2007 [7]. In this test, the prisms receive a concentrated loading (F) by means of a superior cylinder positioned in the middle of the span, which with the existence of the lower notch, a characteristic curve of load by crack opening (CMOD) is obtained. En 14651:2007 [7] defines prismatic specimens with dimensions of 150 mm x 150 mm and length ranging from 550 to 700 mm. The CMOD is measured by a clip gauge that must be positioned in the middle of the width of the test body, such that the distance between the lower edge and the measuring line is less than or equal to 5 mm.

Using the load curve by crack opening, the following parameters can be calculated: proportionality limit and residual resistances FL, fR1, fR2, fR3, fR4, corresponding to CMOD values equal to the first crack, 0.5 mm, 1.5 mm, 2.5 mm and 3.5 mm, respectively. The results generate a curve where the Fj load parameters that are used in the calculations of residual resistance and proportionality limit can be identified.

The main element that hinders the use of this test for the control of THE SRFC is the need for equipment with a closed system of strain control, that is, the deformation imposed in the test must be controlled by the displacement measured in the test body. This type of equipment is not common in technological control laboratories, being more common in universities and research centers. It is a high cost equipment and more complex operation. From this, the discussion of other alternatives begins, one of which is the inverse analysis, an idea that originated the present study.

3 Developed Computational Tool

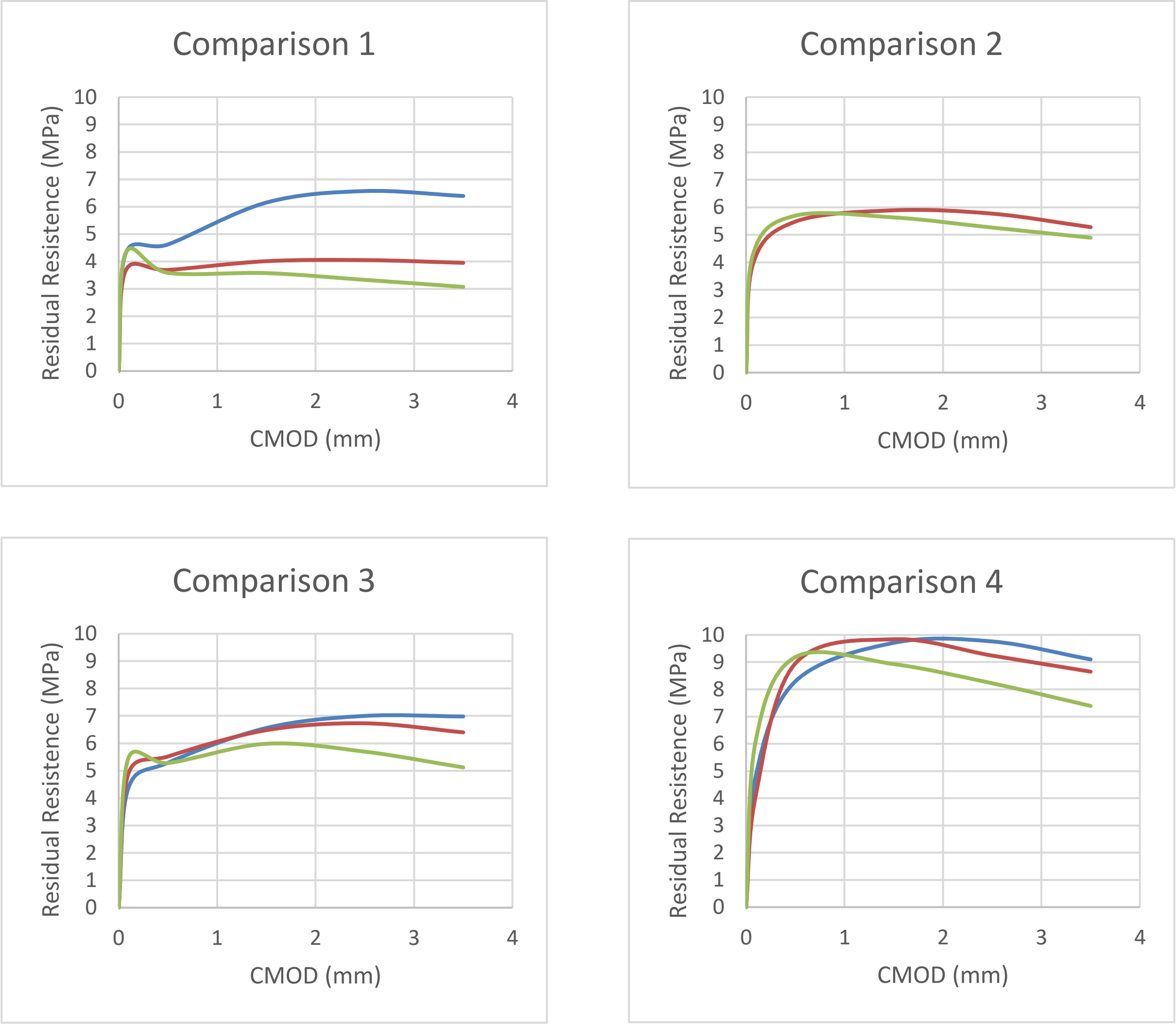
After the analysis of the studies in [1], [2] and [3], the input data that, correlated, inform approximate results of residual resistance (MPa) related to crack opening (CMOD) were extracted.

