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PREDICTION OF CHANGES IN PROPERTIES OF PIPES FROM POLYETHYLENE IN THE RESEARCH OF SIMULATION OF AGEING

Abstract
This study presents a comparative analysis of specimens before and after photochemical and electrochemical ageing processes. The specimens were cut out of the pipes obtained through extrusion. The examinations were carried out for two commercial grades of polyethylene. Ageing with UV radiation was carried out using a gas discharge lamp, whereas simulation of electrochemical ageing was performed in a water solution of NaCl. Tensile strength testing, differential scanning calorimetry, colour and gloss measurements and hardness testing using the method of ball indentation were carried out for both types of specimens (after ageing and without ageing). Analysis of the results of the examinations revealed that ageing caused significant changes in properties of the specimens. In the samples after ageing was observed decrease in tensile strength. Found a decrease in the degree of crystallinity and changing temperatures physical changes. In the samples after ageing was observed different values of the parameters describing the colour. In samples after ageing also reported a reduction in gloss and hardness.

Key words
pipes, polyethylene, ageing, thermal properties, mechanical properties, colour, gloss

Introduction
Simulations of the ageing process allow for determination of changes in thermomechanical properties of the components made of polymeric plastics [1]. Properties of pipes made of polymeric plastics substantially depend on conditions of their storage and use. Working environment and medium that flows through the pipe cause its degradation. As a result of ultraviolet radiation and depending on the chemical composition of the soil in which the pipe is placed, the chain in the plastic might be torn, which leads to a reduction in the molecular mass of the plastic. These processes result in deterioration of mechanical properties of the pipe, which might lead to the breakdown of the whole system of piping [2-7]. Pipes made of polypropylene, which is the material from the group of polyolefin plastics, can be manufactured in various sectors of the industry. The pipes made of polyethylene are characterized by e.g. insignificant mass, high smoothness of surface and easiness of installation [6-10].

The aim of the examinations was analysis of the effect of ageing conditions on thermomechanical properties of pipes made of polyethylene. The examinations used two different commercial grades of polyethylene. Differential scanning calorimetry examinations and tensile strength testing were also carried out for specimens before and after the ageing process.

Research methodology
The examinations were carried out for the specimens made of two different types of polyethylene with commercial names of: PE 3802 YCF used for transport of gas and PE XSC 50 Blue for transport of water, manufactured by Total Petrochemicals. The specimens were cut out from extruded pipes with the following parameters:

- rotational speed of the feed screw: 69.2 [1/min],
- pull-off speed: 1.208 [m/min],
- mass flow intensity: 76.1 [kg/h],

- temperature in individual zones of cylinders in the extrusion machine: t_1 – 180 [^{o}C], t_2 – 181 [^{o}C], t_3 – 182 [^{o}C], t_4 – 183 [^{o}C], t_5 – 185 [^{o}C],
- extrusion machine head temperature: 185 [^{o}C].

Simulation of ageing with ultraviolet radiation was carried out for the polyethylene 3802 YCF in a specialized chamber with an arc tube of high-pressure mercury vapor lamp. It was calculated based on the data concerning power of solar radiation that the time of simulated ageing corresponded to a half-a-year ageing under natural conditions [12, 13]. The examinations of accelerated electrochemical ageing used specimens made of XSC 50 Blue polyethylene. The test stand was equipped with a glass vessel filled with water solution of NaCl with concentration of 35 per mille with specimens placed inside. The ageing process occurred under following conditions: direct current with current intensity of 0.3 A, time: 700h, temperature: 20°C and pH: 7. The equipment used graphite electrodes.

The following examinations were carried out for tensile strength, tensile stress at break and elongation at break. Tensile strength examinations were carried out using a tensile strength testing machine (Inspekt Desk 20 manufactured by Hegewald&Peschke). Examinations of thermal properties were carried out using (DSC Phox 204 PC manufactured by NETZSCH). The measurements were carried out with the specimen heating rate of 10^{o}C/min in the range of temperature of from 50 to 190^{o}C. Evaluation of the crystallinity degree used the Netzsch-Proteus software. This software allows for examination of the course of specimen melting at the specific range of temperatures and determination of the surface area between the thermographic curve and the base line in the range of endothermic reflex. The specimens before placing in the measurement chamber were weighted using SARTORIUS scales with precision of 0.01 mg with internal calibration option and closed weighing chamber. The mass of specimens was within the range of from 7 to 10 mg. The colour of the specimens was measured using X-Rite spectrophotometer. The examinations were carried out using CIELAB model (Fig. 1). This model describes the colour by means of three coordinates, *a*, *b* and *L*. The values of *a* coordinate determine the colour from green to red, while the *b* coordinate defines the colour from blue to yellow. Parameter *L* (luminance) characterizes brightness of the colour from black to white [11]. Gloss was measured by means of ELCOMETER equipment, with the refraction angle of 20^{O}.

