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Effect of Certain Hydrocarbon Compounds on High-density Polyethylene Water Pipes

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Abstract: *Plastic pipes are being more widely used in various industries, as they combine both a rather light weight and quite high physical mechanical performance characteristics. The present article materials are devoted to the researches, relating to the determination of the various hydrocarbon compounds effect on some mechanical properties reduction degree of samples cut from HDPE pipes, represented by characteristic values of curves (strength - tensile strain) as an absorption result. In the course of the research, the gasoline presence in material structure of the pipe samples was noted to make the process unstable, and the curves representing a change in the characteristic values under study, depending on the immersion time in diesel fuel, tended to decrease throughout the entire immersion period. The experiments have shown that in the study of samples absorbing capacity a full saturation was obtained when immersed in diesel fuel and, despite large difference in absorbance values, the volume of absorbed hydrocarbons caused decline close to the studied characteristic values. Motor oils produced the most significant effect on the HDPE samples studied characteristics at the relatively low absorption values.*

Keywords: *HDPE, absorbing capacity, hydrocarbon compounds*

1.Introduction

High density polyethylene pipes used for drinking quality water show high resistance to the effect of many acids and alkaline solutions, solvents and hydrocarbon compounds, which are more stable and resistant in comparison to the known traditional materials used for the manufacture of

HDPE pipes are designed for a relatively long service life, during which a number of structural changes occur, which consequentially affect their physical and mechanical properties. Despite these changes, their average operating life should remain at the level of 50 years, with adherence to general conditions of protection and installation processes [1-4].

Reference studies [5-9] show that obvious structural changes occur when buried HDPE pipes are used at the average temperature of 10°C. The phenomenon of the pipe structure crystallization due to the glass transition temperature is the cause of this. Its temperature is 130°C, which is very far from the ambient temperature and it gives the impression that the entire pipe network is heat treated throughout the investment period.

In the recrystallization process, structure of pipes undergoes mechanical changes, which result in improvement of their behavior during the first years, followed by their degradation in the future.

These inevitable structure changes are included in the international standards provisions, based on which the estimated average service life remains 50 years if the operations of connection between pipes are carried out in accordance with usual standards, and if drilling and installation operations are considered to ensure full pipes protection from any permanent external effects [10-14]. The purpose of the study is to determine the numerical values of the reduction degree in mechanical properties (strength - relative elongation) due to the absorption arising from the constant exposure of various hydrocarbon compounds to HDPE pipe samples.

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2.Methods and materials

The test samples were cut from one large pipe and exposured to tensile tests in accordance with ISO 6259 to maintain stable production parameters Figure 1.

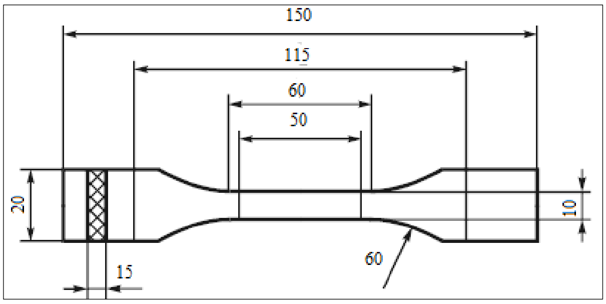

Figure 1. The test samples

The studied samples have the following characteristics:
- length - 6 m;
- outer diameter - 90 mm;
- thickness - 15 mm;
- pipe material density - 0.948 g/cm^3;
- Melt flow rate MFR - 0.3 g/10 min;
- Vikat temperature - 115^{o}C;
- longitudinal shrinkage at 110^{o}C - less than 1.25%;
- absorption - less than 150 mg/kg;
- volatiles - less than 100 mg/kg.

Materials used for induction:
- Hydrocarbon compounds: gasoline - diesel fuel;
- Motor oils W10 and W40.

