Steel fiber reinforced concrete pipes. Part 1: technological analysis of the mechanical behavior

Tubos de concreto reforçado com fibras de aço. Parte 1: análise tecnológica do comportamento mecânico

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Abstract

This paper is the first part of an extensive work focusing the technological development of steel fiber reinforced concrete pipes (FRCP). Here is presented and discussed the experimental campaign focusing the test procedure and the mechanical behavior obtained for each of the dosages of fiber used. In the second part ("Steel fiber reinforced concrete pipes. Part 2: Numerical model to simulate the crushing test"), the aspects of FRCP numerical modeling are presented and analyzed using the same experimental results in order to be validated. This study was carried out trying to reduce some uncertainties related to FRCP performance and provide a better condition to the use of these components. In this respect, an experimental study was carried out using sewage concrete pipes in full scale as specimens. The diameter of the specimens was 600 mm, and they had a length of 2500 mm. The pipes were reinforced with traditional bars and different contents of steel fibers in order to compare their performance through the crushing test. Two test procedures were used in that sense. In the 1st Series, the diameter displacement was monitored by the use of two LVDTs positioned at both extremities of the pipes. In the 2nd Series, just one LVDT is positioned at the spigot. The results shown a more rigidity response of the pipe during tests when the displacements were measured at the enlarged section of the socket. The fiber reinforcement was very effective, especially when low level of displacement was imposed to the FRCP. At this condition, the steel fibers showed an equivalent performance to superior class pipes made with traditional reinforced. The fiber content of 40 kg/m3 provided a hardening behavior for the FRCP, and could be considered as equivalent to the critical volume in this condition.

Keywords: concrete pipes, steel fibers, crushing test, mechanical behavior, standards.

Resumo

A primeira parte deste trabalho se concentra no desenvolvimento tecnológico de tubos de concreto reforçado com fibras (TCRF). São apresentados e discutidos os resultados obtidos em um estudo experimental focado no procedimento de ensaio e na resposta mecânica obtida para cada um dos teores de fibras utilizados nos tubos. Na segunda parte do trabalho ("Tubos de concreto reforçado com fibra de aço. Parte 2: Modelo numérico para simular o ensaio de compressão diametral"), se apresentam os aspectos associados à simulação numérica da resposta mecânica destes tubos. Este estudo foi levado a cabo com a finalidade de tentar reduzir algumas das incertezas relacionadas com o desempenho dos TCRF e proporcionar melhores condições para viabilizar o uso das fibras como elemento de reforço em tubos. Neste sentido, se realizou um trabalho experimental utilizando corpos-de-prova em escala real. O diâmetro destes tubos foi de 600 mm e seu comprimento de 2500 mm. Alguns dos tubos foram reforçados com armaduras convencionais e outros apenas com fibras metálicas com a finalidade de comparar as diferentes respostas mecânicas no ensaio de três cutelos. Empregaram-se dois procedimentos: numa 1ª série, o deslocamento diametral foi medido por meio de LVDTs posicionados em ambas as extremidades dos tubos, enquanto que, na 2ª série se mediu o deslocamento apenas na ponta dos tubos. Neste sentido, os resultados obtidos demonstraram que a avaliação da rigidez do sistema depende da forma de medida dos deslocamentos. Além disso, foi comprovado que o reforço de fibras metálicas era eficiente, especialmente para níveis de carga próximos às cargas de serviço. Para baixas deformações, os TCRF apresentaram um melhor desempenho em termos de resistência em comparação com os tubos de concreto armado convencional. Por último, se concluiu que o consumo de 40 kg/m3 pode ser considerado o volume crítico de fibras, pois pode obter um encruamento para a resposta estrutural do tubo.

Palavras-chave: tubos de concreto, fibras de aço, ensaio de compressão diametral, normas.

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1. Introduction

There is a huge necessity for sewage collecting and treatment systems in underdevelopment countries. The concrete pipes can be considered as a very competitive and sustainable alternative in relation to competitors in the market (Viñolas *et al.* [1]). Brazil has an instrument to reduce the deficiency in this segment since publication of the standard ABNT NBR 8890 [2] that allow the use of steel fibers for concrete pipes reinforcement [3]. This standard is equivalent to the European norm NBN-EM 1916 [4]. Both standards allow the use of conventional reinforcement with steel bars also. The pipes must to be verified in terms of mechanical performance through the crushing test or three-edge bearing test, despite the type of reinforcement used (bars of fibers). However, the steel fibers reinforced concrete pipes (FRCP) are not regularly used in Brazil nowadays, although the Brazilian standard had been published in 2007. One of the main reasons for this situation is related to the doubts concerning the FRCP mechanical performance that still remain in the market segment. These difficulties are also associated with the lack of numerical models capable of predicting the behavior of the component accurately. In order to resolve these problems, an experimental study focusing on the behavioral assessment of concrete sewage pipes was carried out. This study compared the performance between the pipes reinforced with steel fibers (FRCP) and the pipes reinforced with cold drown steel bars. The results turn possible the comparative performance evaluation of FRCP and the steel bars reinforced concrete pipes (SBRCP), and also the validation of a proposed numerical model for prediction of the pipe behavior during the crushing strength (de la Fuente et al. [5]). In this study, the influence of changes in testing methodology in the response of the components was also evaluated.

