REPAIR OF INTERNAL AND EXTERNAL DEFECTS IN PIPELINES BY EXTERNAL SLEEVES OF COMPOSITE MATERIAL SUPPLIED BY STRONGBACK

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1 - INTRODUCTION

This report present the results of the project contracted to PUC/RJ, with resources from the financial year1999 from the sectorial fund FINEP/CTPETRO, on the performance of pipeline repair systems using composite materials. The project concentrated on the analysis of the mechanical behavior of the repairs. The aspects of characterization of the materials and inspection of the metallic pipelines, on the repairs, was the subject of a project that ran in parallel, contracted to COPPE/UFRJ by the Petrochemical Technology Management department of CENPES. This report present the results relating to the reinforcements applied by the supplier STRONGBACK.

2 – RESULTS OF THE PUC/RJ PROJECT

2.1 – APPLICATION OF THE REPAIRS

The previous experience of PUC/RJ in the experimental analysis of long defects in metallic pipelines oriented the definition of the bodies of proof to be tested. The upper limits of applicability of the repairs was also sought, by the machining of defects known to be severe in the tubes. The defects simulate large thickness losses through corrosion, in extensive areas. Although they are very severe, the defects introduced are liable to repair, under the letter of Norm ASME B31.4 [1].

Tubular steel specimens of API 5L degree X60, of external diameter of 527 mm (20 3/4"), nominal thickness of 14.3 mm (0.562") and 3 m length were made, repaired and tested. A mechanism was projected and fabricated to allow the hollow of the defect to be kept a constant thickness. The geometry of the simulated corrosion defect hollows with 500 mm length, 95 mm width and a depth of 0.7 of the nominal thickness, as shown in Figure 1. The closing of the tubes was done with soldered flat lids.

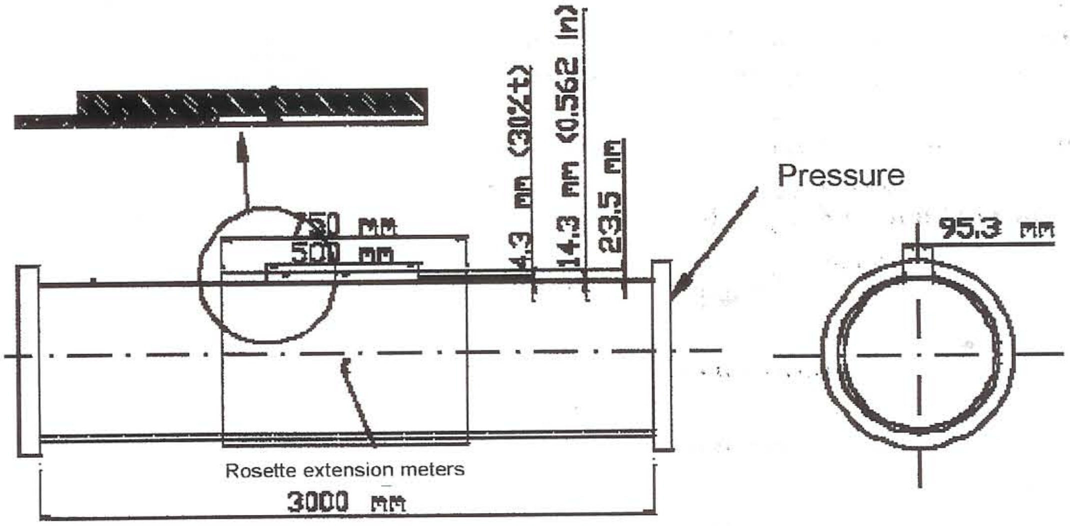


Figure 1 – Geometry of the tubular specimens and the composite repairs

The supplier applied their own repair, according to the specific techniques of plastic lamination reinforced with glass fiber. In general, the length of the repairs exceeded the extremities of the defects by more than 100 mm, as shown in Figure 1. The final thicknesses of the sleeves of composite material varied from 22.0 to 25.0 mm.

The specimens were positioned in the field, under simulated operational conditions, for the application of the repairs. The site of the application, shown in Figure 2, was the ORBEL II strip, next to the DTSE installations in Campos Elíseos, who also supplied all the logistic support required. The field simulation was an important part of the process, as the final quality of the repairs is a direct function of the process of application. This in turn, is greatly affected by the environmental conditions of climate, of cleanness of the channel and of access to the pipeline.

