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Experimental Study Regarding the Mechanical Behavior of PPR Pipes

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Abstract: *The PPR pipes are more and more used in different industrial applications, due to their multiple advantages compared with the conventional metallic pipes. The experimental study presented in this article, was conducted in two directions, analyzing the behavior of welded PPR pipes and also the behaviour of unwelded PPR pipes exposed to different aggressive environments. In the second investigation, the PPR pipes were immersed in different chemically active environments as gasoline, sodium hypochlorite (NaClO), water + sodium hypochlorite (NaClO)-20% NaClO volume concentration, for a period of 3 weeks (21 days), in order to reveal the influence on the mechanical properties of the PPR pipes. The examination was made by using both visual inspection and tensile and bending tests. The investigations made have led to the conclusion that the presence of sodium hypochlorite do not affect the mechanical properties of PPR pipes, unlike the gasoline which significantly decrease the yield stress value. For the welded PPR pipes it was found that they failed at pressures of about 180 bar. Although the optimal welding parameters, recommended by the manufacturer, were modified (maintenance time), the only sample that failed in the welded joint was the one with the most acute misalignment and the shortest welding time. However, the sample withstood high pressures, reaching about 55% of the burst pressures obtained for welded pipes with the recommended welding parameters. The need to conduct such studies derived from the fact that most of the information regarding the behavior of PPR pipes is provided by the manufacturers and there is insufficient information in the scientific literature.*

Keywords: *PPR pipes, yield stress, welding, aggressive environments, burst pressure*

1. Introduction

PPR pipes are widely used for household hot and cold water installations [1]. In comparison with the conventional steel pipes or other plastic pipes, the PPR pipes offer a range of economical and ecological benefits such as [2]: low thermal conductivity (resulting in heat loss reduction, energy efficient systems and lower insulation costs), simple installation, the pipes and fittings joining is performed by using heat fusion instead of any additional chemicals or materials, longer functional life, polypropylene is durable and chemically inert without reacting with water or many dissolved chemicals in water, is resistant to corrosion, scaling and erosion - three major causes of long-term piping failure. For these reasons, they are used in many applications such as drainage, pollutants discharge, irrigation, heating, mining and pharmaceutical industry [3].

The mechanical behavior of PPR pipes was less investigated. In [4] the mechanical behavior of PPR pipes is investigated through tensile tests, using experimental and numerical analysis and so Young Modulus, Poisson ratio and the yield stress were determined.

Reference [5] aims to investigate the effect of axial and circumferential defects on the behavior of PPR pipes, based on burst tests on virgin and pre-damaged pipes, resulting that both types of defect caused a decrease in the ultimate burst pressure of pipes in comparison with virgin ones and axial defects are more critical than circumferential ones.

Scientific paper [6] presents the experimental results of frost heave failure mechanism of PPR water pipes, establishing a theoretical model that can be used in order to determine the pipe wall thickness.

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Because there is insufficient information in the scientific literature and most of the information regarding the behavior of PPR pipes is provided by manufacturers, the experimental study conducted in this paper, was focused in two directions: studies regarding the behavior of welded PPR pipes with different welding parameters and studies regarding the behavior of unwelded PPR pipes exposed to different chemically aggressive environments.

2. Materials and methods

In order to determine the welding behavior of PPR pipes, the following products were used (Figure 1): two types of PPR pipes with the following geometrical features: Ø63x10.5 mm and Ø32x5.4 mm EN ISO 158742 [7], Evo PP-R pipes EvoToolspackage kit for gluing - 2000 W, 230 V, maximum temperature 300°C and the main type of accessories such as PPR fittings, elbows, tees, plugs.

Figure 1. The joining elements used in the experimental investigation

The joining of PPR pipes, according to [8], can be done in the following way:

a) The sockets corresponding to the diameter of the pipe are mounted on the welding machine;

b) The pipe is cut to the desired length. The cut must be made perpendicular to the pipe axis;

c) The maximum depth of insertion of the pipe into the fitting is marked;

d) The device is connected to the electrical network and the operating temperature is set by turning the thermostat to the polyfusion temperature, indicated by the manufacturer. The welding process can start when the thermostat light turns off (it reaches the temperature that was set);

e) The welded end of the pipe and fitting are inserted into the sockets without turning them and they are kept in this position for the heating time indicated in the table of parameters (Table 1);

f) After simultaneously removing the tube and fitting from the sockets, they are connected without turning and are being kept pressed throughout the welding time. At the end, they are allowed to cool.