2. Methodology

The mechanical performance of concrete pipes is regularly measured with the crushing test method as specified by the standards ABNT NBR 8890 [2] and EN 1916 [4] (Figure [1]). These standards prescribe two different procedures for the qualification of pipes, one for SBRCP, and the other for FRCP.

In the case of SBRCP, the pipe is subjected to a continuous loading up to rupture in order to determine the proof and ultimate loads. The proof load (F_c) is defined as 0.67 F_n, and F_n is the minimum crushing load. The strength class is defined by the F_c, and is acceptable to be equal to the crack load (F_{cr}), corresponding to a crack with an opening of 0.25 mm [2] or less than 0.3 mm [4] and length of 300 mm or more according to Brazilian [2] and European [4] standards, respectively. The ultimate load (F_u) is the maximum achieved during testing and shall be equal or greater than F_n.

In the standard crushing test method for FRCP there is a cyclic loading [2 and 4]. The first cycle consists of loading the pipe until an equivalent level of the proof load of the SBRCP. At this moment, the load is maintained for one minute and the pipe is checked for evidence of any damage. The pipe is rejected if any crack or other damage is observed. Thus, it is required that F_{cr} shall be greater F_c. Once approved at this stage, the loading of the pipe is continued until the maximum load (F_u). When the load start to decrease and reach the value of 95% of F_u it shall be release, finishing the first cycle of the test. On the second cycle of the test, the pipe is reloaded up to F_c and held for one minute. The pipe has to withstand this post-peak proof load in order to be approved. The test procedure established by the European standard [4] is finished at this point. In the specific case of the Brazilian standard [2], the second cycle is continued increasing the loading up to the moment that the pipe reach the maximum measured post-peak load ($F_{max,pos}$). The $F_{max,pos}$ shall be greater than 1.05F_c, named minimum required post-peak load ($F_{min,pos}$).

Although there are different test procedures prescribed by the standards to verify pipes with varied types of reinforcement, the continuous test was used in this experimental program in order to evaluate all specimens under uniform conditions of

Figure 1 – Front and side views of the configuration adopted for the crushing test of concrete pipes
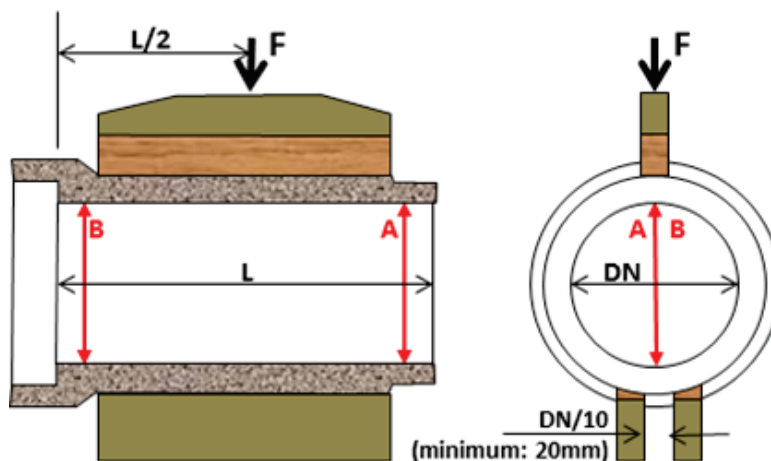
Figure 2 – Configurations adopted for the measurement of displacements (A) at both extremities in the 1st Series and (B) at the spigot for the 2nd Series

Figure 3 – LVDT positioned at the upper part of the inner surface of the pipe

assessment. This solution was chosen because it was proven that there is no influence of number of cycles used in the test on the response of FRCP [6 and 7]. Devices were fixed to specimens providing a continuous acquisition of diametral displacement in order to improve the verification of pipes mechanical behavior during the tests. A similar test set up was used in previous studies [8 and 9]. This system consists of using LVDTs positioned against the upper part of the inner surface of the pipe and attached at supports fixed at the bottom part of the pipe as shown in Figures [2] and [3]. The set up used for LVDTs positioning allows the measurement of diametral displacements of the pipes without any interference of external strains or dislocations in the results.

This paper presents an experimental program broader than previously published by the same authors [10]. Two test configurations were used to measure the diametrical displacement of the pipes. At first one, the measurement of displacement occurred simultaneously at the spigot and the socket, corresponding to positions A and B (Figures [1] and [2a]). So, that situation turns possible to obtain the curve of load by average diametrical displacement of the pipes. In the second test configuration, only one LVDT was placed at position A, corresponding to the spigot of the pipe (Figures [1] and [2b]). Thus, two series of pipes were produced with fiber and conventional reinforcement to be tested with each of those test configurations.

Each series was produced in a single day in order to diminish the influence of intervening variables in the pipes production. In that sense, the same features and basic materials that were being regularly used by the company were applied for the pipes fabrication. The demanded amount of fiber was added directly on the aggregates conveyor belt. The rebars set up used is the same that had been routinely used by the factory (Figure [4]). Three levels of steel fibers consumptions (10 kg/m^3, 20 kg/m^3 and 40 kg/m^3) were produced in each series together with three other SBRCP, totaling 24 pipes per series.

