Study of the Tensile Strength and Shore Hardness Behavior of PE100 SDR11 Electrofusion Welded and Artificially aged Pipes

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ABSTRACT

This paper presents the tensile strength and Shore D hardness behavior of electrofusion-welded and artificially aged polyethylene (PE) pipes of the PE100 SDR11 classification with a nominal diameter of 125 mm and a wall thickness of 11.40 mm. For the study, 12 samples were taken from the body of a PE100 SDR11 pipe (9 of which were obtained from the fusion-welded joint). Subsequently, the 12 samples were divided into 3 groups of 4 pieces (1 unwelded sample and 3 welded samples). Following the Arrhenius method, the samples of the 2 groups (group II and group III) were artificially aged, those belonging to group II were aged 10 for years and those belonging to group III were aged for 20 years. Subsequently, all 12 samples were tested for tensile strength and Shore D hardness. The 10-year aging of the welded samples increased the tensile strength by 12.31% and the 20-year artificial aging increased the tensile strength by 18.44%. For the unwelded samples, artificial aging for 10 years increased the tensile strength by 11.12%, whereas aging for 20 years increased the tensile strength by 12.63%. Artificial aging of the PE100 SDR 11 pipes does not have a significant influence on the Shore D hardness, which was found within the high range of hardnesses. The results show that the PE100 SDR pipes welded by electrofusion can be used for 20 years with safety.

Keywords-polyethylene; electrofusion welding; tensile strength; shore hardness; artificial aging

I. INTRODUCTION

With the emergence and evolution of plastic materials, there has been an increase in demand and consequently in the supply and production of these materials [1]. The success of plastics emerges from the numerous technical and economic advantages they have compared to other non-plastic materials: absence of corrosion, low price, low mass, flexibility, etc. [2-7]. Plastics are used in various applications by numerous industries, such as electronics and household appliances, textiles, packaging, cars, ships and aircraft, medical and optical materials [8-15]. Polyethylene (PE) is utilized mainly in the distribution networks of natural gas, drinking water, and wastewater [1, 16-21].

Increasing the operational safety and the service life of PE pipes and fittings is a field of interest for the academic community, with significant progress being made in improving plastics and their welding processes through ongoing research [22, 23]. The welding of PE pipes is performed adopting one of the following processes: hot air welding, portable extruder welding, butt welding, electrofusion welding, polyfusion welding [1, 24-26].

In the literature, there are numerous reports on the performance of High-Density PE (HDPE) pipelines used in the transport and distribution of natural gas, but there is very limited information on how the aging of the pipeline material affects its reliability.

In [22], the damage to steel pipelines used in natural gas distribution is studied. This damage is caused by rigid structures, which result from trench excavation. The experimental study was carried out on a steel pipe isolated with HDPE on which a duralumin mandrel was operated. The experiment was conducted on 3 sets of samples of the same type-size, each set being given different operating environments. The first set of samples was kept in an atmospheric environment, the second set was kept in water for 72 hours, and the third set was kept in clay sand for 72 hours. The results indicated that the best performance regarding the breaking strength was obtained for the samples kept in the ambient environment.

In [23], it is presented how natural aging affects the reliability of PE80 pipelines used in natural gas transportation. The study was performed on new pipelines and on pipelines operated for a period of 9, 11, 13, 16, and 18 years. The findings exhibited that in the first 0 - 9 years there is an accelerated decrease in the mechanical properties of the PE80 pipes, whereas after 9 - 18 years there is a slow decrease in the mechanical properties. In terms of operational safety, after 18 years the performance of PE80 pipes is stable, so they can continue to be used without compromising operational safety.

In our previous work [27], the influence of aging on the tensile strength and Shore hardness behavior of non-detachable PE100 SDR11 butt-welded press-fit joints was presented. The test samples were artificially aged for 10 and 20 years by a heat treatment at 110 °C for 170 and 340 hours, respectively. The artificially aged and the control samples were subjected to tensile strength and hardness measurements. The results demonstrated that the tensile strength of the 10-year aged butt-welded samples was 6.5% higher than the control and 6.16% higher for the 20-year aged samples. The hardness of the PE100 SDR11 samples was found to be in the medium/soft range, and not influenced by the artificial aging process. Expanding on that previous work, in this study, the tensile strength and Shore hardness behavior of artificially aged PE100 SDR11 pipes, welded by electrofusion are elucidated.