Table 1. Recommended welding parameters for PPR pipes [13]

Diameter, mm	Heating time, s	Welding time, s	Cooling time, s
20	5	4	2
25	7	4	2
32	8	6	4
40	12	6	4
50	18	6	4
63	24	8	6

The aspect of the welded pipes used in the case study is shown in Figure 2, and their denomination and welding parameters are presented in Table 2. For the experimental study made on Ø32x5.4 mm PPR pipes a variation of welding time was made in order to investigate how this parameter influences the quality of welded PPR joints subjected to internal pressure. No welds were made on sample F in order to see the difference between altered welded parameters and unwelded pipes.

The case of exposure of Ø63x10.5 mm PPR pipes in different chemically active environments (gasoline, sodium hypochlorite (NaClO), water + sodium hypochlorite (NaClO)- volume concentration 20% NaClO) for a period of about 21 days was chosen as an additional study variant (Figure 3).

Table 2. Welding parameters for the welded PPR pipes tested

Denomination	Diameter, mm	Welding time, s
A	32	4 – 16*
B		16 – 16*
C		4 – 4*
D		6
E		4
F		unwelded
G		6 – 6*

*the welding time if different for the 2 parts welded (eg. for sample A 4-16 means that the first weld – between the pipe and the fitting has 4 s welding time and the welding time between the fitting and the second pipe was 16 s)

Figure 2. The aspect of the welded PPR pipes

Figure 3. Immersion of PPR pipes in chemically active environments

The NaClO solution comes from an usual laundry whitener. The water used in the experimental investigation comes from the distribution network in the city of Ploiesti, having the characteristics indicated by the drinking water supplier: *p*H = 7.480, conductivity = 603 µs/cm [16].

3. Results and discussions

A. Welded PPR pipes

According to manufacturer's specifications [15], tests to determine the quality of welded joints can be tensile test and the visual examination. In addition, for a better assessment of the quality of the welds made, a series of additional tests were performed, namely Bending and Pressure Tests.

A.1. Visual examination

The scientific literature [9, 10] recommends several criteria for accepting or rejecting a weld in visual examination. The main unacceptable defects are related to the misalignment or the use of inadequate welding parameters.

The misalignment is the main factor leading to major welding defects. Although the end-to-end placement is done, including on manual ground, special attention must be paid to the observation of the non-uniformity in the welded area around the pipe and of different weld reinforcements on the joint ends, the excessive joining force, overheating and other aspects that depend exclusively on the operator or working equipment. In the welds made for the experimental study (Figure 4), the visual inspection revealed that the pipes misalignment and excessive or too low forces were applied to the joints. Thus, the quality of the operator is essential for the proper conduct of such a process.

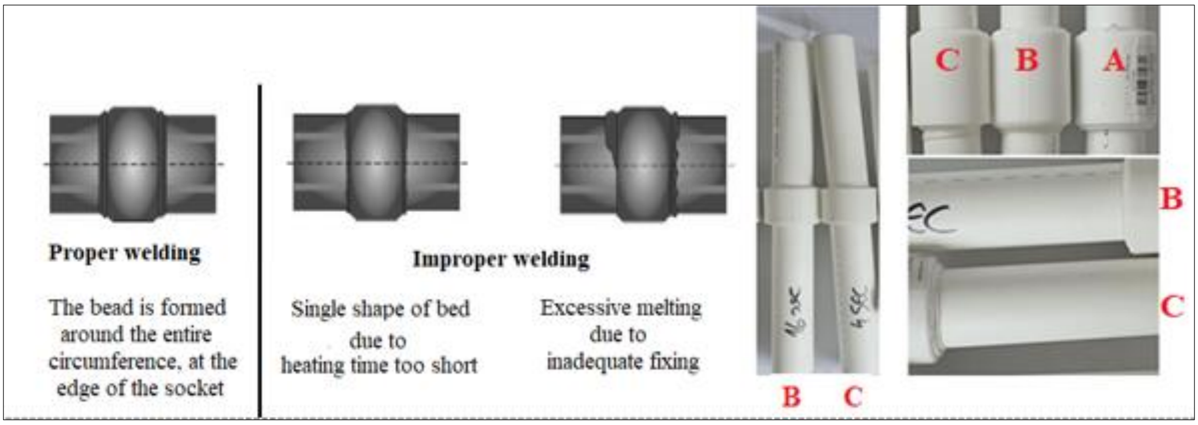

Figure 4. Proper/improper PPR pipe joints [18]

