A Study on the Influence of aging of the Butt-welded PE100 SDR11 on Shore A Hardness and Tensile Strength

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ABSTRACT

This paper presents the results of an experimental study on the influence of aging on the shore A hardness and tensile strength of butt-welded PE100 SDR11 pipeline joints with a nominal diameter of 125 mm and wall thickness of 11.40 mm used in natural gas distribution transportation. For the experimental determination, 12 samples were taken from the body of the pipe, 9 of which were taken from the area of the butt-welded joint. The test tubes were divided into 3 groups of 4 pieces each (1 unwelded test tube and 3 welded test tubes). Using the Arrhenius method, the test tubes in 2 groups were given artificial aging treatments of 10 and 20 years. Subsequently, all 12 test tubes were tested for shore A hardness and tensile strength. For the welded samples, an increase in tensile strength was observed with increasing aging time by 6.5% for the 10-year aged samples and by 6.16% for the 20-year aged samples. For the unwelded samples, the tensile strength decreased by 3.57% for 10-year aging and increased by 5.84% for 20-year aging. Artificial aging of 10 and 20 years of natural gas transmission and distribution pipelines did not considerably influence the Shore A hardness values, as they were in the medium/soft hardness range.

Keywords-polyethylene; pressure welding; tensile strength; shore A hardness

I. INTRODUCTION

Polyethylene (PE) has become one of the most widely used thermoplastic materials due to its many technical and economic advantages compared to other materials in this range [1-15]. The major advantage of this plastic material is that it can be repeatedly softened and reshaped under heating without changing its core structure and properties, [12, 26, 20]. The assortment diversity, the multitude of practical applications, and the fact that it is easy to recycle have imposed the use of PE in many industrial fields, such as drinking water distribution networks for domestic and industrial consumers, natural gas distribution networks, irrigation and water management networks, sewerage systems, protection systems for electrical cables, transport of food or industrial liquids, protection pipes in thermally pre-insulated systems, etc. [2, 22, 28]. The safe use of PE pipes and fittings in the construction of natural gas distribution networks is a constant concern, supported by the results of research into the knowledge and continuous improvement of plastic materials, their manufacturing technologies, non-demountable welding assembly processes (hot air jet welding, portable extruder welding, butt welding, electrofusion welding, polyfusion welding), and their quality control methods [2-4]. In this context, the tensile strength behavior of samples taken from pipes obtained by butt-welding pipes made of PE100 is studied in [22]. Tensile tests were performed on welded and unwelded samples, using various values of crosshead velocity, ranging from 5 to 500 mm/min. Increasing crosshead speed resulted in increasingly higher elasticity values for both types of test tubes. Regardless of the crosshead speed values, higher tensile strength values were obtained for the welded samples than for the unwelded ones. In [23], the way the parameters of the PE100 SDR17 (SDR: Standard Dimension Ration) PN10 pipe electrofusion welding influence the mechanical characteristics of the welded assembly was studied. One of the studied parameters was the cooling speed of the welded joint, which decisively influenced the mechanical characteristics of the welded joint. In [24], the influence of the mechanical properties of high density PE pipes, which have been subjected to the artificial aging process, was presented. Artificial aging was carried out by heating the pipes with hot air at 90 ± 1 °C for up to 8 cycles, each consisting of 7 days. The mechanical properties of the artificially aged pipes were determined by tensile testing. It was found that tensile strength improved along with increasing aging time.

The novelty of the current paper is the experimental study on the influence of aging on the shore A hardness and tensile strength of butt-welded butt joints of PE100 SDR11 pipes with a nominal diameter of 125 mm and a wall thickness of 11.40 mm.

II. SHORE A TENSILE AND HARDNESS STRENGTH TESTING

A. *Tensile Test*

Tensile testing is widely used to determine the in-service performance of various materials and welded assemblies [17-19]. Tensile tests were carried out on 9 welded and 3 unwelded tubes taken from pipelines used in natural gas transmission and distribution, obtained through butt welding of pipes made of PE100SDR11. Out of the total of 12 tensile tested tubes, 4 were artificially aged by 10 years and 4 by 20 years.