II. EXPERIMENTAL PROCEDURE

A. Tensile Strength Testing

To determine the mechanical properties of the welded HDPE assemblies, 12 samples were made from a welded by electrofusion PE100 SDR11 pipe with a nominal diameter of 125 mm and a wall thickness of 11.40 mm and named accordingly. Of the 12 samples, 3 were cut from the base material and 9 from the welded assembly.

1) *Samples Preparation*

Figure 1 illustrates a typical HDPE pipeline deployed for the transport and distribution of natural gas, which was assembled by electrofusion welding of PE100 SDR11 pipes. The arrows in Figure 1 note the characteristic areas in the assembly and point out the locations from which the samples for the tensile strength measurements were acquired.

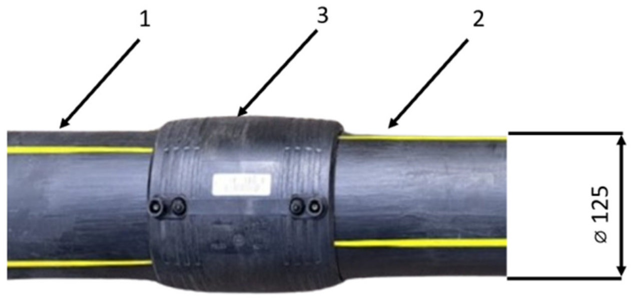

Fig. 1. The PE100 SDR11 pipe welded by electrofusion. The arrows 1 and 2 point to the pipes and arrow 3 points to the welded assembly.

The samples for the tensile strength measurements were made in accordance with the SREN ISO 527-2:2012 type 1A standard [28]. The dimensions of the samples estimated on the basis of the standard are portrayed in Figure 2 and the resulting 12 samples are depicted in Figure 3, where the samples were categorized into 3 groups each of which contained 4 samples.

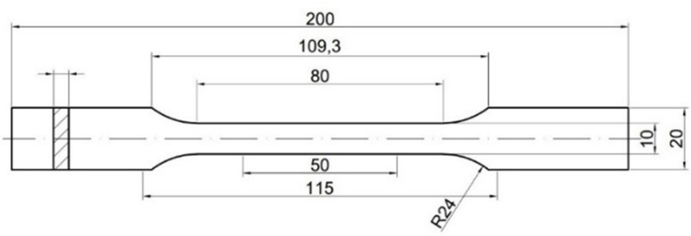

Fig. 2. Tensile sample model, type 1A.

Fig. 3. Tensile samples made of PE100 SDR11.

Each group contains 1 sample from the unwelded area of the pipe and 3 samples from the welded joint. 2 of the 3 groups were subjected to artificial aging by heat treatment and following the Arrhenius method. The samples of the second group, numbered 5 to 8, were heat treated for 170 hours at a temperature of 110 °C, whereas samples 9 to 12 were heat treated for 340 hours, resulting in artificially aged samples of 10 and 20 years, respectively.

2) Performing the Tensile Strength Test

The 12 samples from the 3 groups were subjected to a tensile strength test using the Mecmesin Multitest 10-i universal test machine, observed in Figure 4.

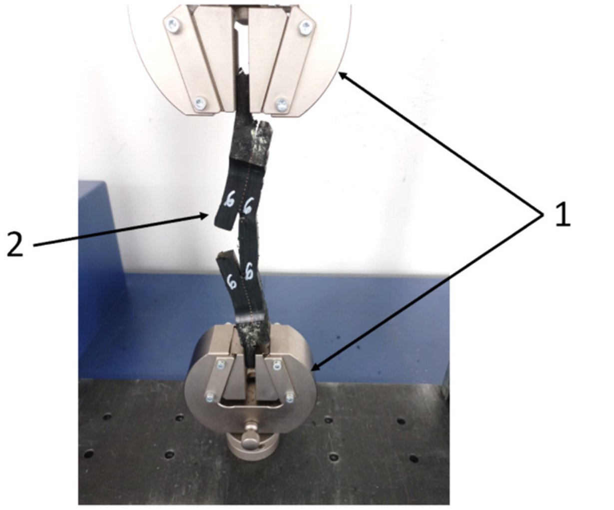

Fig. 4. Tensile strength testing on the Mecmesin Multitest 10-i universal testing machine: 1- pans; 2- welded sample.