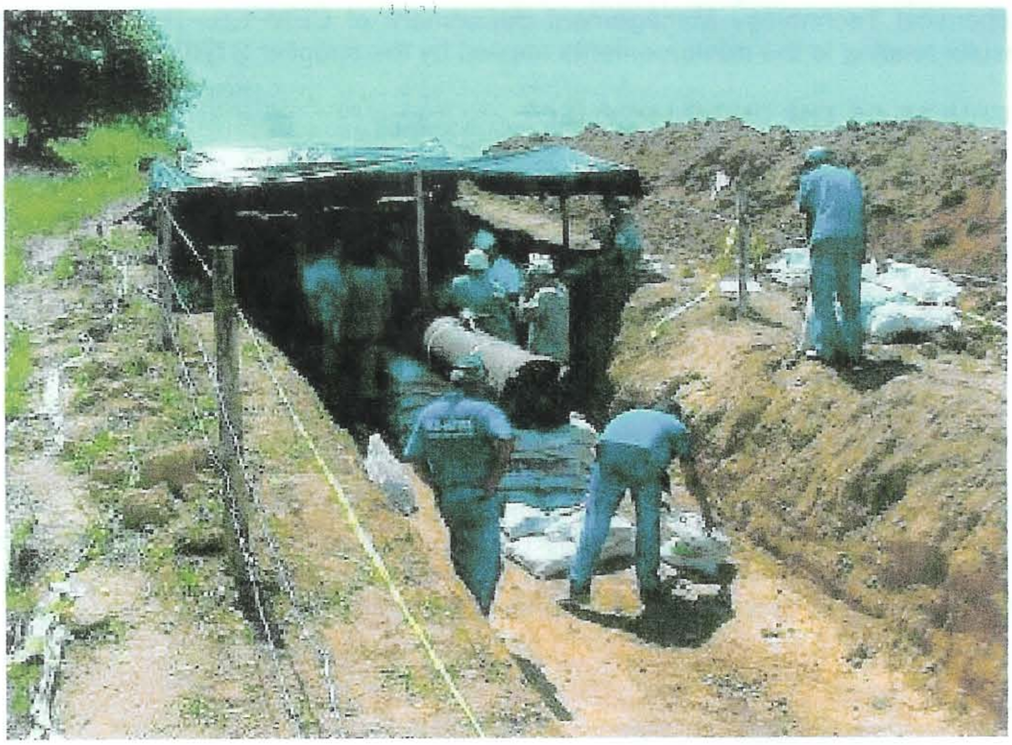


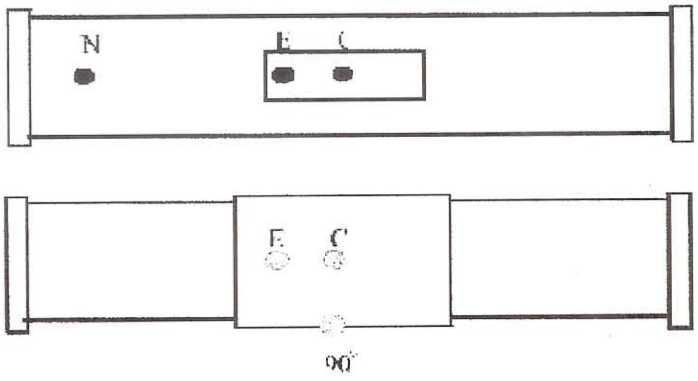
Figure 2 – Application of the repairs in simulated field operation.

Before the application of the repairs tubular specimens were pressurized to 5.5 MPa. The application of the repairs in the pressurized pipeline constituted a situation more likely to occur in real life, given that this is one of the greatest attractions to doing the repairs cold. It also constitutes a more severe test, as the repair is more effective the lower the pressure of application, given that the composite material has much lower rigidity than the steel. The pressure adopted was the maximum that a defective pipeline of similar material and geometry can operate at, according to norm ASME B31.4.

2.2 – TESTS CARRIED OUT

After the application of the repairs and the setting time had transpired, the specimens were depressurized and transported to the laboratory, to the instrumentation and execution of the program of hydro-static tests. Six extension meter rosettes of type TML YFRA-5, for large deformations, were installed with cyano-acrylate adhesive.