1) Preparation of the Test Tubes

The samples were taken from pipelines used for the transmission and distribution of natural gas, obtained by butt welding pipes made of PE100SDR11, with a nominal diameter of 125 mm and a wall thickness of 11.40 mm, using the George Fisher TM315 welding machine. Figure 1 presents the steps of butt pressure welding of PE100SDR11 pipes and the main elements and components of the George Fisher TM315 welding machine.

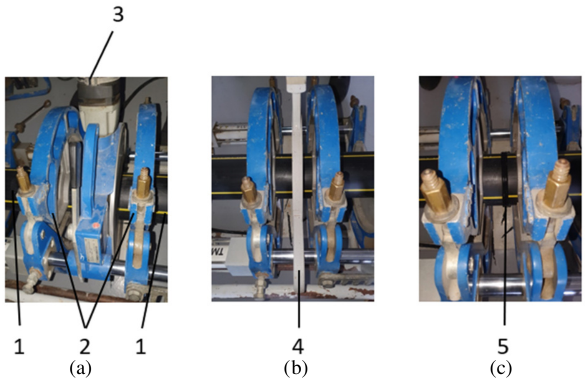

Fig. 1. Butt pressure welding of PE100SDR11 pipes: (a) milling the pipe butts, (b) heating the pipe butts to welding temperature, (c) welding the pipe butts: 1- pipe, 2- adjustable bins, 3- milling cutter, 4- heated plate, 5- welded joint.

Figure 2 shows the pipeline used for the transport and distribution of natural gas, obtained by butt-welding pipes made of PE100SDR11, from which tensile test tubes were taken for experimental determination. According to SR EN ISO 527-2-2012 type 1A [26], we took the 12 samples shown in Figure 3 from the pipe shown in Figure 2.

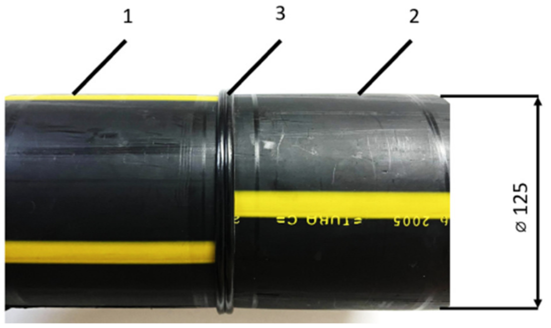

Fig. 2. Pipe made of PE100 SDR11: 1, 2 - pipe, 3 - welded assembly.

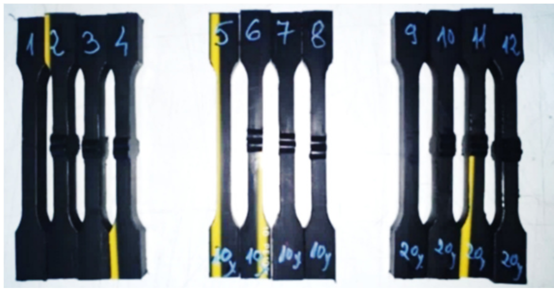

Fig. 3. Tensile test tubes made of PE100 SDR11.

The test tubes were split into 3 groups of 4 pieces (1 non-welded and 3 welded tubes). Using the Arrhenius method, the samples in 2 groups were subjected to artificial aging treatments by 10 and 20 years by exposure at a temperature of 110 °C for 170 and 340 hours, respectively.

2) Performing the Tensile Test

Tensile testing of the 12 samples was performed on the Mecmesin Multitest 10-I Universal Testing Machine (UTM) (Figure 4).

Fig. 4. Tensile test on the Mecmesin Multitest 10-i UTM.

3) *Shore A Hardness Test*

The hardness measurement on the 12 sampleswas performed using the Sauter HDA 100-1 digital hardness tester depicted in Figure 5.

Fig. 5. Shore A hardness test.