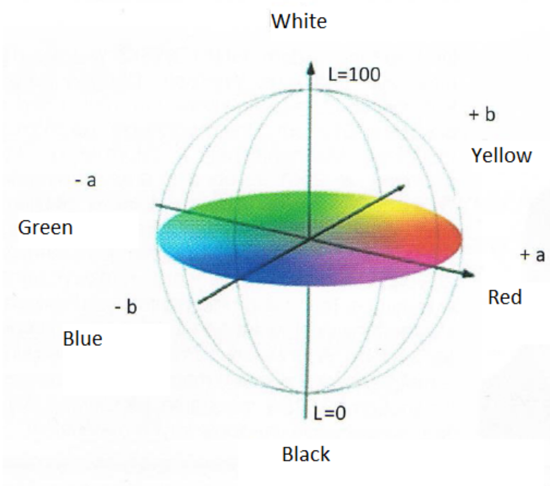

Fig. 1. CIELAB space [12]

Results and discussion of research

Results obtained for tensile strength are presented in Table 1 and Figs. 2 and 3. Both processes of photochemical ageing and electrochemical ageing caused changes in strength properties of commercial polyethylene grades studied. Lower value of tensile strength was recorded for the aged specimens. Elongation and tensile stress at break were also reduced.

Table 1. Results of tensile strength investigations for polymers before and after ageing

Polymer	Tensile strength, MPa	Elongation at break, %	Stress at break, MPa
Polyethylene 3802 YCF	17,8	370	12,55
Polyethylene 3802 YCF after ageing	18,1	56	5,3
Polyethylene XSC 50 Blue	25,3	457	16,44
Polyethylene XSC 50 Blue after ageing	23,3	421	14,91

Source: Author's

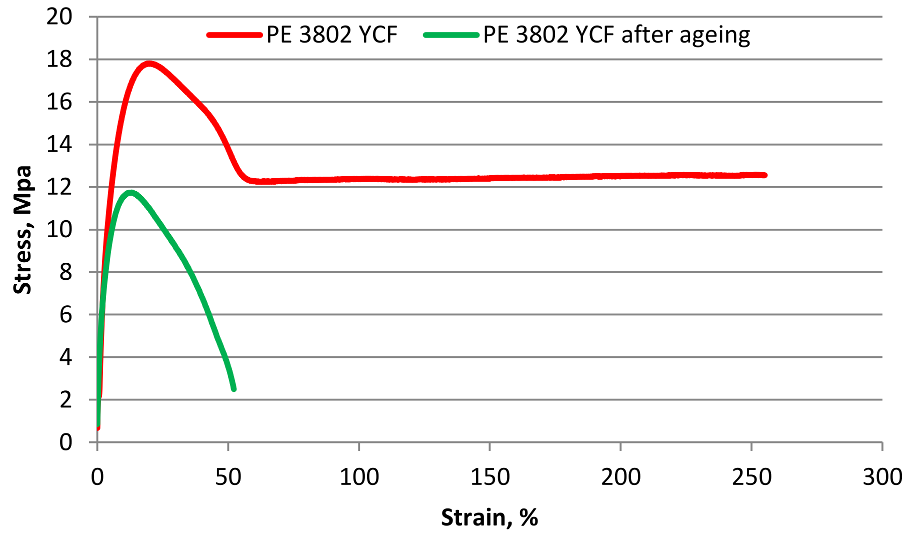

Fig. 2. Tensile strength for polyethylene 3802 YCF before and after ageing
Source: Author's