Table 3. Results of visual inspection of welded PPR pipes

Sample no.	A	B	C	D	E	F	G
Visual inspection	Proper welding	Improper welding		Proper welding			

Using the recommendation from [18] the results of visual inspection for each welded PPR pipe are presented in Table 3. It can be seen that samples B and C present improper welding due to heating time too short or inadequate fixing. All samples, including B and C were tested in order to see the influence of the defects at the main in service load (internal pressure)

A.2. Pressure test

For this experiment, a setup consisting of compressor, pump, working pipe and sealing caps (Figure 5) was used and seven samples of welded PPR pipes were subjected to burst pressure.

Figure 5. Experimental device used for the burst pressure test

In this experimental test (Figure 6), all the samples failed at pressures of about 180 bar (Table 5) in the pipe area and only in one case (sample C) it failed in the welded joint (but also reached a high burst pressure value of around 100 bar), reaching about 55% of the burst pressures obtained for welded pipes with the recommended welding parameters.

Figure 6. Samples subjected to burst pressure tests

Table 5. Burst pressure test results

Sample no.	A	B	C	D	E	F	G
Burst pressure, bar	180	160	100	180	170	160	170

Figure 7. Failure of improper welding seen on pressure test

B. PPR pipes in aggressive environments

B.1. Tensile test

The tensile test was performed according to the specifications indicated in ISO 527:2012 [11]. Two specimens were taken from each pipe that was immersed in the chemically active environment (Figure 8) and the main mechanical characteristics were determined on the Lloyd - LRX plus machine (Figure 9).

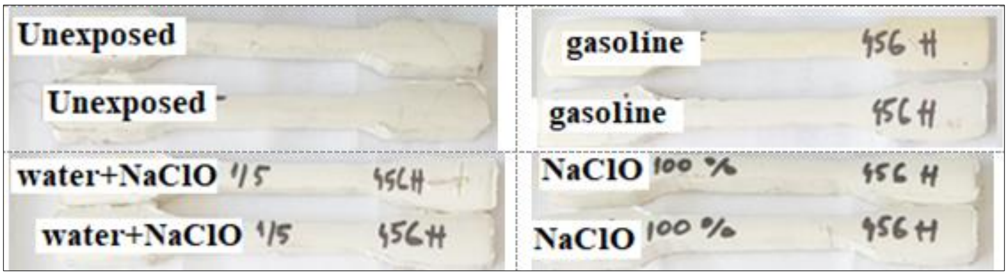

Figure 8. The aspect of the samples used for tensile test

The main mechanical properties obtained from the tensile tests performed are presented in Figure 10 and Table 6.

It can be seen that the NaClO concentration does not significantly affect the quality of the pipes, the yield stress decreased with no more than 7.64%. Instead, the presence of gasoline alters the mechanical properties of PPR pipes, in this case the yield stress decreased with 22.08%.

Figure 9. Device used for tensile test of PPR pipes

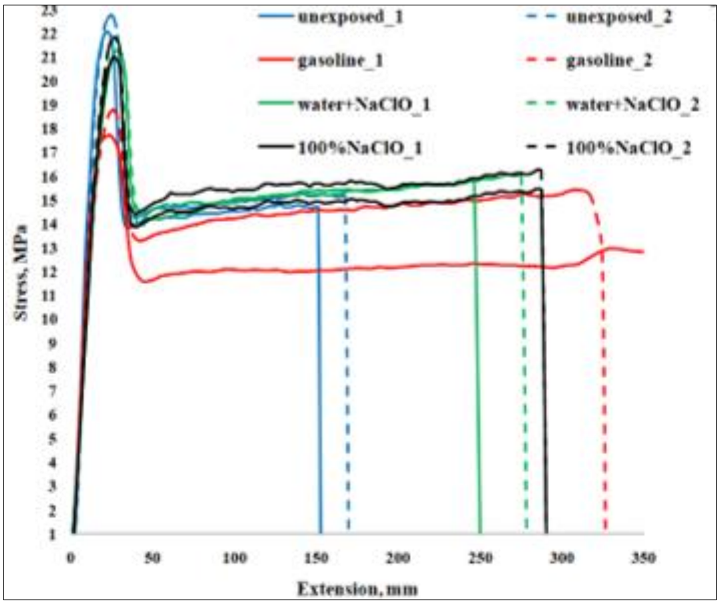

Figure 10. The results recorded during the tensile test

Table 6. The results of the tensile tests performed

Sample	Elongation *A*, %	Yield stress σ_y, Mpa
Unexposed_1	180	22.079
Unexposed_2	169	22.762
Gasoline_1	326	17.735
Gasoline_2	350	18.744
Water+NaClO_1	249	21.265
Water+NaClO_2	278	21.738
100%NaClO_1	280	21.021
100%NaClO_2	291	21.862

B.2. Bending test

The test was performed in accordance with the specifications of ISO 178: 2019 - Plastics. Determination of flexural properties [12] and the 3 Point bending Test (Figure 11) was chosen.