Figure 4. Rebars set up used in SBRCP production that served as a parameter for comparative performance evaluation with FRCP. Some problems were observed molding the 1st Series of pipes due to increased cohesion provided by the steel fibers. These problems were corrected in the 2nd Series by adjusting the moisture of the mixture to maintain the fixed level of cohesion of the material. There was also changing the cement brand from first to 2nd Series due to problems with suppliers. The materials used in this study and its consumption per cubic meter of concrete are presented in Table [1]. The steel fiber type used in the experiment was a glued hooked end drawn wire, 60 mm in length and diameter of 0.75 mm. So, the aspect ratio of the fiber was 80.

Figure 4 – Rebars set up used in SBRCP production that served as a parameter for comparative performance evaluation with FRCP

Table 1 – Material and its consumption per cubic meter of concrete used in the production of pipes used in this experimental study	
Material	**Consumption (kg/m^3)**
Fine aggregate I (Natural river sand)	629
Fine aggregate II (crushed sand)	315
Coarse aggregate (crushed stone)	988
Cement (CP III 40 RS)*	329
Water**	141

* A different brand of cement was used for each series of pipes.
** This amount of water was changed in the 2nd Series through visual analysis of the mixture in order to maintain fixed the concrete consistency.

The main steel reinforcement (transverse reinforcement) was made with cold drawn steel bars (yield strength of 600 MPa) with a diameter of 6 mm, and spaced each 85mm. The main reinforcement was positioned at the center of the pipe wall with equal distance for both inner and outer surface. A support reinforcement (longitudinal) made with 6 wires of the same type of steel was also used. The main reinforcement was positioned at the center of the pipe wall. The consumption of steel for this family of pipes was approximately 40 kg/m^3. It was observed that the pipes produced with fibers presented a very good final finishing of the surface (Figure [5]), which reinforces the idea of the feasibility of its implementation.

After the production, the pipes remained in the storage yard of the factory until the moment of the crushing tests. All pipes were tested over the age of 28 days and at the same time. Other studies [11] found that there was no significant change in the behavior of reinforced concrete pipe in the hardened state when tested at ages ranging from 10 to 96 days. So, it was assured that there was no influence of age of the pipes in the results. The pipes were produced using the vibro-compression method with high speed (5000 rpm) to compact the concrete. The geometric characteristics of the pipes are presented in Figure [6]. A summary of the differences between the two series is shown in Table [2].

3. Results and Analysis

The characteristic compressive strength of the concrete was 50 MPa, obtained directly from the regular quality control results obtained by the factory. For each pipe, it was recorded the load versus displacement curve during the crushing test. The results obtained with the 1st Series, where the average displacement was measured at the spigot and the socket simultaneously, are presented in Figures [7] to [10]. The results obtained with the measurement made only at the spigot, corresponding to the 2nd Series, are presented in Figures [11] to [14]. In order to facilitate the comparison between the results, they are also presented in Figures [15] and [16] in terms of average curves obtained for the first and 2nd Series, respectively. Only two results of the 1st Series were lost

Table 2 – Differences between the two series of pipes used in the experimental study			
Series	LVDT position	Cement	Water content
First	At the spigot and socket	Brand 1	Fixed on 141 liters/m^3
Second	Only at the spigot	Brand 2	Adjusted for each mix (constant consistency)

due to failures in the test system, where the reading of the strain was impaired. Because of that, only two curves are shown in Figures [7] and [8].

The fact that pipes have been tested in real scale caused a reduction of the results variability. In ordinary tests to determine the toughness of fiber reinforced concretes, the coefficient of variation can exceed 20% [12]. This occurs because the crack area (where the fibers act as a stress transfer bridge) is much larger in a tube than in a prismatic specimen. This reduction in variability has been observed in previous studies [7 and 13].

The first perceptible aspect was the behavior with a well defined pattern for pipes reinforced with smaller amounts of fiber. This softening pattern was characterized by a reduction of the strength of the pipe with increasing vertical displacement. The pipes reinforced with steel bars or 40 kg/m^3 of fibers had presented a

Figure 5 – General appearance of a new fiber reinforced concrete pipe

Figure 6 – Geometric characterization of the pipe used in the experiment
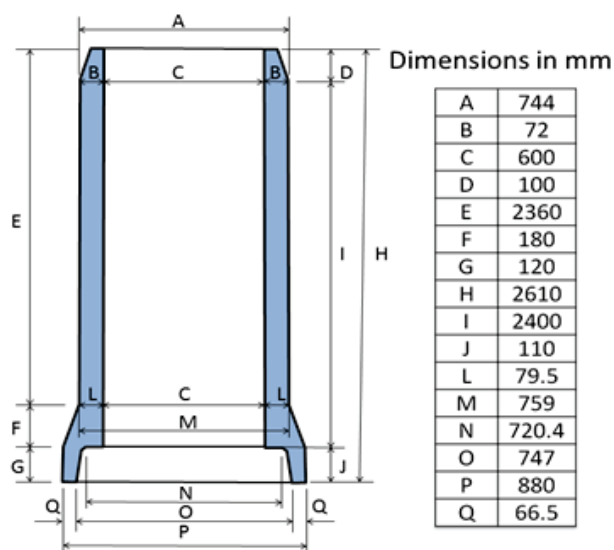
Dimensions in mm