III. RESULTS AND DISCUSSION

A. *Tensile Strength Test*

Figure 6 shows the PE100 SDR 11 samples after performing the tensile tests. The welded samples broke in the thermally influenced area and the unwelded ones elongated up to 500 mm, (maximum stroke of the UTM). The graphical results of the tensile tests for all the samples are illustrated in Figures 7-9.

Fig. 6. PE100 SDR 11 samples after the tensile test.

Figure 10 shows the values of the tensile strengths and Figure 11 the values of the elongations at break obtained after the tensile testing of the 12 samples. Analyzing Figure 10, it can be observed that artificial aging increases the fracture toughness of butt-welded joints of PE100 SDR11 pipes with a nominal diameter of 125 mm and a wall thickness of 11.40 mm. The best results obtained (24.12-24.71 MPa) were for samples artificially aged by 10 years. In the case of non-welded samples, the maximum value of the tensile strength was 24.17 MPa and was obtained for samples artificially aged by 20 years. For the welded samples, artificial aging by 10 years resulted in an increase in tensile strength from 1.28 to 1.51 MPa while artificial aging by 20 years resulted in an increase in tensile strength from 0.46 to 1.43 MPa. Summarizing, the tensile strength of the welded samples is 1.92 to 10% higher than the tensile strength of unwelded samples.

(a)

(b)

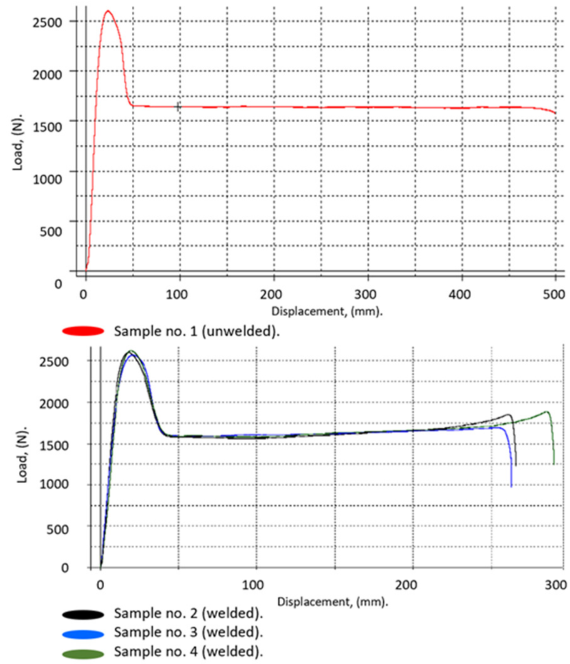

Fig. 7. Tensile test charts of non-artificially aged samples: (a) sample 1 (unwelded), (b) samples 2, 3, 4 (welded).

(a)

(b)

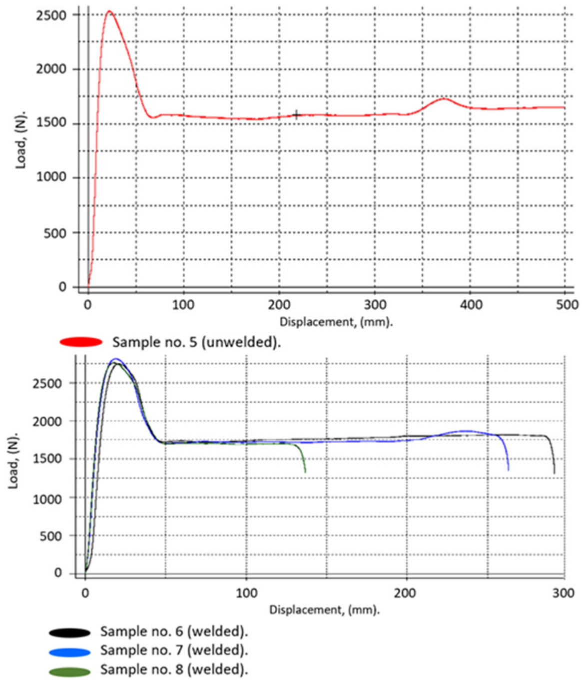

Fig. 8. Tensile test plots of samples artificially aged by 10 years: (a) sample 5 (unwelded), (b) samples 6, 7, 8 (welded).