Three rosettes were installed on the surface of tube in two regions: one rosette in a nominal region, for comparison with the simple analytical results and another two rosettes on the surface of the defect (one in the center of the same and the other 50mm from the transversal wall). Then, the repairs of the composite material were applied. Three rosettes were installed over the surface of the repair material. Two rosettes were installed immediately above those installed on the steel tube. A third rosette was installed at 90° to the center of the defect. Figure 3 shows the placing of the rosette installations.



- Metallic tube
- Composite material

Figure 3 – Places of installation and identification of the rosettes.

The pressure during the tests was measured with manometers based on extension meters. The pressure was applied by an Amsler pump. The rate of elevation of the pressure was of 0.5 MPa/min. The test sequence was started with a first test of 90% of project pressure. For the nominal values of the properties of the steel and of the geometry of the tube, the project pressure of the whole tube is 170 bar. A second test raised the pressure up to 1.38 times the project pressure (235 bar) and this was maintained for 4 hours as recommended by ASME B31.4. After the depressurization, a sequence of ten cycles of pressurization up to the project pressure was applied.

The mechanical properties of the steel of the tubes was measured to refine the analysis of the tests. Table 1 shows the values relating to each specimen. The average final dimensions of the tubes and of the machine made defects are also shown in Table 1. The nomenclature of the specimens in the project is exemplified by the first specimen in the Table: T3086 is the number of the original API 5L X60 tube which was cut in 5 pieces, identified from "A" to "E", with the present case being the first of them (letter "A"). The Table shows that the defect is external and the tube was tested no repair, to act as a reference of the effectiveness of the reinforcements.

Table 1 – Characteristics of the tubular specimens and test results.

Specimen	Type of defect and repair	Thickness of tube (mm)	Minimum thickness of tube (mm)	Flow limit (Mpa)	Resistance limit (Mpa)	Length (%)	Thickness of reinforce-ment (mm)	Max pressure in the tests (bar)
T3086A	External, no repair	14.6	4.4	504	627	37	-	Burst at 148.6 [1]
T2746D	External, Strongback	14.5	4/9	481	605	35	23.5 – 25.0	237.9
T4363E	Internal, no repair	14.8	5.5	521	617	33	-	Burst at 160.9 [2]
T3993D	Internal, Strongback	14.4	4.8	449	583	41	22.0 – 23.0	Busrt at 235.4 [3]

Observations:
1 – For the purpose of comparison, the PB formula to determine the failure pressure of long corrosion defects [2] indicates a value of 143 bar, given the specific values of flow of the steel and the geometry of the tube and of the defect introduced.
2 – The PB formula indicates a failure pressure 171 bar, for the specific case.
3 – The rupture happened after a period of 33 minutes of maintaining pressure at the level of the hydro-static test.

The repaired tube T2746D survived all the tests, including the ten cycles up to the project pressure, without significant modification in the maximum values of deformation read by the extension meters. Figure 4 shows some of the specimens positioned at the test site.

Figure 4 – Some tubular specimens positioned at the test site

2.3 – RESULTS OF THE NON-REPAIRED TUBES

Figure 5 shows the instrumentation of the hydro-static tests in the PUC/RJ laboratories. The tubes were positioned under the reaction plate of the laboratory of civil engineering, as a safety measure. The signals from the extension meters were plotted on a computer screen and recorded. The output from a video camera was also shown and recorded.

The analyses of the tests used the specific properties of each tube, considering the average values of the properties of the materials and of the geometric parameters of the specimens as listed in Table 1.