A	744
B	72
C	600
D	100
E	2360
F	180
G	120
H	2610
I	2400
J	110
L	79.5
M	759
N	720.4
O	747
P	880
Q	66.5

Figure 7 – Load versus displacement curves obtained during crushing test of pipes with a fiber consumption of 10 kg/m^3 and with the diametrical displacement measured at the spigot and the socket

Figure 8 – Load versus displacement curves obtained during crushing test of pipes with a fiber consumption of 20 kg/m³ and with the diametrical displacement measured at the spigot and the socket
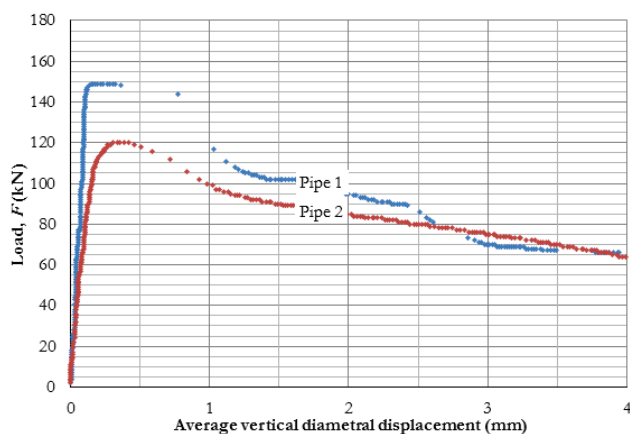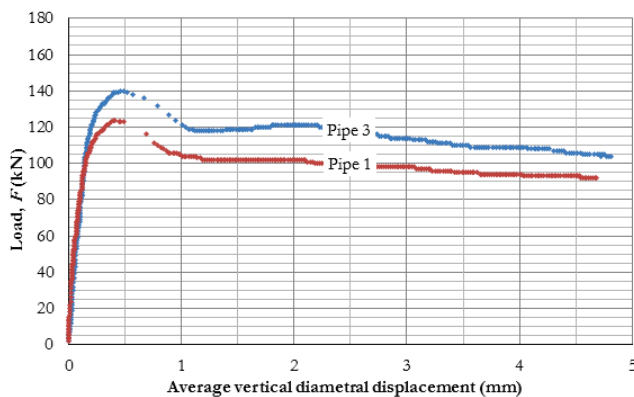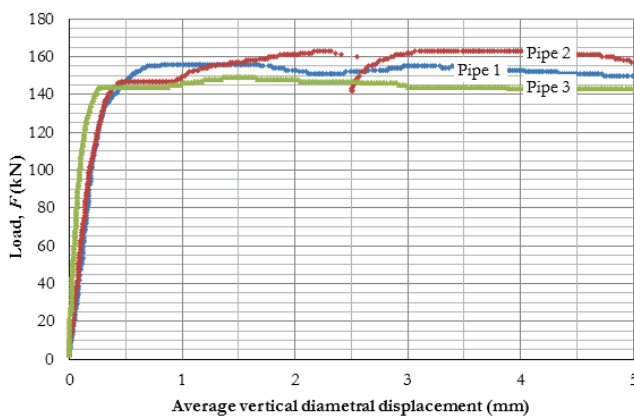

Figure 9 – Load versus displacement curves obtained during crushing test of pipes with a fiber consumption of 40 kg/m³ and with the diametrical displacement measured at the spigot and the socket

In order to facilitate the analysis of the influence of the setups for measuring displacements in the pipes during the crushing test the results of the average curves obtained with the greater fiber content are presented in Figure [17]. The results obtained in the 1st Series, where the displacement measurements were made at the spigot and at the socket simultaneously, had presented higher stiffness in the beginning of the curve. The end of the initial elastic line was prolonged by the influence of the socket region where the concrete matrix contributes more intensely [14]. For the 2nd Series, where the displacements were measured only at the spigot, they were more intense for smaller loads, due to lower rigidity of this part

Figure 10 – Load versus displacement curves obtained during crushing test of pipes with a conventional reinforcement and with the diametrical displacement measured at the spigot and the socket
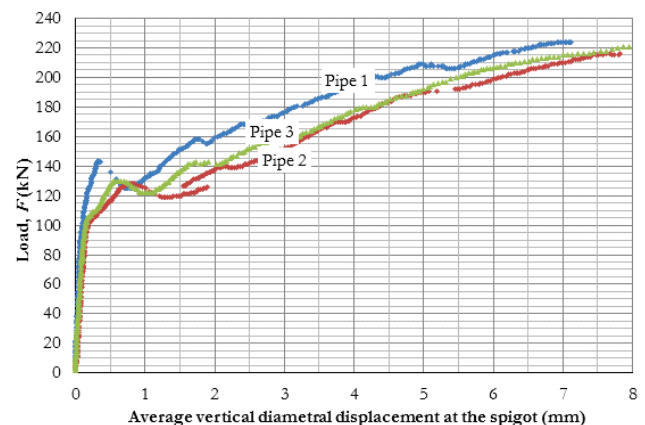