Graph 1 a), 1 b), 1 c) and 1 d), in which they were constructed with the aid of *EXCEL* and with the data extracted from each author and are presented in Table 1, represent the following views:

1) Comparison 1 - Concrete Matrix Strength: 20 MPa, Fiber Volume :0.5 % or 40 kg/m³ and Fiber Shape Factor Index: 67
2) Comparison 2 - Concrete Matrix Strength: 20 MPa, Fiber Volume :1.0 % or 80 kg/m³ and Fiber Shape Factor Index: 67
3) Comparison 3 - Concrete Matrix Strength: 40 MPa, Fiber Volume :0.5 % or 40 kg/m³ and Fiber Shape Factor Index: 67
4) Comparison 4 - Concrete Matrix Strength: 40 MPa, Fiber Volume :1.0 % or 80 kg/m³ and Fiber Shape Factor Index: 67

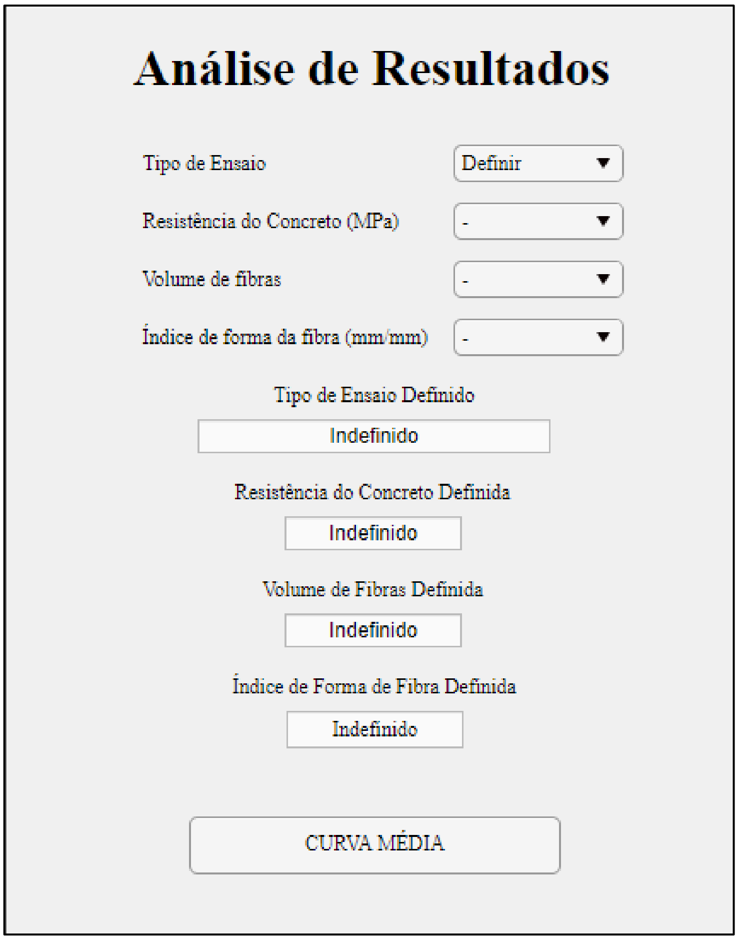
Table 1. Results extracted from the authors' experimental results