2.1. Measurement technique

Precise scales with accuracy up to 0.001 mg were used to carry out the experimental section related to absorption. Weight of the prepared samples was measured before and after immersion in various environments, and weight gain percentage was calculated using the following formula:

$$\frac{m_2 - m_1}{m_1}\cdot 100 = \frac{\Delta m}{m_1}\cdot 100,$$

where: Δ m - weight gain;
m_1 - initial weight;
m_2 - sample weight after immersion in testing environment.

Surplus liquid was carefully removed using cotton cloth before weighing without any additional surface treatment. Tensile tests were carried out on the tension machine shown in Figure 2 after the immersing process of all the samples in the container of hydrocarbon compounds (gasoline - diesel fuel), after which the first sample was taken after one week, and the second sample was taken after two weeks, and so on for 12 weeks, with each sample being tested three times, and then the average was taken. The test conditions for all samples were constant, i.e. the test temperature was 22°C, and the tensile strength was determined at a speed of 50 min/mm.

Figure 2.
Tension machine

3.Results and discussions

The immersion results of the test samples in gasoline and diesel fuel illustrate the curves shown in Figure 3, in which two trajectories can be clearly observed with a clear difference in the absorption rate, despite stability of immersion time. Moreover, maximum absorption with the value increasing to 85% was shown by the samples when immersed in gasoline; and when they were immersed in diesel fuel, the maximum value reached 4%.

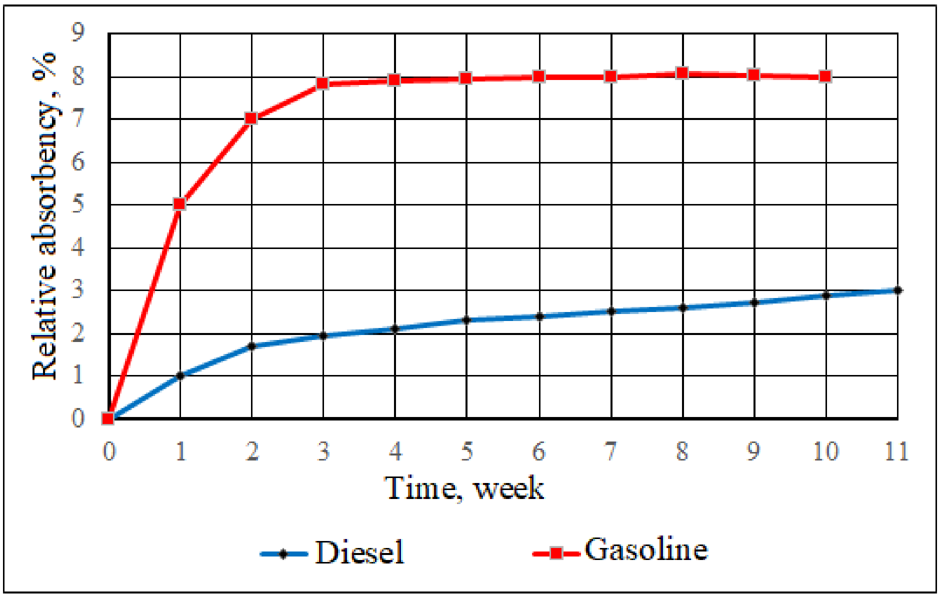

Figure 3. Relative absorption curves of the samples cut from a HDPE pipe as a time-varying immersion function in two different environment: gasoline and diesel fuel

Figure 3 shows that the gasoline absorption curve follows the Fick curve, where a linear increase up to the second week and absorption values stabilization after the third week can be noticed with a non-linear immersion transient period after the 11th week. When the test samples were immersed in gasoline and diesel fuel, it was found that these samples showed higher absorbing capacity of gasoline within the first three weeks until they reached saturation, after which the absorption process almost stabilized. When immersed in fuel oil, the samples showed a relatively weak and regular absorbing capacity, especially during the period of immersion.

Large difference in maximum values of absorbents for gasoline and diesel fuel actually was a reason for the researchers to study the effect of this phenomenon on the mechanical properties, represented by each force development curves of yield strengths, ultimate strength and fracture depending on the time of immersion.