Figure 11 – Load versus displacement curves obtained during crushing test of pipes with a fiber consumption of 10 kg/m³ and with the diametrical displacement measured only at the spigot
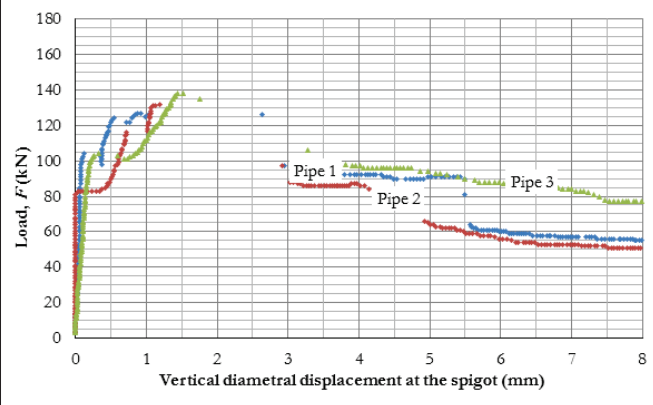

hardening pattern, which consists of increasing resisted load with increasing vertical displacement of the pipe. Thus, the resistance displayed by pipes with regular reinforcement was largest than the presented by FRCP at higher displacements. However, for lower strain, the residual strength capacity was greater for FRCP. This occurs because the bars are positioned at the innermost part of the pipe wall and they are mobilized more intensely when there is greater displacement and hence higher level of cracking. On the other hand, the fibers are distributed throughout the thickness of the pipe wall. Thus, the fibers reinforcement is mobilized with small levels of displacement and cracking, which provides better performance in this situation.

Figure 12 – Load versus displacement curves obtained during crushing test of pipes with a fiber consumption of 20 kg/m³ and with the diametrical displacement measured only at the spigot
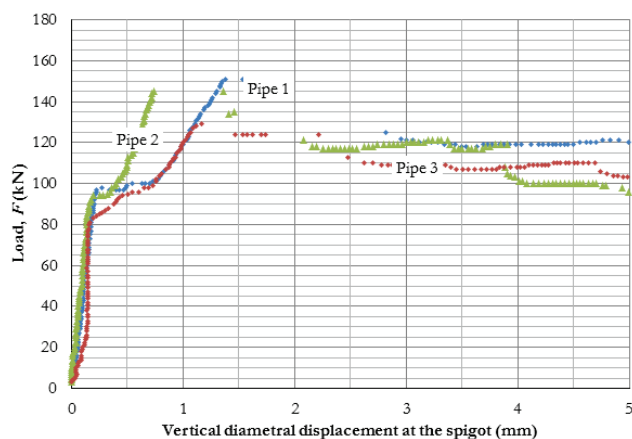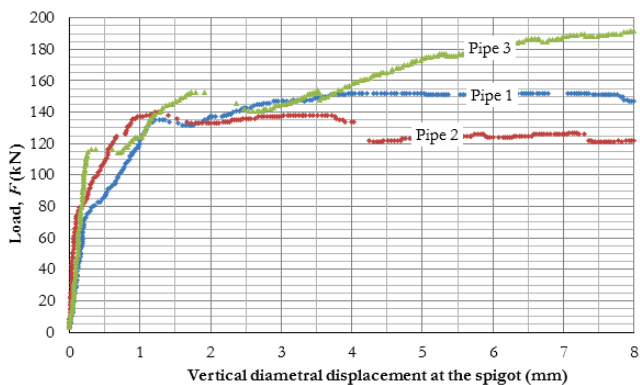

Figure 13 – Load versus displacement curves obtained during crushing test of pipes with a fiber consumption of 40 kg/m³ and with the diametrical displacement measured only at the spigot

of the pipe. The difference observed in the pattern of the curves obtained in the two series of test is only attributed to geometric factors, and the characteristics of matrix and type of reinforcement have no influence on the results. So, the displacement measured at the socket will always be smaller than the one measured at the spigot. In that sense, the enlargement of the socket is the main factor influencing the pattern of the curves at the elastic region.

Due to the fact that the spigot will present a higher level of displacement, this region will present the higher level of strain and, consequently, will reach the elastic limit sooner. So, is possible to conclude that the cracking of the pipes always begins at the spigot,

because the concrete reaches its elastic strain limit in this region before it occurs in the socket. In the particular case of this study it occurs around 80 kN of loading, when the stiffness of the component was greatly reduced. As the displacements measured in the 2nd Series were much superior to the 1st Series due to the previously discussed loss of stiffness, it is also possible to conclude for the equivalence of the two behaviors, because both series reached close levels to residual strength. It should be emphasized that this pattern of behavior is totally consistent with the model proposed by de la Fuente et al. [5] for numerical modeling of pipes behavior during the crushing test.