3) Results and discussion

Figure 5 illustrates the PE100 SDR 11 samples after the tensile testing. The results obtained from the tensile strength testing, that is, the load, the elongation, the tensile strength, and the percentage of elongation, are shown in Table I. Figure 6 displays the tensile strength curves of samples 1, 5, and 9, which were acquired from the unwelded area of the PE100 SDR 11 assembly.

TABLE I. TENSILE STRENGTH TEST RESULTS OF PE100 SDR11 SAMPLES

Sample	Load (N)	Elongation (mm)	Tensile strength (MPa)	Elongation percentage (%)
1	2629	34.41	18.13	17.21%
2	2357	34.43	20.68	17.21%
3	2580	19.79	22.63	9.90%
4	2734	23.40	23.98	11.70%
5	2958	73.37	20.40	36.68%
6	2688	24.31	23.58	12.15%
7	2743	26.44	24.06	13.22%
8	2771	26.67	24.31	13.33%
9	3009	63.73	20.75	31.87%
10	2659	36.00	23.32	18.00%
11	2890	27.14	25.35	13.57%
12	2522	24.10	22.12	12.05%

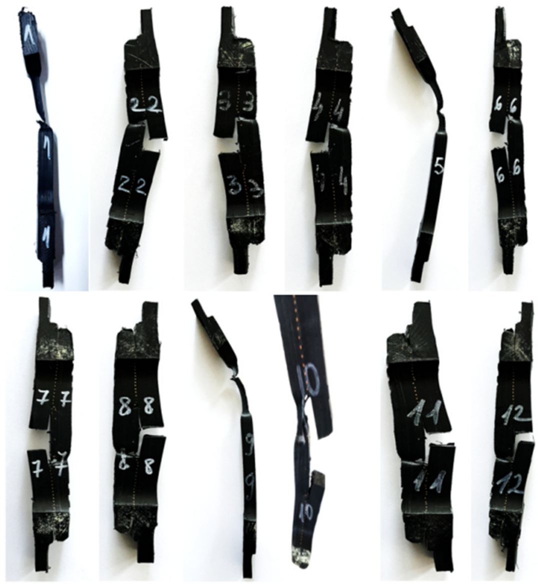

Fig. 5. PE100 SDR 11 samples after tensile strength testing.

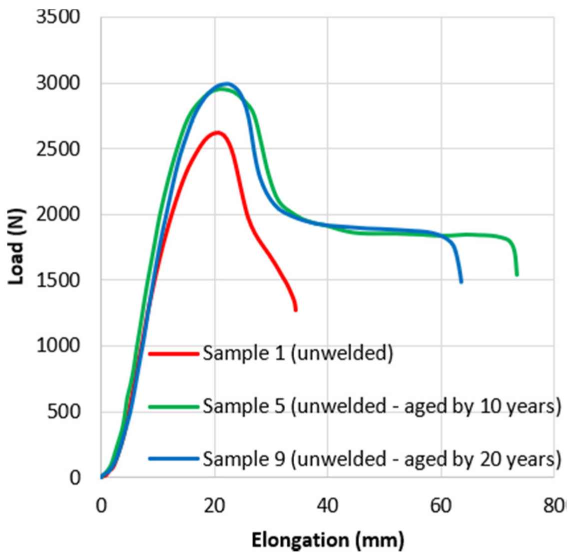

Fig. 6. Tensile strength test charts of unwelded samples.

According to Figure 6, the highest load of 3009 N was recorded for the sample artificially aged for 20 years, namely sample 9. This result is 51 N higher than the value attained for the sample artificially aged for 10 years and 380 N higher than the control sample. Figure 7 manifests the tensile strength curves of the samples from the welded area of the PE100 SDR11 pipe. The artificial aging increases the breaking strength of the welded joints. The highest load values (2688 - 2771 N) were observed in samples that were artificially aged for 10 years. The 10-year aging led to an increase in the breaking strength of 37 - 331 N, whereas the 20-year artificial aging resulted in an increase of 156 - 165 N in the breaking strength. Figure 8 exhibits the percentage of elongation of the unwelded samples according to the tensile strength tests. When comparing the values of the percentage of elongation at rupture of the unwelded samples, as noticed in Figure 8, it can be estimated that the percentage of elongation at rupture increases by 53.09% and 46 % compared to the control for samples aged for 10 and 20 years, respectively. In Figure 9, the percentage elongation values obtained at the breakage of the electrofusion welded joints are plotted.