Figure 4 shows the force development curves of yield strength, and fracture depending on the time of immersion in gasoline., while there is a clear decrease in all characteristic values under study in terms of immersion time.

It can be seen that the trajectories of the obtained experimental curves fall in the average value range and it can be noted that the force at the yield point fluctuates at the level of 800 N, and breakout force - at the level of 1000 N. Moreover, the results in Figure 4 prove the greatest influence of gasoline on the studied parameters values, which occurs approximately two weeks after the immersion time; and this represents the fact that the maximum destruction caused by the gasoline to the pipe structure occurs within this period. This result is very important from a practical point of view, as it indicates the need for special care, and that the pipes surface should be cleaned of such materials due to their rapid destructive effect on the mechanical properties.

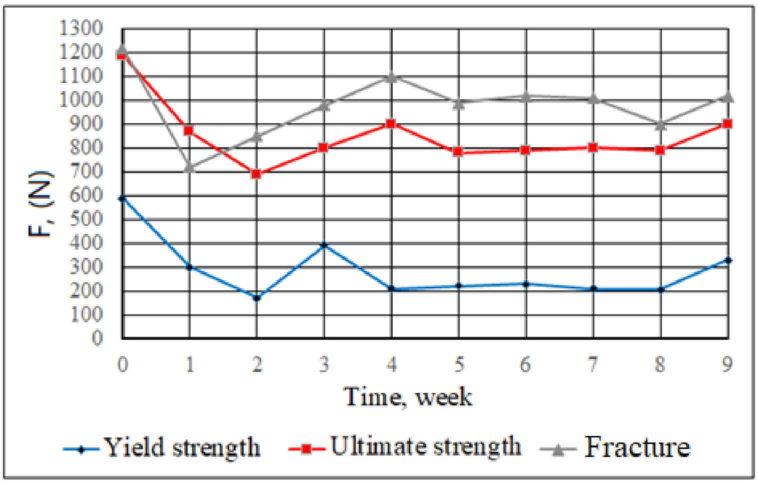

Figure 4. Force development curves of yield strength, ultimate strength and fracture depending on the time of immersion in gasoline

The obvious curve trajectories fluctuation in Figure 4 confirms instability of the structure throughout the immersion period. The reason for this is that the effect of gasoline is at the level of amorphous transition zones located among crystals Figure 5. As the penetrating gasoline substance contributes to the separation of the crystalline regions from each other, which leads to an increase in the free void and a decrease in the mutual influence forces between them, and this explains the low values compared to the average values of the curves oscillation. As for the high values oscillating around the middle values, they can be explained based on the entropic forces resulting from the memory possessed by the existing molecules, which sometimes succeed in reducing the free space, causing the structure to compact and improving the properties. It can be said simply that the structure is exposed when immersed in gasoline to the two states of action and reaction between its constituent elements, this explains the state of oscillation in the path of the curves shown in the Figure 4.

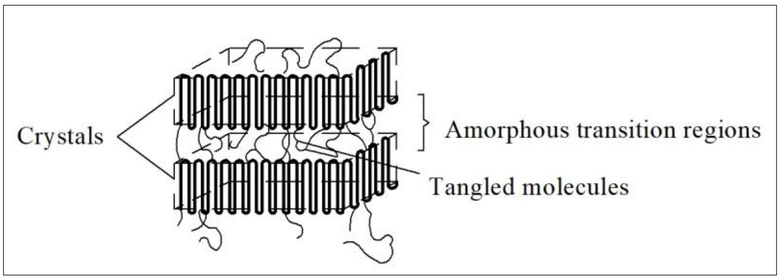

Figure 5. Relationship between crystalline and amorphous parts

Difference in the sorption curves of gasoline and fuel oil evoked the researchers to study the effect of diesel fuel sorption on the yield strength, neck morphology and breakout depending on the immersion time. Figure 6 shows the development curves of characteristic values under study depending on the immersion time, and, as can be seen from this Figure, the onset of a successive decrease in these values depends on the immersion time; moreover, tendency to stability and fluctuations at their average values occurs after the fourth week of immersion. The values of yield strengths fluctuate at the level of 800 N, the force of a neck formation - at the level of 200 N, and the breakout force - at the level of 1000 N. Comparing the average values in Figure 6 with the results in Figure 4, it can be seen that they are the same, and this indicates the same effect of gasoline and diesel fuel in terms of immersion time on the studied values, despite the obvious difference in the absorption values and despite the deviation of the diesel absorption curve from the Fick curve behavior.