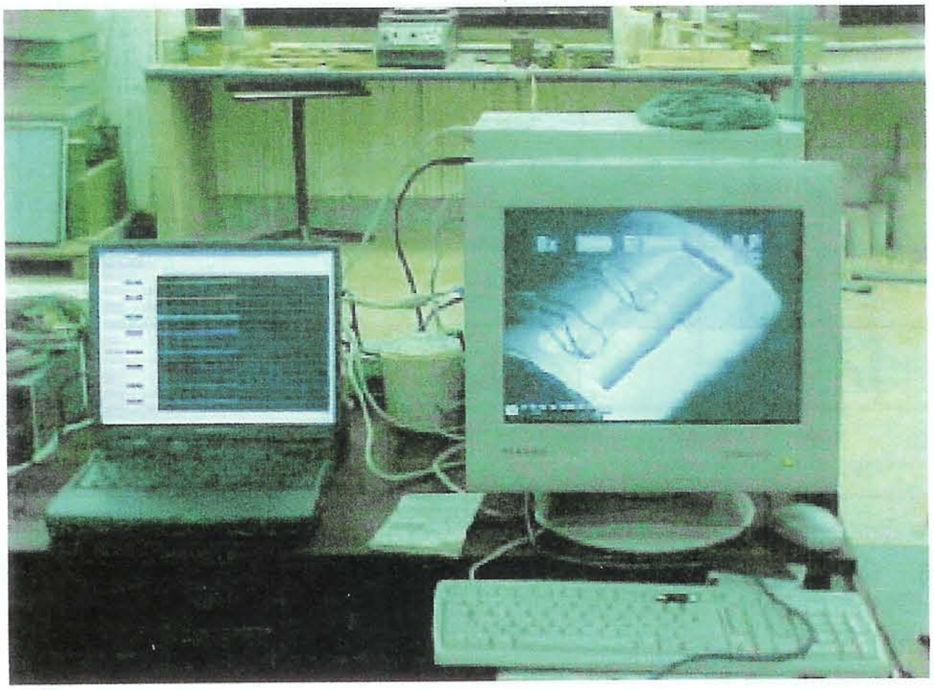


Figure 5 – Instrumentation of the hydro-static tests on the tubes.

The hydro-static test of the tube T3086A – with an external defect and no repair – showed a rupture pressure of 148.6 bar (14.6 MPa). The graph in Figure 6 shows the evolution of the experimental deformations with the test pressure. The deformations were taken at the external surface of the tube. The nomenclature of the points is as follows:

CC – center of defect, circumferential direction;
CL – center of defect, longitudinal direction;
90C – position at 90°, circumferential direction;
90L – position a 90 °, longitudinal direction.

The start of the plastic process in the center of the defect and the establishing of the striction at the end of the test can clearly be seen in the graph of Figure 6.