Comparison	Concrete Resistance (MPa)	Fiber Volume	Fiber Shape Factor Index	Peak Residual Stress - FL (MPa)	F1	F2	F3	F4	author
1	20	0.5 % - 40 kg/m³	67	3,680	3,690	4,010	4,050	3,950	[1]
				4,310	4,620	6,150	6,570	6,390	[2]
				4,320	3,584	3,575	3,328	3,072	[3]
2		1.0 % - 80 kg/m³		3,970	5,480	5,890	5,770	5,280	[1]
				4,320	5,696	5,632	5,264	4,896	[3]
3	40	0.5 % - 40 kg/m³		4,870	5,520	6,480	6,730	6,400	[1]
				4,350	5,290	6,560	7,000	6,980	[2]
				5,440	5,280	5,984	5,696	5,120	[3]
4		1.0 % - 80 kg/m³		4,070	8,950	9,840	9,240	8,650	[1]
				4,790	8,290	9,710	9,760	9,100	[2]
				4,070	8,950	9,840	9,240	8,650	[3]



Graph 1. Representation of curves related to experimental data, being a) comparison 1 b) comparison 2, c) comparison 3 and d) comparison 4. The colors: red [1], blue [2] and green [3], represent the authors who provided the preparation of The study

From Table 1, a code is elaborated in *the Matlab* software that correlates the comparative data and prints an average curve of the data. Figure 1 demonstrates the main display screen that demonstrates the input parameters that are, respectively, the type of the test, the strength of the concrete, the volume of fibers and the fiber shape index.



Análise de Resultados

Tipo de Ensaio: Definir

Resistência do Concreto (MPa): -

Volume de fibras: -

Índice de forma da fibra (mm/mm): -

Tipo de Ensaio Definido: Indefinido

Resistência do Concreto Definida: Indefinido

Volume de Fibras Definida: Indefinido

Índice de Forma de Fibra Definida: Indefinido

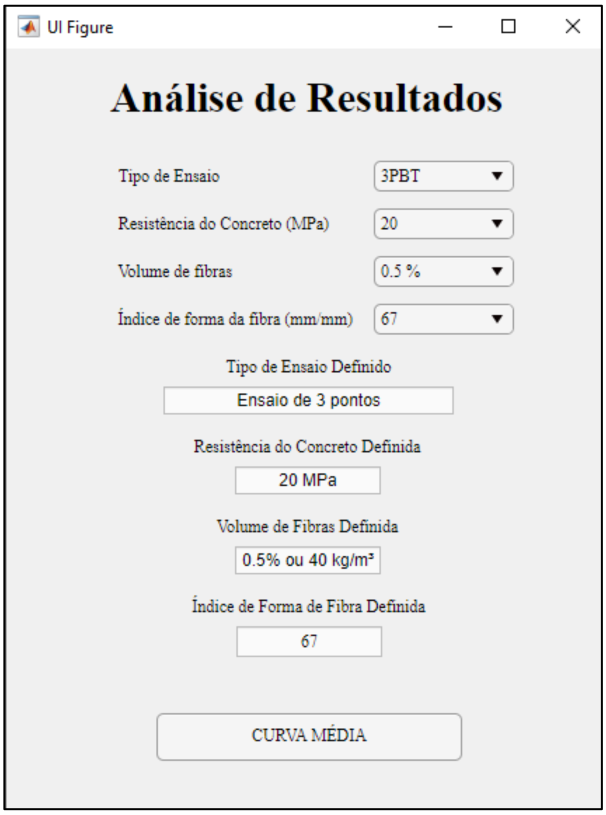
Figure 1. Home screen software

The user has the freedom to select the data according to the database composed of the literatures adopted. Selecting a particular sample to be Figure 2 as shown in Figure 2, the results are printed after selecting the “Curva Média” option, which means the average curve between the results obtained by each author. An example of a middle curve is demonstrated in Figure 3

The result of the mean curve represents the mean value between the results obtained in the literature and the errors go from 1.719 to 0.136 as a function of residual stress, and are respectively referent,comparison 1 and comparison 3, both in modular values.

That 1.2 is, as stated in 1.2, the residual stress values in relation to the fissure CMOD opening depend on Graph 1 the steel fibers, as shown in Graph 1a), see-whether the divergence of the residual values of resistance of the authors, especially the author [2], who had his experimental curve not approximated with the other authors.