An important aspect to have attention is the fact that it is impossible to carry out the standard cyclic test with pipes reinforced with 40 kg/m³ of steel fibers. The difficulty occurs because of the hard-

Figure 14 – Load versus displacement curves obtained during crushing test of pipes with conventional reinforcement and with the diametrical displacement measured only at the spigot
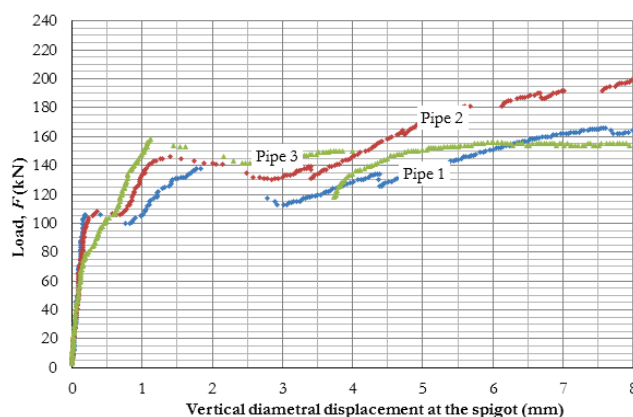

Figure 15 – Average load versus diametrical displacement curves of pipes tested in the 1st Series
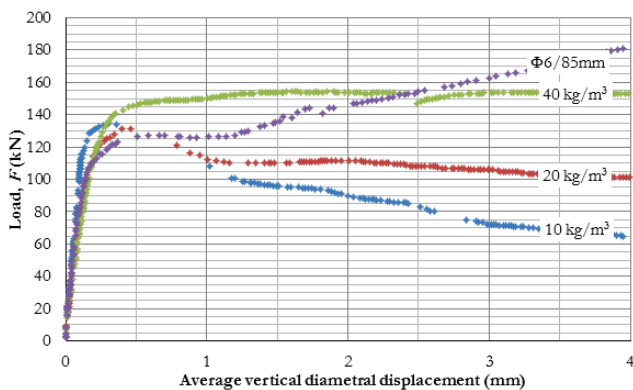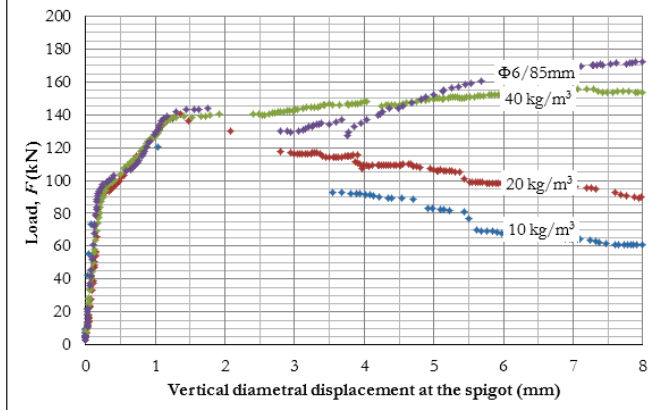
Figure 16 – Average load versus diametrical displacement curves of pipes tested in the 2nd Series

ening behavior of these pipes. In this particular case, the drop in post-peak strength at low displacements could not possible be observed. Thus there will be a high level of displacement and cracking when the unloading was done during the regular cyclical test. So, the standard procedure had the implicit concept that the FRCP should always show a softening behavior to turn possible to perform the cyclical test. Thus, the continuous measurement system using LVDTs provides greater reliability to the test in these situations. Especially when the serviceability conditions associated to the level of crack opening is considered.

There were also regions of post-peak instability in the crushing test response, similar to those observed by Figueiredo [7] when low amounts of fiber were used. This instability is provoked by the process of slipping and loss of adhesion of the fibers, in addition to possible rupture of some of them, occurring during the stress transfer from the matrix to the fibers. Furthermore, the increase in fiber content enhanced the cracking load of the matrix, corresponding to the end of the initial linear part of the curve. This, however, became clear only for the 1st Series of pipes. In this series there was an increase of the material cohesion due to the fiber addition in to the matrix. So, there was the correction of water content in the concrete for the 2nd Series in order to maintain the level of mobility of the matrix. In that situation, the increase in water/cement ratio gives a reduction of the matrix strength, which reduced the contribution of fiber to the elastic behavior of the component. Although this, a reduction in the load at the end of the elastic part of the curves was not observed. It occurs due to the increase in the fiber content that had improved the tensile strength capacity of concrete pipe.

It was observed that the pipes also met the requirements of the standards [2 and 4] for Class AE2. In the case of pipes with 600 mm nominal diameter the Brazilian [2] and European [4] standards require that the pipes have to present a load control of 36 kN/m and an ultimate load of 54 kN/m. As the pipe length was 2.5 m, it accomplish that a total load control is 90 kN per pipe, and a ultimate load is 135 kN per pipe.