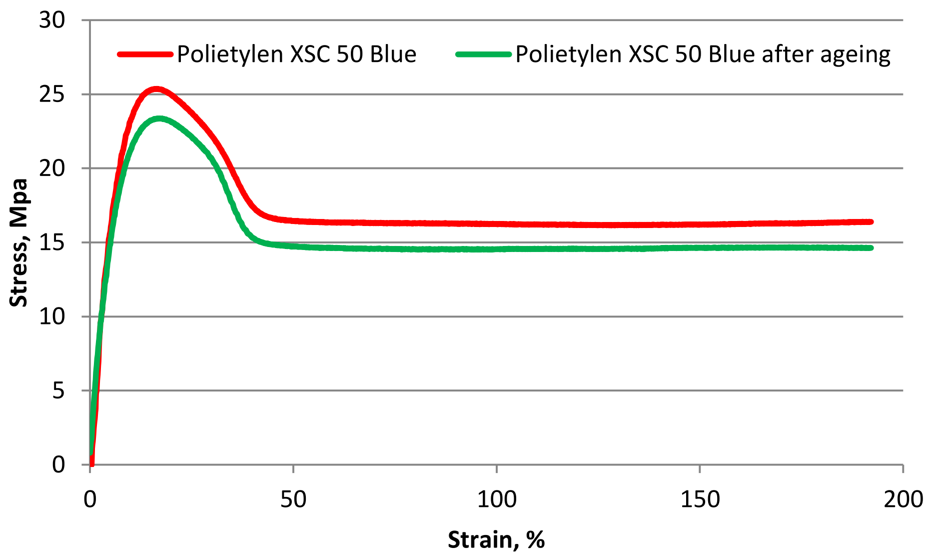

Fig. 3. Tensile strength for polyethylene XSC 50 Blue before and after ageing
Source: Author's

Table 2 and Figs. 4 and 5 present the results obtained from differential scanning calorimetry of the plastics studied. The process of electrochemical ageing caused a decline in the degree of crystallinity of the polymers analysed. Extension of the range of melting point and a shift towards higher temperatures with melting of crystalline phase occurring at the fastest rate were observed for both 3802 YCF polyethylene and XSC 50 Orange polyethylene.

Table 2. Results of DSC investigations

Polymer	***Degree of crystallinity, %***	***Melting range, °C***	***Max. melt temperature, °C***
Polyethylene 3802 YCF	47,9	127,1 – 138,1	131,2
Polyethylene 3802 YCF after ageing	46,2	121,2 – 138,9	134,2
Polyethylene XSC 50 Blue	39,8	125,7 – 139,2	135
Polyethylene XSC 50 Blue after ageing	33,2	124,6 – 141,3	136,7

Source: Author's

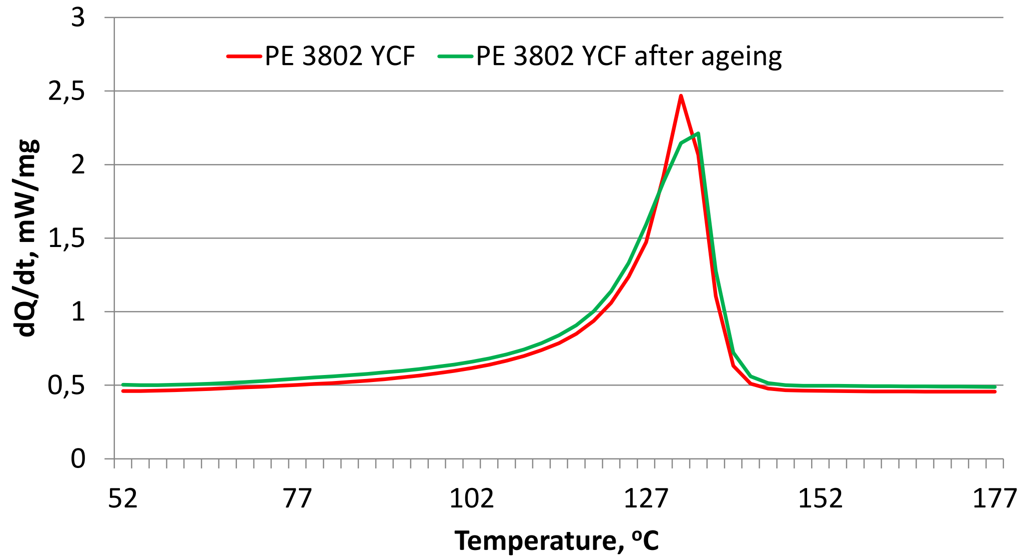

Fig. 4. Thermograms for polyethylene 3802 YCF before and after ageing
Source: Author's