As the study is still under development, its use is extremely restricted to the limits of the database of the results of the cited authors. Thus, the future objective of this research is to capture even more studies of experimental responses to generate an even more optimized algorithm so that the user has a practical tool of predictability of the resulting diagrams from the input data.



Análise de Resultados

Tipo de Ensaio: 3PBT

Resistência do Concreto (MPa): 20

Volume de fibras: 0.5 %

Índice de forma da fibra (mm/mm): 67

Tipo de Ensaio Definido: Ensaio de 3 pontos

Resistência do Concreto Definida: 20 MPa

Volume de Fibras Definida: 0.5% ou 40 kg/m³

Índice de Forma de Fibra Definida: 67

Figure 2. Example of using the software

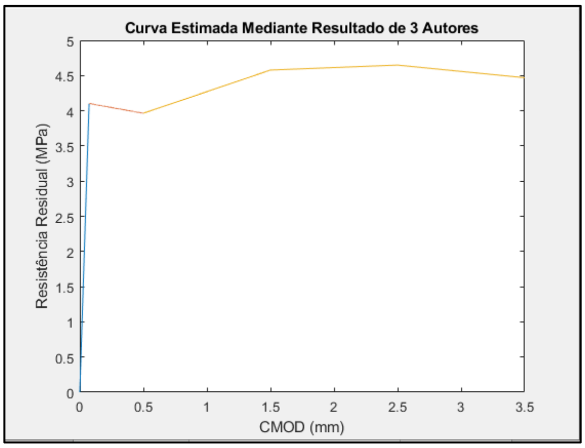


Figure 3. Result of the previous example

4 Conclusion

It is remarkable, observing the curves in Graph 1, that there is an increase in residual strength with the increase in fiber volume, however, it is not the focus of this study to discuss the influences caused by the change in parameters, but to show the reader and to the software user, that authors with input parameters obtained significantly close results.

Due to the difficulty of associating researches that have the same values of the prism parameters to be tested, the database becomes duly limited, and with this, the accuracy for estimating the resistance of an SRFC is dependent on the literature of the database.

The arrangement of steel fibers in concrete has a lot to do with its post-cracking strength and its workability, it is extremely important to identify a disparity in the test results that are not of equal density. Despite this, the authors chosen for the software model present similar results with low variations of tension values.

The strategy to be followed by respondents is to increase the volume of research, and thus obtain a database with indicators for each author for certain initial parameters. Thus, future research describing the experimental test in concrete reinforced with steel fiber succeeded results generated by the widest possible range of correlated authors, which will guide the future author's research if his results differ or not from the other authors.

Acknowledgments

This work is the result of a Research Project submitted to the Voluntary Scientific Initiation Program linked to the Federal University of Oeste da Bahia. The authors appreciate the opportunity to request this University to carry out the research.

References

[1] M. G. CARDOSO, "Contributions To The Dosage of Self-Adensable Concrete Reinforced with Fibers by the Method of Compressible Packaging," p. 167, 2020.

[2] I. Löfgren, H. Stang, and J. F. Olesen, "Fracture Properties of FRC Determined through Inverse Analysis of Wedge Splitting and Three-Point Bending Tests," *J. Adv. Concr. Technol.* , vol. 3, no. 3, pp. 423–434, 2005, doi: 10.3151/jact.3.423.

[3] A. Venkateshwaran, K. H. Tan, and Y. Li, "Residual flexural strengths of steel fiber reinforced concrete with multiple hooked-end fibers," *Struct. Concr.* , vol. 19, no. 2, pp. 352–365, 2018, doi: 10.1002/suco.201700030.

[4] M. di Prisco, G. Plizzari, and L. Vandewalle, "Fibre reinforced concrete: new design perspectives," *Mater. Struct.* , vol. 42, no. 9, pp. 1261–1281, Nov. 2009, doi: 10.1617/s11527-009-9529-4.

[5] H. Singh, *Steel Fiber Reinforced Concrete Behavior, Modelling and Design*. 2017.

[6] FIB- Bulletin 42, *Model Code 2010*. 2013.

[7] Européen Normalisation Committee, "EN 14651-2005 Test method for metallic fibred concrete — Measuring the flexural tensile strength (limit of proportionality (LOP), residual)," *Br. Stand. Inst.* , vol. 3, pp. 1–17, 2005.