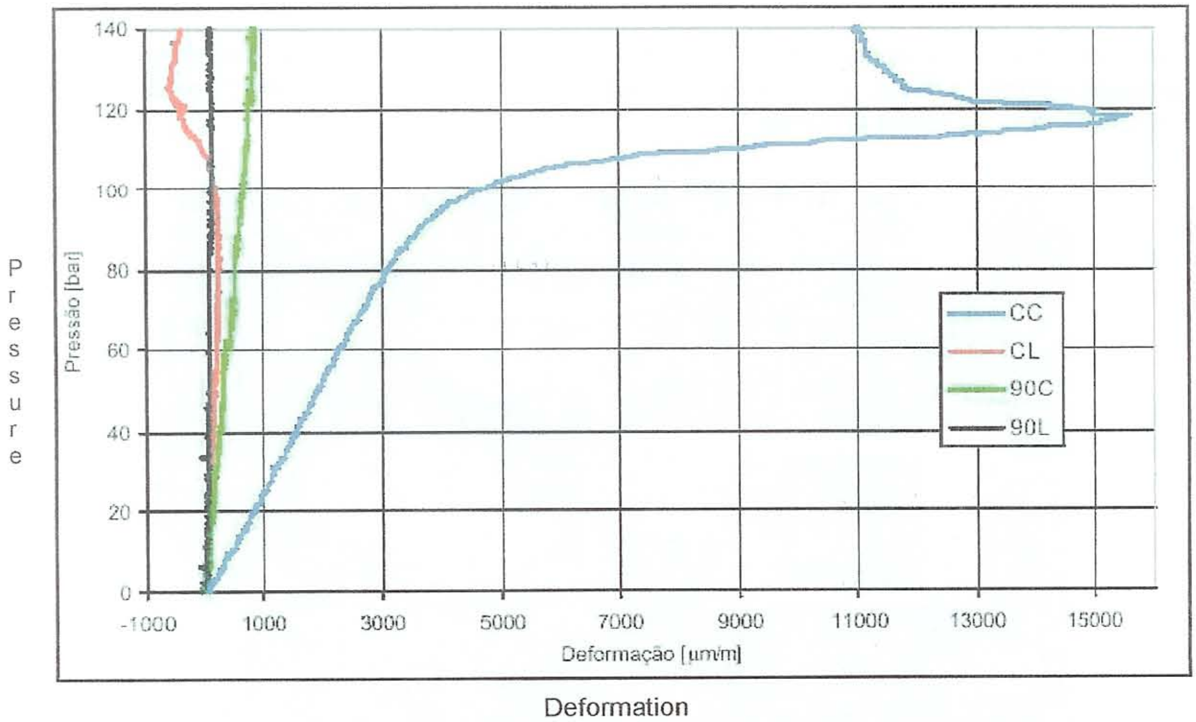
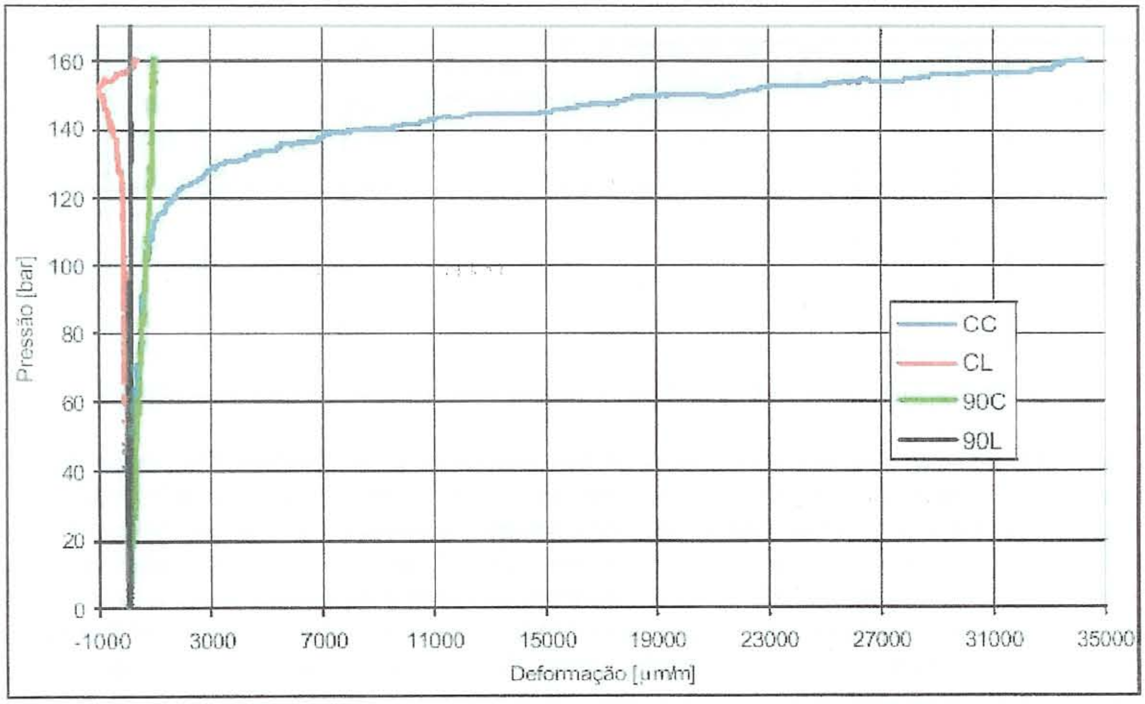


Figure 6 - Results of the test of tube T3086A, with an external defect and without reinforcement.

Innumerous attempts to describe the results of the tests using the Finite Elements Method were not successful and had to be abandoned. Because of these attempts, the publishing of the results was delayed. The test of tube T4363E – with an internal defect and no repair – presented failure at a pressure of 160.9 bar. Figure 7 shows the experimental results. In this case only the plastic point was observed, and not the inflection in the deformations associated with the striction process.

Pressure



Deformation

Figure 7 - Results of the test of tube T4363E, with an internal defect and no reinforcement.

2.4 – RESULTS OF THE REPAIRED TUBES

Some basic mechanical tests were carried out on bodies of proof obtained from the flat plates of the reinforcement materials. Only the tests necessary for a minimal characterization of the materials were carried out. Tables 2 and 3 show the results. The more complete evaluation of the properties is part of the scope of the project contracted to COPPE/UFRJ by Petrochemical Technology Management of CENPES.

Supplier	C.P. Nº	Module of longitudinal elasticity E_1 [MPa]	E_1 Average [MPa]	Module of transversal elasticity E_2 [MPa]	E_2 Average [MPa]
Strongback	1	26851	28270	12544	12126
	2	29689		11707	

Table 2 – Mechanical properties of the reinforcement materials - resistance.