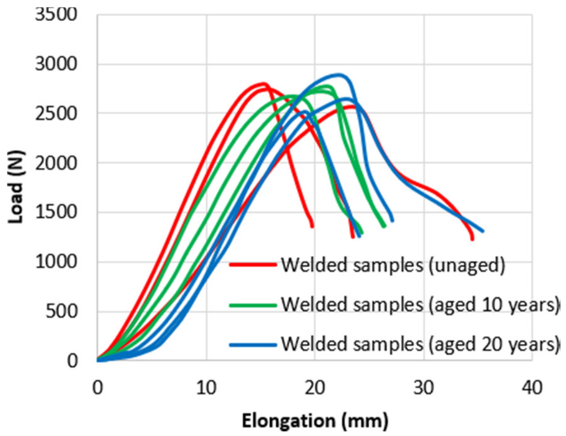

Fig. 7. Tensile strength test charts of welded samples.

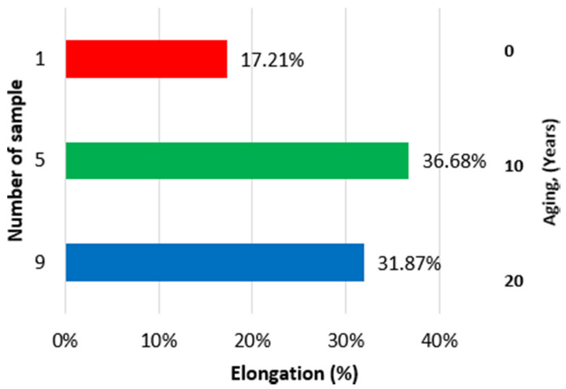

Fig. 8. Percentage elongation values obtained just before the breakage of the unwelded samples in the tensile strength tests.

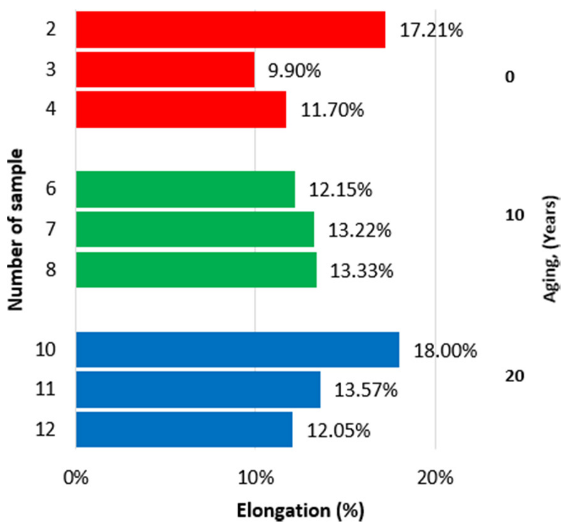

Fig. 9. Percentage elongation values obtained at the breakage of tensile strength tested welded samples.

When comparing the highest elongation values for each age group in Figure 9, it can be observed that the 10-year artificial aging results in a decrease of 0.27% in the percentage of elongation. However, the 20-year artificial aging leads to an increase of 11.03% in the percentage of elongation at break for the electrofusion welded assemblies of PE100 SDR11 pipes.

Based on the tensile strength results in Table I and in Figures 8 and 9, it is found that the percentage of elongation of the samples taken from the welded area, are 42.49 to 66.87% lower than that of the unwelded samples. Furthermore, artificial aging for 10 and 20 years resulted in a decrease of up to 66.97% and 62.19% in the percentage of elongation values of the welded and unwelded samples, respectively.

B. Shore D Hardness Testing

The Shore D hardness of the 12 samples (see Figure 3) was determined at the 3 points illustrated in Figure 10, using the Shore D analogue hardness tester exhibited in Figure 11.

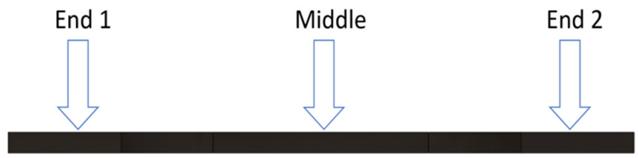

Fig. 10. Hardness measurement points of PE100 SDR11 samples.

Fig. 11. The Shore D analogue hardness tester.