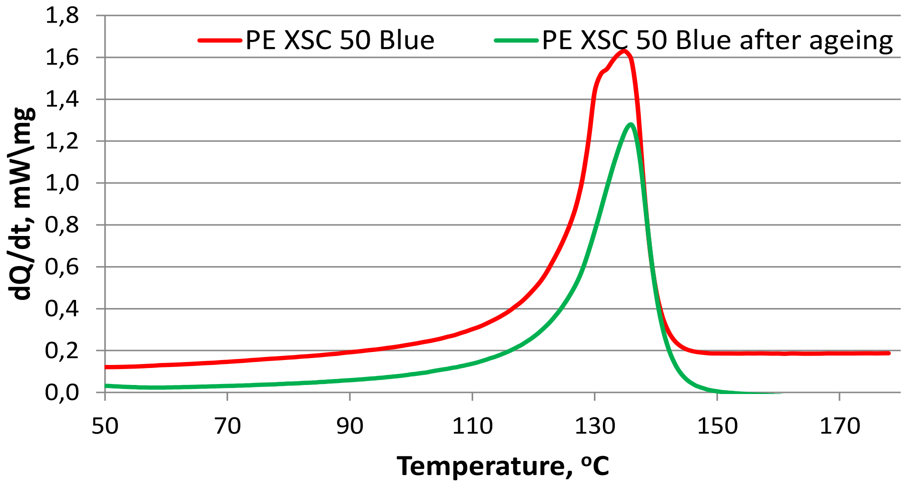

Fig. 5. Thermograms for polyethylene XSC 50 Blue before and after ageing
Source: Author's

Results of colour measurement for the materials analysed in the study are presented in Table 3 and Figs. 6 and 7.

Table 3. Results of colour investigations before and after ageing

Polymer	***L***	***a***	***b***
Polyethylene PE 3802 YCF	71,83	-1,18	52,37
Polyethylene PE 3802 YCF after ageing	72,4	-2,2	48,67
Polyethylene XSC 50 Blue	38,9	-3,5	-35,6
Polyethylene XSC 50 Blue after ageing	37,4	-3,6	-34,9

Source: Author's

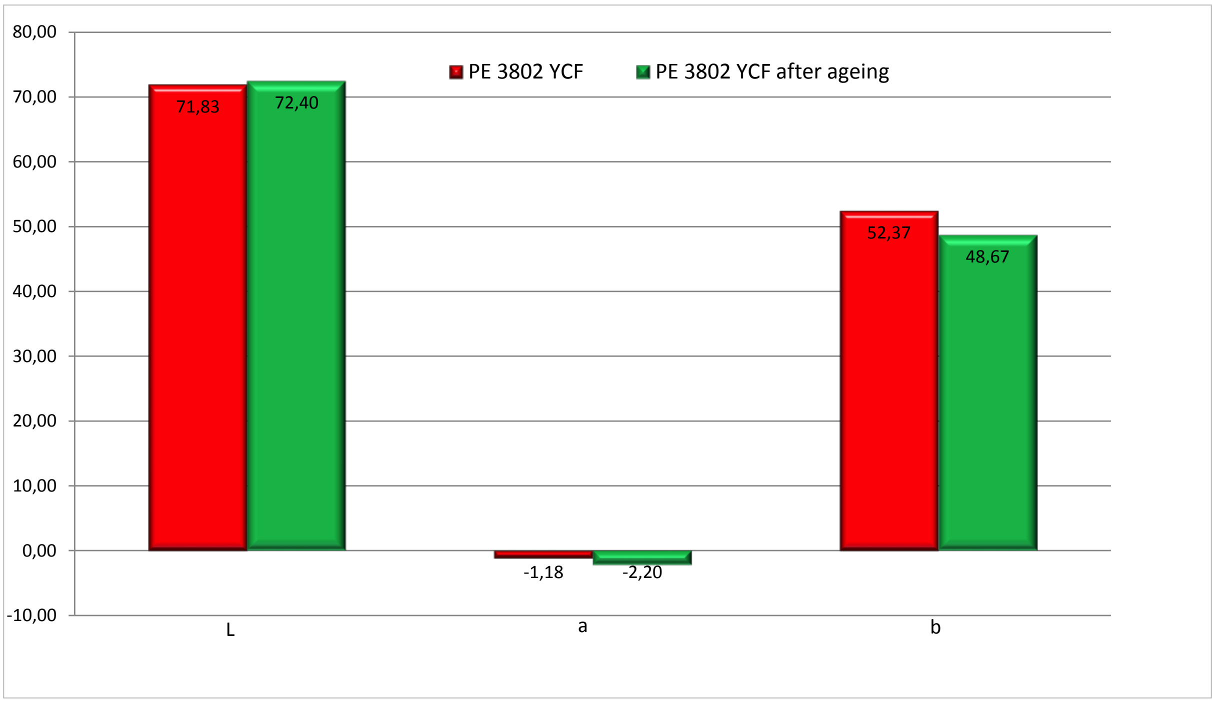

Fig. 6. Colours investigations for polyethylene 3802 YCF before and after ageing
Source: Author's