Supplier	C.P. Nº	Fraction of resin by mass fm (%)	fm Average (%)	Resistência à tração longitudinal S_1 [MPa]	S_1 Average [MPa]	Maximum longitudinal deformation e_1 (%)	e_1 Average (%)	Resistance to transverse traction S_2 [MPa]	S_2 Average [MPa]	Deformação longitudinal máxima e_2 (%)	e_2 Average (%)
Strongback	1	22.5	22.7	321.5	343.3	1.21	1.24	150.4	148.6	1.53	1.99
	2	22.7		365.5		1.27		145.7		2.1[illegible]	

Table 3 - Mechanical properties of the reinforcement materials – rigidity.

The Tables show the wide variation of the mechanical properties the same mix of composite material, much larger than the variation verified in the metallic materials. The mass fractions were obtained from weight analyses of the process of total burning of the resin matrices, without the fibers burning, as in the standardized method [3]. The analysis of Table 2 confirms the fact that composite materials with fiber glass reinforcement have limits of resistance to longitudinal traction of the same order as the limits of the mild steels, while Table 3 indicates that the modules of longitudinal elasticity are of an order of magnitude lower. Such a fact is of importance fundamental in the understanding of mechanical behavior and therefore for the project of these systems of reinforcement of metallic tubes.

Figure 8 shows the circumferential deformations resulting from the first test, up to 90% of the project pressure (153 bar), for the tube T2746D (with external defect and repaired).

The additional nomenclature is:
CRC – external surface of reinforcement, just above the center of the defect, circumferential direction;
NC – nominal deformation of the metallic tube, distant from the repair, circumferential direction

The extension meter CC was positioned at the interface between the metallic tube and the reinforcement. The graph shows that the reinforcement only begins to absorb effort effectively after the plastification of the defect in the metallic tube, given the difference of rigidity between the steel and the composite material. The small difference between the values of deformation in the positions NC and 90C illustrate the small contribution of the reinforcement in the elastic regime.

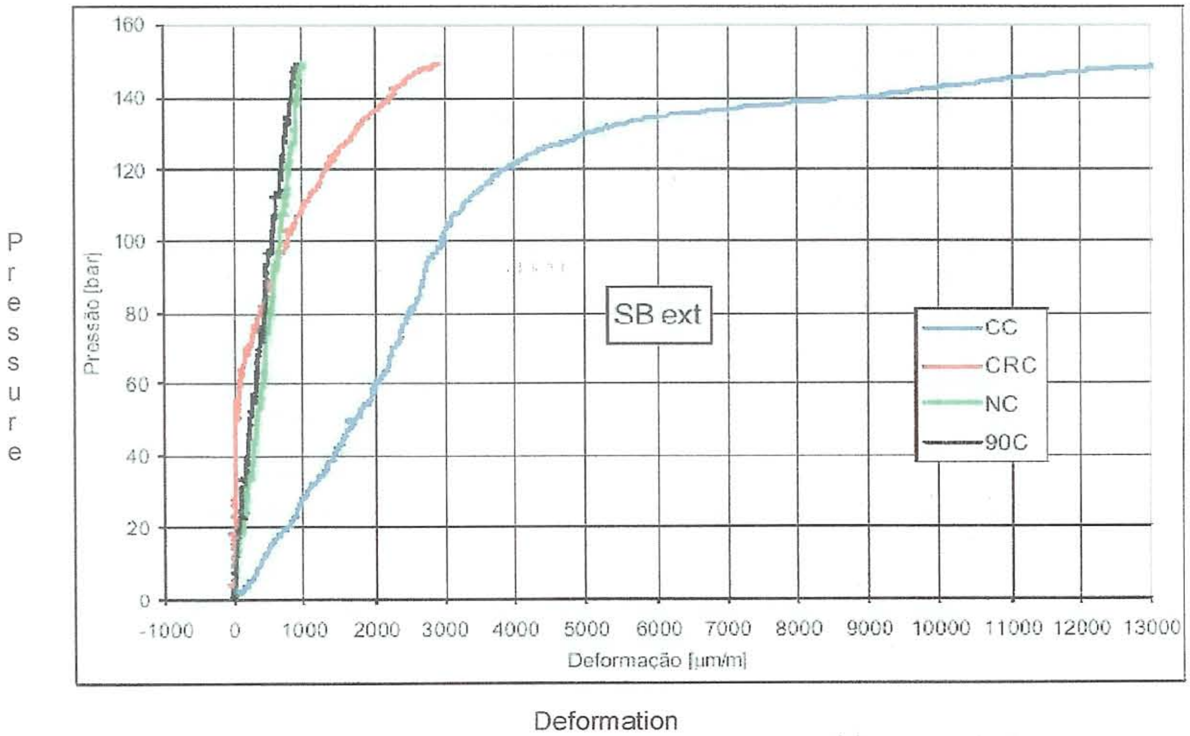


Figure 8 – Circumferential deformations up to the pressure of 153 bar, tube T2746D.