1) Results and discussion

Table II provides the Shore D hardness values estimated from the tests performed at the 3 different points (Figure 10) for each of the 12 PE100 SDR11 samples. Figure 12 presents the average Shore D hardness. The Shore D hardness was slightly lower at the welded points of the pipe compared to the unwelded spots. Furthermore, the artificial aging of the PE100 SDR11 pipes does not have a significant influence on Shore D hardness. The values of the Shore D hardness in Table II fall within the range of strong hardness, according to ISO 828:2003 [29]. In [23], it has been demonstrated that the performance of the PE80 pipes can be stable for 18 years. This research demonstrates the reliability of the PE100 SDR11 pipes for up to 20 years. Compared to [27], the break strength values obtained in this study are up to 2.52% higher.

TABLE II. RESULTS OF SHORE D HARDNESS TESTS AT THREE POINTS OF PE100 SDR11 SAMPLES.

Sample	Measurement points			Average
	End 1	Middle	End 2	
(no.)	*(Shore D)*			
1	57	62	55	58.00
2	54	52	56	54.00
3	54	49	55	52.67
4	54	51	51	52.00
5	57	65	56	59.33
6	52	43	56	50.33
7	56	52	51	53.00
8	54	43	52	49.67
9	57	65	57	59.67
10	51	52	46	49.67
11	52	48	48	49.33
12	52	49	50	50.33

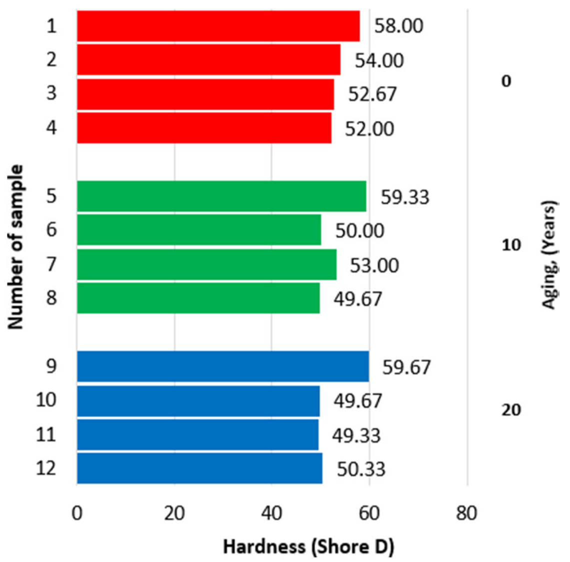

Fig. 12. Average Shore D hardness values for PE100 SDR11 samples.

III. CONCLUSIONS

This paper presents the tensile strength and Shore D hardness behavior of electrofusion welded and artificially aged Polyethylene (PE100 SDR11) pipes. In this context, 12 samples of the welded and unwelded areas were taken from the body of a PE100 SDR11 pipe with a nominal diameter of 125 mm and a wall thickness of 11.40 mm. The samples were divided into 3 groups containing 4 pieces (1 unwelded and 3 welded area samples). The first control group was left without further treatment. The samples in the second group were artificially aged for 10 years by heat treatment at 110 °C for 170 hours. The samples in the third group were artificially aged for 20 years by doubling the heat treatment time.

Tensile strength tests indicated that the artificial aging influences the tensile strength behavior of the samples. The maximum tensile strength of the unwelded samples was 20.75 MPa and the maximum tensile strength of the welded samples was 25.35 MPa. Furthermore, the tensile strength of the unwelded samples increased by 11.12% and that of the welded samples by 12.31% compared to the control. Regarding samples aged for 20 years, the tensile strength of the unwelded samples increased by 12.63% whereas the one of the welded samples increased by up to 18.44%.

The maximum elongation at break of the unwelded samples was 73.37 mm for the sample aged for 10 years and for the welded samples it was 36 mm for the sample artificially aged for 20 years. Moreover, it was observed that for the samples aged for 10 years, the elongation of the unwelded samples increased by 53.09%, but the elongation decreased by 0.27% for the welded samples. However, the elongation of the samples aged for 20 years increased by 46% and 11.03% for the unwelded and welded samples, respectively.

The Shore D hardness tests indicated that the welded areas exhibit slightly lower hardness than the unwelded areas. Furthermore, the Shore D hardness values for all samples fall within the strong hardness range.