Checking the average results presented in Figures [15] and [16], it is possible to figure out that all SBRCP exceeded both the control and ultimate load by a wide margin, especially in the 1st Series. In this

particular case, the limit of the elastic behavior reached about 130 kN (less than the proof load where the pipe may have a certain level of cracking). The average ultimate load was 230 kN, obtained directly from the test machine record system because it occurs when the displacement was larger than the measurement limit of the LVDTs. With these results, these pipes were about to fit the requirement of the superior class (EA3 for the Brazilian standard), which requires control and ultimate loads of 135 kN and 202.5 kN, respectively. In the 2nd Series, the results were slightly lower than the first one for the ultimate strength, which reached the averaged load of 174.7 kN. Since the end of the initial elastic segment was close to 90 kN, it is possible to affirm that the pipes reached the standards requirement narrowly. Anyway, it is possible to consider them as appropriate to the requirements of the standards for class EA2.

Observing the curves presented in Figures [15] and [16], it is possible to affirm that there is proximity between the behavior of SBRCP and FRCP in the first half of the load versus displacement curves. This behavior occurs in more intense way until a vertical displacement of about 0.4 mm and 2 mm for the first and 2nd Series respectively. The FRCP with 40 kg/m³ exceeded the strength loads of SBRCP until displacements of about 2.5 mm and 4.5 mm for the first and 2nd Series respectively. It is possible to affirm that the FRCP presented a similar behavior to a superior class of SBRCP in those circumstances. The initial region of the curves could be associated to the serviceability limit state or, in other words, corresponding to the elastic or low level of cracking behavior. So, the fiber contribution will be more effective for the pipes service life than the contribution presented by the steel bars. Note that all the pipes of the 1st Series showed the initial elastic part of the curve slightly exceeding 100 kN. With respect to this aspect, it was observed that cracking began, in all cases, at the top of the section A with values of F_{cr} around 90 kN. On the other hand, in the pipes from the 2nd Series, it was observed that the appearance of the first cracks coincided with the change in the slope of the load-displacement curve. This change was not detected in the pipes from the 1st Series until the springline had also cracked,

Figure 17 – Comparison between the average curves measured at the socket and spigot (1st Series) and only at the spigot (2nd Series) for FRCP with 40 kg/m³ steel fibers
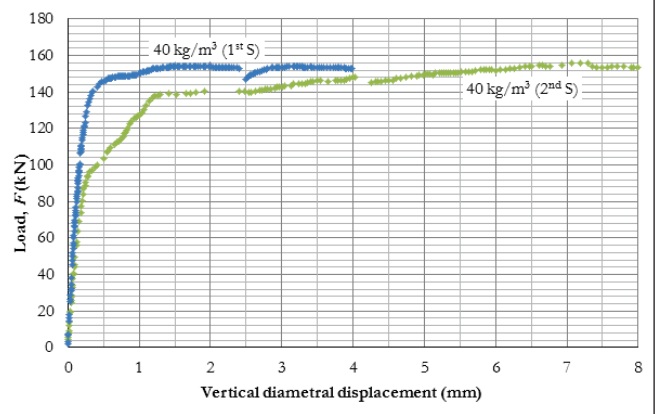
Table 3 – Maximum load and maximum post-peak load obtained in the two series of tests

Series	C_f (kg/m³)	F_u (kN)				$F_{1.2mm}$ y F_{3mm} (kN)			
		Individual values			Average	Individual values			Average
1st	10	149	120	n/a	135	107	94	n/a	101
	20	140	124	n/a	132	118	102	n/a	110
	40	156	163	149	156	-	-	-	-
2nd	10	127	132	138	132	97	88	98	94
	20	151	145	129	142	121	120	108	116
	40	152	140	193	162	-	-	-	-

a situation which took place when load F reached average values of 126 kN, 114 kN and 138 kN for the pipes with 10 kg/m³, 20 kg/m³ and 40 kg/m³, respectively. So, the load F_{cr} can be deduced from the load-displacement curve at the point where the first slope change takes place. On the other hand, if the measurement is performed as in the 1st Series, this procedure would lead to values of F_{cr} on the side of insecurity, requiring a visual inspection in order to detect F_{cr}., which could indicate if the control load fits the standard requirements. Since the load displacement curves obtained to the 2nd Series of tests showed that linear region finishing when the load was about 90 kN. Thus, these pipes would be probably approved because is possible to associate this level of loading to the F_{cr}..

The Brazilian standard requirements [2] for FRCP are a little broader than the European [4]. This is because, besides the load control (F_c) of 90 kN and ultimate load (F_u) of 135 kN, common to both, the Brazilian standard requires a minimum post-peak load ($F_{min,pos}$) of 94, 5 kN. This fact increases the importance of the post-peak residual strength of the pipes. As the tests performed for this study have not the cycle of loading, this parameter could not be determinate

in order to evaluate if the pipes comply with the requirements. Nevertheless, a displacement level was fixed in order to determining a residual strength in the post-peak region to assess the influence of the fiber in this specific behavior of the pipe. The results presented in Table [3] and also in Figures [15] and [16] were used for the evaluation of this condition. As tests were performed continuously without re-loading cycle, it was adopted a reference displacement a little beyond post-peak instability limit for each series. Consequently, the displacements of 1.2 mm and 3 mm were adopted for determining the post-cracking load for the first and 2nd Series, respectively. The different level of displacement was chosen due to the disparity in geometric rigidity of pipes observed when the displacement was measured only at the spigot or at the spigot and socket. That condition provides different level of displacement for the same level of cracking and post-peak residual strength.