Figure 9 shows the circumferential deformations resulting from the test up to 90% of the project pressure (153 bar), for the tube T4363A (with an internal and repaired defect). The difference from the previous case is that in this case the external surface of the reinforcement is subject to the compression, given the form in which the internal defect deforms, curving into the tube.

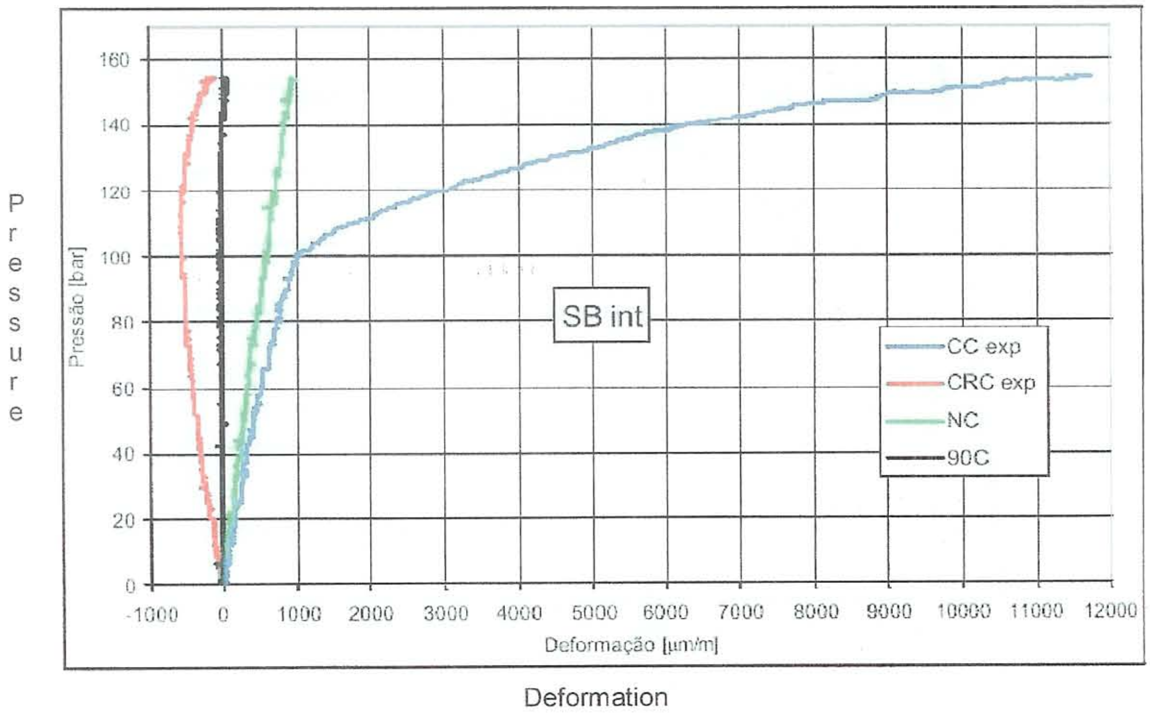


Figure 9 – Circumferential deformations up to the pressure of 153 bar, tube T3993D.

The deformation shown in the lateral position of the repair (90C) indicated problems with the extension meter in that position.

3 – CONCLUSIONS AND FUTURE WORKS

The tests show that the repairs made by STRONGBACK were effective in restoring the resistance of the tubes up to the original hydro-static test pressure of 138% of the project pressure of a tube with no defect. However, the tube with an internal defect (T3993D) burst after 33 minutes at that pressure. The other repaired tube (T2746D, with an external defect) survived all the tests.

The tube T2746D will now be tested up to breaking point to evaluate its resistance a year after the application of the repair, which was made in May2001.

4 - REFERENCES

1 – American Society of Mechanical Engineers. Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, ASME Code for Pressure Piping, B31.4, 1998.

2 – Benjamin, A.C., Vieira, R.D., Freire J.L.F. e Castro, J.T.P. Modified Equation for the Assessment of Long Corrosion Defects. Annals of the 20th International Conference on Offshore Mechanics and Arctic Engineering, Rio de Janeiro, 2001.