The tests performed led to the conclusion that the samples had a normal behavior, as they deformed without noticing defects, which implies that from the point of view of plasticity, the exposure to the aggressive environments did not affect the pipe, as it can be seen in Figure 11.

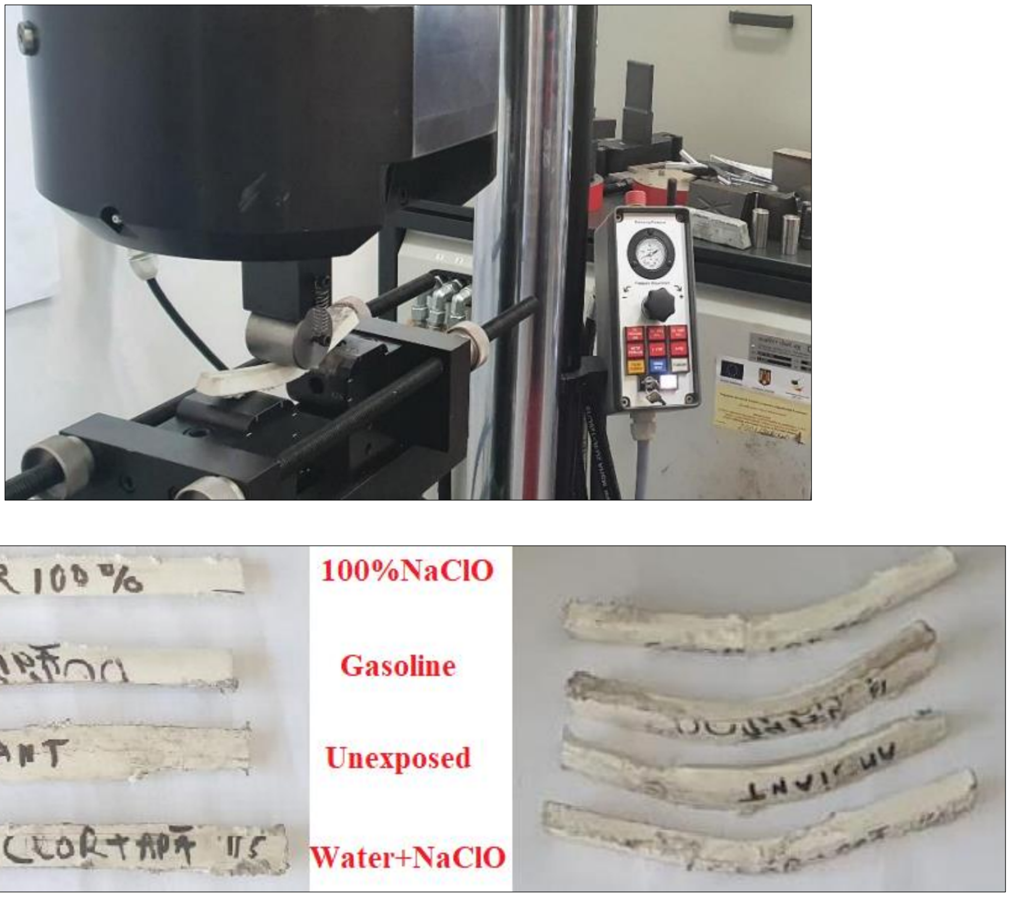

Figure 11. Bending test of PPR pipes before (left) and after (right) the test

4. Conclusions

After performing the experimental tests, the following aspects were found:

• the misalignment is the main factor leading to major welding defects;

• for the welded PPR pipes it was found that they failed at pressures of about 180 bar. Although the maintenance time, recommended by the manufacturer, was modified, the only sample that failed in the welded joint was the one with the most acute misalignment and the shortest welding time. However, the sample withstood high pressures, reaching about 55% of the burst pressures obtained for welded pipes with the recommended welding parameters;