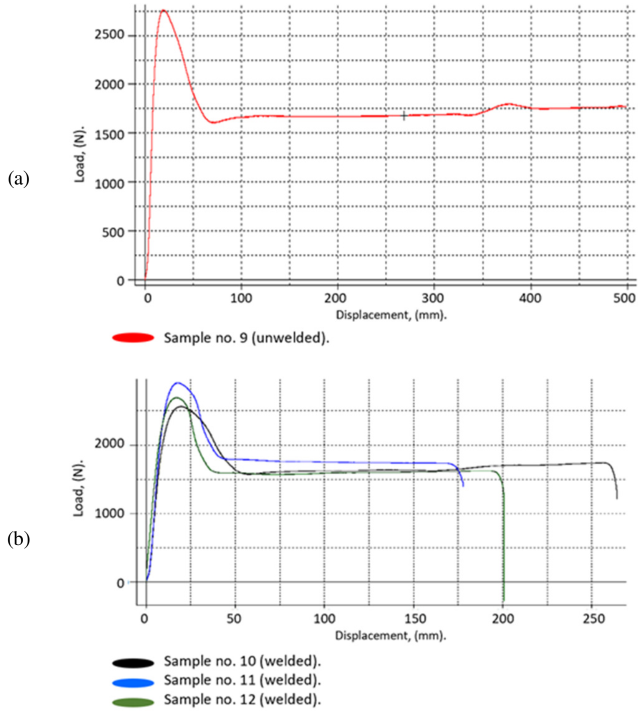

Fig. 9. Tensile test plots of samples artificially aged by 20 years: (a) sample 9 (unwelded), (b) samples 10, 11, 12 (welded).

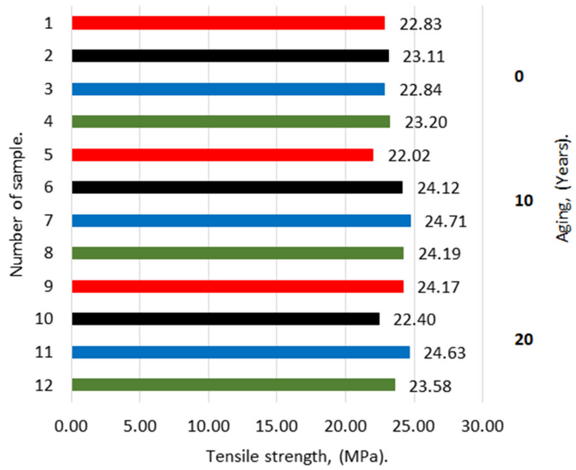

Fig. 10. Tensile strength values for samples tested in tension.

Analyzing Figure 11, it can be concluded that artificial aging causes a decrease of 6.45 to 88.89% in the elongation at break for butt pressure welded joints of PE100 SDR11 pipes. In the case of non-welded samples tested in tension, artificial aging resulted in an insignificant decrease in elongation at break from 0 to 0.34%. For the welded samples, artificial aging by 10 years resulted in a decrease in elongation at break from 1 to 123 mm while artificial aging by 20 years resulted in a decrease in elongation at break from 16 to 82 mm. The aging of butt-welded butt joints of PE100 SDR11 pipes was found to significantly influence the tensile behavior of pipelines used for the transport and distribution of natural gas. This drawback was highlighted by tracking the effects of temperature aging without quantifying other elements such as pressure (internal and external) or chemical elements that can affect the life-span of polyethylene pipes.