Fig. 7. Colours investigations for polyethylene XSC 50 Blue before and after ageing
Source: Author's

The specimens subjected to the process of ageing had different values of the colour coordinates compared to the non-aged specimens. The colour of pipes in the case of polyethylene 3802YCF after ageing was moved towards green and blue colours. A shift in the coordinates towards green and yellow colours was observed for the XSC 50 Blue polyethylene after ageing. Luminance of specimens as a result of ageing was reduced. The results of examinations of the luminance were presented in Fig. 8 and 9. The process of electrochemical ageing caused a decline in luminance of the specimens studied both in the case of 3802 YCF and XSC 50 Blue polyethylene.

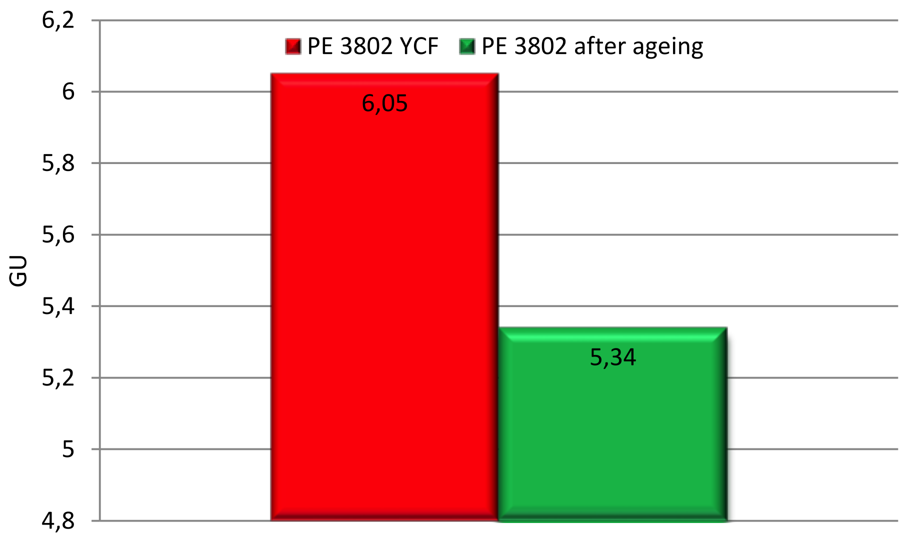

Fig. 8. Gloss investigations for polyethylene 3802 YCF before and after ageing
Source: Author's

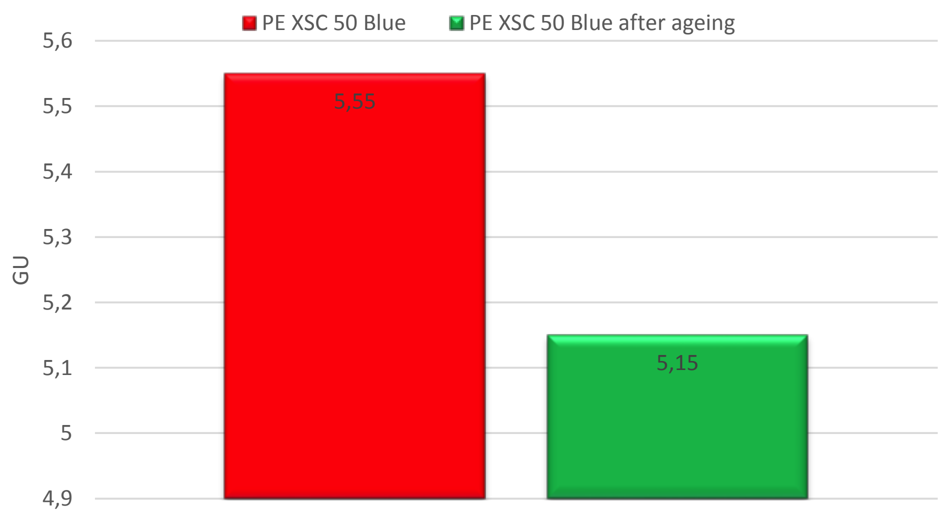

Fig. 9. Gloss investigations for polyethylene XSC 50 Blue before and after ageing
Source: Author's

Figs. 10 and 11 present the results of hardness measurements using ball indentation. A decline in hardness was recorded as a result of electrochemical ageing. Lower values of hardness were found for both specimens after ageing with UV radiation and specimens after chemical ageing process compared to the specimens before ageing.