In Figures [18] and [19] are presented the correlations between the fiber content and ultimate load (F_u) and the post-cracking load at

Figure 18 – Correlations between ultimate load and fiber content for both series of tests
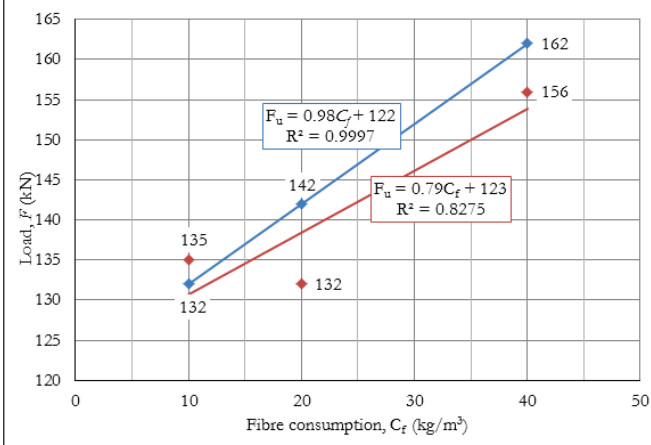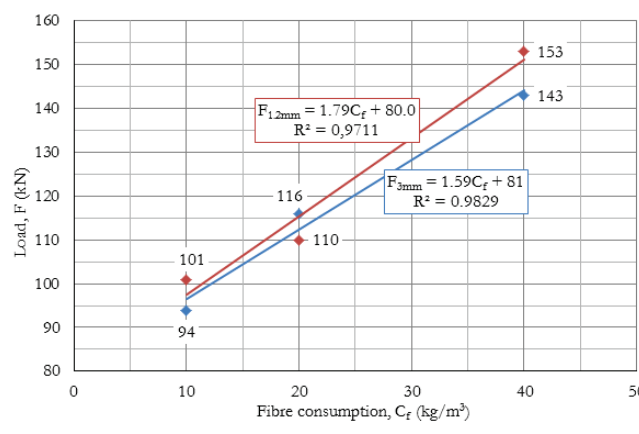

Figure 19 – Correlations between fiber content and the post-peak load at the displacements of 1.2 mm and 3 mm for the first and 2nd Series of tests respectively

the displacements of 1.2 mm and 3 mm, for the first and 2nd Series respectively. It is possible to observe clearly that the fibers content interferes in both parameters. The linear regression between fiber content and ultimate load or post-cracking load provide good level of correlations, as shown by the coefficients of correlation. Thus, this type of curves can be used in a mix-design procedure, if the variability of the test is well known. However, the fiber mix-design in order to accomplish a required post-peak residual strength has a greater relevance when the Brazilian standard [2] is used for pipes control.

4. Final remarks

The performance demonstrated by the FRCP was higher than the presented by the SBRCP when they were submitted to lower levels of displacement and cracking. A similar behavior has been observed in previous studies [9]. This fact occurs because the fibers are mobilized early in the process of cracking due to their position along the wall surface of the component. Since the steel bars are eventually being placed along the neutral line, by the requirement of minimum coverage, it will demand a high level of displacement and cracking in order to mobilize their resistance. So, the behavior of FRCP with low contents of fiber is typically softening, while the pipes with rebars present a typical hardening behavior. Thus, even for low fiber consumptions, the performance of FRCP is comparable or even superior to SBRCP at low cracking and displacement level. This is particularly interesting since this is the stage of primary interest to the component application because the pipes are still in good conditions to meet the durability requirements. Moreover, in the particular case of this experimental study, the SBRCP had much better performance than the prescribed class. It also indicates that the fiber reinforcement is so efficient that approximates the behavior of FRCP to the one presented by a higher class SBRCP at the serviceability conditions.

It has been shown that the fiber content affects equally the ultimate load as the post-peak maximum load presented by the pipe in the crushing strength test. For this reason, it is important to take into account the contribution of the fiber in mix design analysis of the FRCP concerning to meeting the requirements of the ultimate and maximum post-peak load.

The results also confirmed the critical condition related to the spigot displacement in relation to the socket area. This fact shows that the component displacement measured at this position could be associated to the more demanding pipe condition in terms of displacement and crack initiation. However, this is a conservative approach concerning only to the test method, since the spigot will be protected by the follow pipe socket during use. This effect, however, is not applicable to pipes where the socket has no enlargement [2] [4]. Thus, the crushing test carried out in pipes which diametrical displacement is measured only at the spigot is very much in favor of security. Furthermore, this arrangement test proved to be much more suitable to evaluate the pipes performance. This occurs because, for pipes with higher fiber consumptions, it would not be possible to verify when the load drops to 95% of its value at low level of displacement. In that situation, the technician in charged to run the test could not observe the right moment to impose the end of the first cycle and start up the second one.

5. Acknowledgements

6. References

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