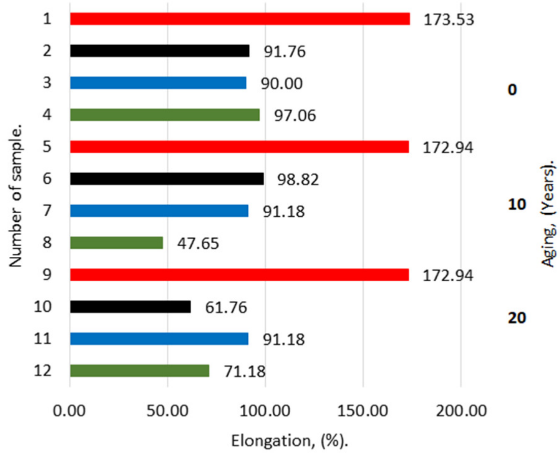

Fig. 11. Tensile elongation at break values for samples tested in tension.

B. Shore A Hardness Test

Figure 12 illustrates the Shore A hardness values obtained from the Sauter HDA 100-1 digital hardness meter tests on the 12 samples.

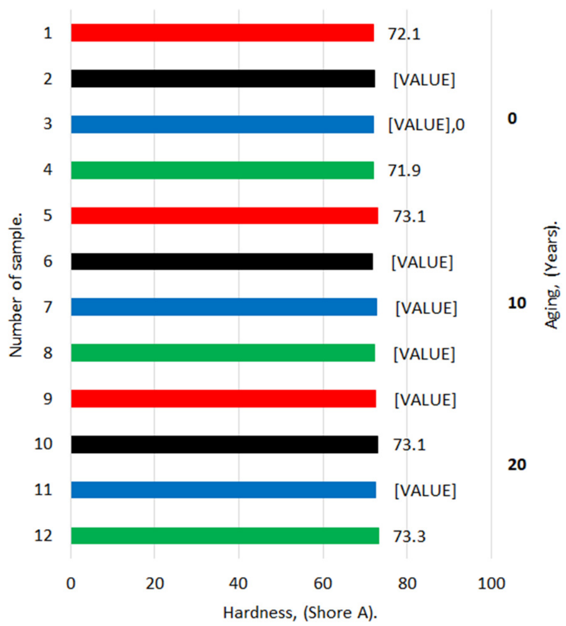

Fig. 12. Shore A hardness values for the 12 samples.

Analyzing Figure 12, it can be concluded that artificial aging does not significantly affect the hardness of butt pressure welded joints of PE100 SDR11 pipes and that all the values obtained are within the range of average/soft hardness Shore A according to SR EN ISO 868, [27].

IV. CONCLUSIONS

To determine the influence of aging of pipelines used in natural gas transport and distribution on the shore A hardness and tensile behavior of butt-welded butt joints of PE100 SDR11 pipes with 125 mm nominal diameter and 11.40 mm wall thickness, 12 test samples were used in this study. The samples (9 taken from the butt-welded area) were divided into 3 groups of 4 pieces each (1 unwelded and 3 welded samples). Using the Arrhenius method, the samples in 2 groups were artificially aged by 10 and 20 years. In [22], higher tensile strength values were obtained for the welded samples than for the unwelded ones. Our study results show that the welded samples obtained higher tensile strength by 1.23-1.61%. The tensile tests for the welded sample artificially aged for 10 years (sample no. 6 in Figure 3) showed the maximum tensile strength value of 24.71 MPa.

The butt pressure welding significantly influenced the elongation at break of the non-artificially aged samples, decreasing it by 44.07-48.14%. In [24], the tensile strength improved along with increasing aging time. In our study the 10-year pipeline increased its breaking strength by 5.61-6.50% and decreased its elongation at break by 0.65-88.89%. For the same type of pipe size and 20 years artificial aging, the ultimate tensile strength increased by 2.01-6.16% and the elongation at break decreased by 6.45-45.71%.

The Shore A hardnesses obtained from the Sauter HDA 100-1 digital hardness meter tests on the 12 samples are within the range of average/soft hardnesses.

This type of pipes is used in natural gas transportation and distribution. In a future paper, research will be conducted on how the reliability of polyethylene pipes is influenced by the butt welds made during over a longer period of time along with the addition of other factors that can influence the life of the pipe.

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