The results of this study reveal that the PE100 SDR11 pipes welded by electrofusion can be used safely for 20 years without a significant decline in the tensile strength and hardness. These results can be applied to other HDPE pipe assembly processes.

REFERENCES

[1] M. Minescu and D. G. Zisopol, *Sudarea țevilor și fitingurilor din polietilenă de înaltă densitate (HDPE Pipe & Fittings Welding)*. Ploiesti, Romania: UPG Ploiești Publishing House, 2021.

[2] D. G. Zisopol, A. I. Portoaca, I. Nae, and I. Ramadan, "A Comparative Analysis of the Mechanical Properties of Annealed PLA," *Engineering, Technology & Applied Science Research*, vol. 12, no. 4, pp. 8978–8981, Aug. 2022, https://doi.org/10.48084/etasr.5123.

[3] D. G. Zisopol, I. Nae, A. I. Portoaca, and I. Ramadan, "A Theoretical and Experimental Research on the Influence of FDM Parameters on Tensile Strength and Hardness of Parts Made of Polylactic Acid," *Engineering, Technology & Applied Science Research*, vol. 11, no. 4, pp. 7458–7463, Aug. 2021, https://doi.org/10.48084/etasr.4311.

[4] D. G. Zisopol, M. Minescu, and D. V. Iacob, "A Study on the Influence of FDM Parameters on the Tensile Behavior of Samples made of PET-G," *Engineering, Technology & Applied Science Research*, vol. 14, no. 2, pp. 13487–13492, Apr. 2024, https://doi.org/10.48084/etasr.6949.

[5] D. G. Zisopol, M. Minescu, and D. V. Iacob, "A Study on the Evaluation of the Compression Behavior of PLA Lattice Structures Manufactured by FDM," *Engineering, Technology & Applied Science Research*, vol. 13, no. 5, pp. 11801–11806, Oct. 2023, https://doi.org/10.48084/etasr.6262.

[6] D. G. Zisopol, M. Minescu, and D. V. Iacob, "A Theoretical-Experimental Study on the Influence of FDM Parameters on the Dimensions of Cylindrical Spur Gears Made of PLA," *Engineering, Technology & Applied Science Research*, vol. 13, no. 2, pp. 10471–10477, Apr. 2023, https://doi.org/10.48084/etasr.5733.

[7] D. G. Zisopol, D. V. Iacob, and A. I. Portoaca, "A Theoretical-Experimental Study of the Influence of FDM Parameters on PLA Spur Gear Stiffness," *Engineering, Technology & Applied Science Research*, vol. 12, no. 5, pp. 9329–9335, Oct. 2022, https://doi.org/10.48084/etasr.5183.

[8] M. Amjadi and A. Fatemi, "Tensile Behavior of High-Density Polyethylene Including the Effects of Processing Technique, Thickness, Temperature, and Strain Rate," *Polymers*, vol. 12, no. 9, Sep. 2020, Art. No. 1857, https://doi.org/10.3390/polym12091857.

[9] B. Zhao, S. Zhang, C. Sun, J. Guo, Y. X. Yu, and T. Xu, "Aging behaviour and properties evaluation of high-density polyethylene (HDPE) in heating-oxygen environment," *IOP Conference Series: Materials Science and Engineering*, vol. 369, no. 1, May 2018, Art. No. 012021, https://doi.org/10.1088/1757-899X/369/1/012021.

[10] M. Stan and D. G. Zisopol, "Modeling and Optimization of Piston Pumps for Drilling," *Engineering, Technology & Applied Science*

Research, vol. 13, no. 2, pp. 10505–10510, Apr. 2023, https://doi.org/10.48084/etasr.5714.

[11] D. G. Zisopol, M. Tănase, and A. I. Portoacă, "Innovative Strategies for Technical-Economical Optimization of FDM Production," *Polymers*, vol. 15, no. 18, Jan. 2023, Art. No. 3787, https://doi.org/10.3390/polym15183787.

[12] O.-L. Petraşcu and A.-M. Pascu, "Comparative study of polyamide 6 (PA6) and polyamide 6 reinforced with 30% of glass fiber (PA6GF30)," *Materials Today: Proceedings*, vol. 93, pp. 625–629, Jan. 2023, https://doi.org/10.1016/j.matpr.2023.04.112.