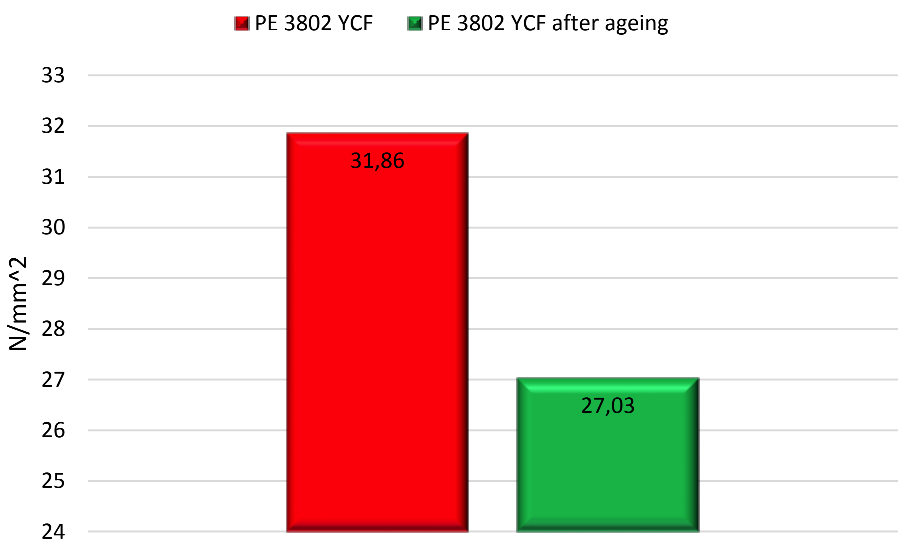

Fig. 10. Hardness investigations for polyethylene 3802 YCF before and after ageing
Source: Author's

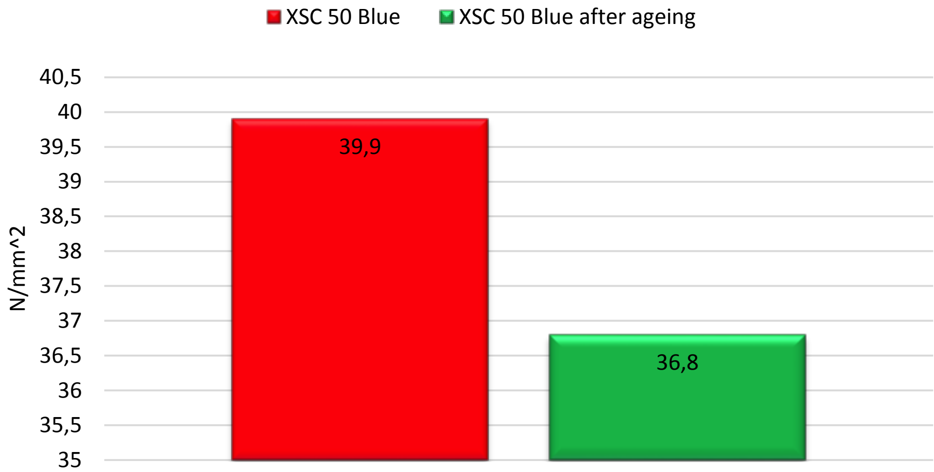

Fig. 11. Hardness investigations for polyethylene XSC 50 Blue before and after ageing
Source: Author's

Summary and conclusions

Analysis of the examinations carried out in this study demonstrates that photochemical and electrochemical ageing affected the properties of the two grades of polyethylene used for the tests. Aged specimens were characterized by lower tensile strength and lower elongation at break compared to non-aged specimens. Lower degree of crystallinity was also found. Ageing caused changes in parameters of colour and luminance. A decline in hardness was observed compared to non-aged specimens. The study allows the determination of changes occurring in the pipes of plastics due to the impact of degradation factors. They open the way to further studies aimed at reducing the impact of ageing and allow extend the time of using of polymer pipes.

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