• the experimental tests have shown that due to the large contact surface of the welded joint, the improper welding time is not such an important factor unlike other pipes made of other types of plastics – for example in [17] it was found that during welding, the duration of maintaining the heating plate on the pipes is very important in order to achieve proper welded joints;

• the experiment conducted in order to simulate the extreme working conditions revealed that the presence of sodium hypochlorite in different volume concentration does not affect the quality of the pipelines, the yield stress decreasing with maximum 7.64% compared with the unexposed sample. On the other hand, the presence of gasoline significantly alters the mechanical properties of PPR pipes, decreasing their yield stress with 22.08%;

• the influence of defects on the behavior of PPR pipes in the presence of different aggressive environments is a unique research direction so further studies will be conducted in this direction in future articles.

References

1. GEERTZ, G., Stabiliser diffusion in long-term pressure tested polypropylene pipes analyzed by IR microscopy, Polymer Degradation and Stability 94 (2009), 1092–1102 https://doi.org/10.1016/j.polymdegradstab.2009.03.020
2.***https://poloplast.us/what-are-the-advantages-of-polypropylene-random-pp-r-piping-systems/ Accesed May 2021
3.***https://www.bindasmalgeneraltrading.com/advantages-offered-plastic-ppr-pipes/Accesed May 2021
4. MEDDAH, H.M., Analysis of the polypropylene mechanical behaviour response: Experiments and numerical modeling, Materials and Design 30 (2009) 4192–4199, https://doi.org/10.1016/j.matdes.2009.04.043
5.OUARDIA, A., MOUHIBA, N., WAHIDC, A., Comparative study of axial and circumferential defects severity on the failure of polypropylene (PPR) pipes, Engineering Failure Analysis 105 (2019) 1201–121, https://doi.org/10.1016/j.engfailanal.2019.07.058
6. ZHENG, J., ZHANG, J., XU, J., Experiment on frost heave failure mechanism of PPR water pipe, Engineering Failure Analysis 117 (2020) 104831, https://doi.org/10.1016/j.engfailanal.2020.104831,
7. ***EN ISO 158742:2013. Plastics piping systems for hot and cold water installations - Polypropylene (PP) - Part 2: Pipes.
8. ***http://www.plasticsystems.ro/pdf/1329136445Sisteme_de_alimentare_extrudere.pdf Accesed June 2021
9.***NPCS BOARD OF CONSULTANTS & ENGINEERS, Manufacture of Thinners & Solvents (Properties, Uses, Production, Formulation with Machinery Details): Solvents for Pharmaceutical Manufacturing, Book of Solvents, Solvents for Production and Purification, How to start Solvents manufacturing business, How to start Solvents business, Manufacture of Solvents, Solvent use in production and cleaning processes, Starting a Solvents Business, Paint & Solvents Business, Solvents Science and Technology, Industrial Solvent book, Thinner Used in Paint Industry Niir Project Consultancy Services, 2017
10.DASILVA, L., BARBOSA, E., Polypropylene: Synthesis, Applications and Environmental Concerns, Nova Science Publishers, 2013
11.***ISO 527: 2012 - Plastics. Determination of tensile properties.
12.***ISO 178: 2019 - Plastics. Determination of flexural properties.
13.***https://www.fvplast.com/media/cache/file/8e/FV-Aqua-Tech-manual-ENG.pdf Accesed February 2022
14. CICIC, D.T., RONTESCU, C., AMZA, C.G., CHIVU, O.R., IACOBESCU, G., Qualitative and Quantitative Comparisons Concerning the Influence of Jointing Parameters on the Quality of the PPR Without Insertion Components Assembly, *Mater. Plast.*, **53**(1), 2016, 38-41
15.***Water corporation - welding and joining specifications ws-2 thermoplastics, Version 2, Revision 1, June 2021
16.***https://www.apanova-ploiesti.ro/20190209_ZD102.pdf, Accesed January 2022
17. RAMADAN, I., TANASE, M., Experimental Study Regarding the Influence of Welding Parameters on the Mechanical Behavior of High Density Polyethylene Pipes, Materiale Plastice, Volume 57, Issue 4, 2020, 209-215, https://doi.org/10.37358/MP.20.4.5420
18.***AQUATERM - Training Manual for fusion welding, http://aquatherm.co.nz/wp-content/uploads/2016/06/aquatherm-Training-Manual-2015.pdf, Accesed May 2021

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