[13] N. Rosca et al., "Minimizing the Main Strains and Thickness Reduction in the Single Point Incremental Forming Process of Polyamide and High-Density Polyethylene Sheets," *Materials*, vol. 16, no. 4, Jan. 2023, Art. No. 1644, https://doi.org/10.3390/ma16041644.

[14] E. Avrigean, "Studies and Research on the Behavior of Polyethylene when Electrofusion Welding Fittings to High Density Polyethylene Pipes," *Materiale Plastice*, vol. 58, no. 1, pp. 85–98, Apr. 2021, https://doi.org/10.37358/MP.21.1.5448.

[15] N. Stefanoaea, D.-M. Rusu, and A.-M. Pascu, "A Simulation Method for the One-time Snap-fit Assembly Process of PA6 GF60 - Components," *Engineering, Technology & Applied Science Research*, vol. 14, no. 1, pp. 12988–12992, Feb. 2024, https://doi.org/10.48084/etasr.6715.

[16] D. G. Zisopol and M.-J. Săvulescu, *Bazele tehnologiei*. Ploiesti, Romania: UPG Ploieşti Publishing House, 2003.

[17] D. G. Zisopol, *Tehnologii industriale şi de construcţii. Aplicaţii practice şi studii de caz (Industrial and Construction Technologies. Practical Applications and Case Studies)*. Ploiesti, Romania: UPG Ploieşti Publishing House, 2003.

[18] M. J. Savulescu, D. G. Zisopol, and I. Nae, *Bazele tehnologiei materialelor. Îndrumar de lucrări practice*. Ploiesti, Romania: Editura Premier Ploiești, 1997.

[19] D. G. Zisopol, A. Dumitrescu, M. Minescu, and A. Dinita, "New materials intended for use within natural gas installations and quality testing procedures," *Journal of Engineering Sciences and Innovation*, vol. 7, no. 2, pp. 241–252, Jun. 2022, https://doi.org/10.56958/jesi.2022.7.2.241.

[20] M. Săvulescu and D. G. Zisopol, *Tehnologii industriale şi de construcţii*. Ploiesti, Romania: UPG Ploieşti Publishing House, 2002.

[21] D. G. Zisopol, *Ingineria valorii (Value Engineering)*. Ploiesti, Romania: UPG Ploieşti Publishing House, 2004.

[22] S.-M. Filip, E. Avrigean, and A.-M. Pascu, "Damage to Natural Gas Distribution Steel Pipelines Caused by Rigid Bodies Resulting From the Excavation of Laying Trenches," *Engineering, Technology & Applied Science Research*, vol. 14, no. 1, pp. 12984–12987, Feb. 2024, https://doi.org/10.48084/etasr.6716.

[23] Y.-C. Chen, Y.-F. Li, Y. Xi, Q. Li, Q. Lu, and J. Yang, "Natural aging mechanism of buried polyethylene pipelines during long-term service," *Petroleum Science*, vol. 20, no. 5, pp. 3143–3156, Oct. 2023, https://doi.org/10.1016/j.petsci.2023.03.001.

[24] D. G. Zisopol and A. Dumitrescu, *Materiale şi tehnologii primare. Aplicaţii practice şi studii de caz (Materials and Primary Technologies. Practical Applications and Case Studies)*. Ploiesti, Romania: UPG Ploieşti Publishing House, 2005.

[25] D. G. Zisopol and A. Dumitrescu, *Ecotehnologie: studii de caz*. Ploiesti, Romania: UPG Ploieşti Publishing House, 2020.

[26] D. G. Zisopol, A. Dumitrescu, and T. Ciprian, *Ecotehnologie. Noțiuni teoretice, aplicații practice și studii de caz*. Ploiesti, Romania: UPG Ploiești Publishing House, 2010.

[27] D. G. Zisopol, M. Minescu, and D. V. Iacob, "A Study on the Influence of aging of the Butt-welded PE100 SDR11 on Shore A Hardness and Tensile Strength," *Engineering, Technology & Applied Science Research*, vol. 14, no. 1, pp. 12722–12727, Feb. 2024, https://doi.org/10.48084/etasr.6635.

[28] "ISO 527-2:2012. Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics," https://www.iso.org/standard/56046.html.

[29] "ISO 868:2003. Plastics and ebonite — Determination of indentation hardness by means of a durometer (Shore hardness)," https://www.iso.org/standard/34804.html.