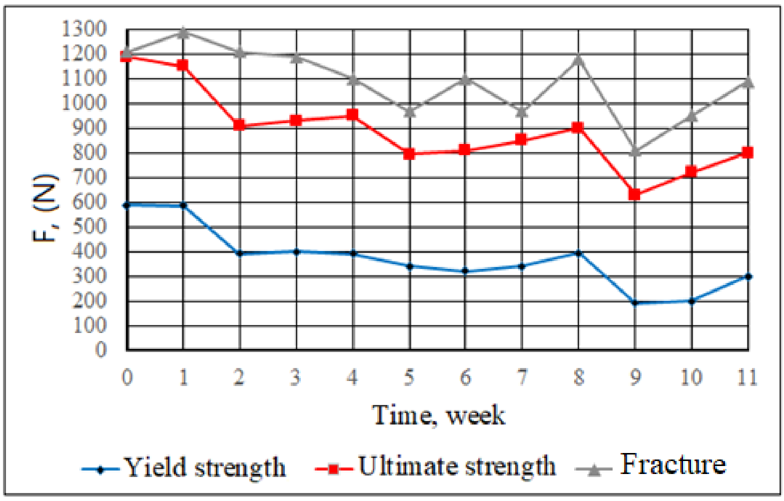

Figure 6. Force development curves of yield strength, ultimate strength and fracture depending on the time of immersion in diesel fuel

The achieved experimental results are very important from a practical point of view, as they demonstrate an obvious convergence with respect to values of mechanical degradation depending on time, despite the difference in the percentage of penetrating materials in the structure. On this basis, the effect of gasoline, diesel fuel and engine oils W10 and W40 on HDPE samples was studied.

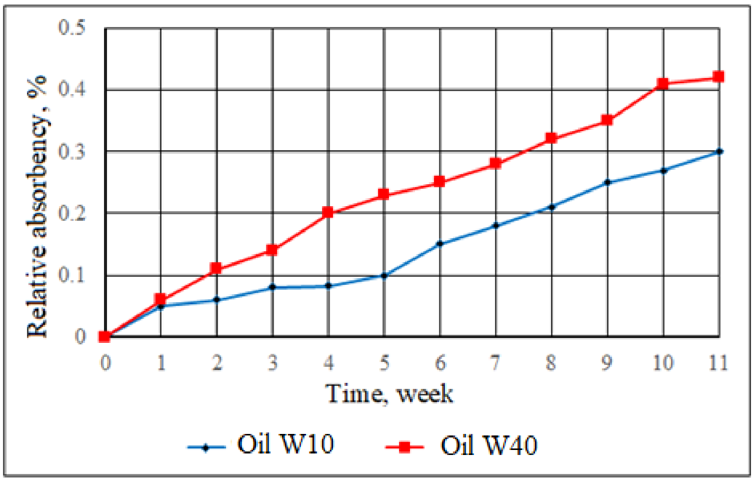

Figure 7. Relative absorption development curves of the samples cut from HDPE pipe depending on the immersion time in motor oils W10 and W40

The absorbance values curves for samples cut from a HDPE pipe shown in Figure 7 depending on the immersion time in motor oils prove that the values were higher in case of immersion in oil W10 compared to oil W40; and the Figure shows that the sorption curves behavior of motor oils does not depend on the Fick curve behavior, which indicates the impossibility of reaching a saturated state by such materials.

The results indicated by Balchuklin (3, 7) confirm high absorbency of high-density polyethylene pipes made of previously mentioned hydrocarbon materials, and that a difference in absorbance values fundamentally differs from high-quality composite hydrocarbon raw materials, as the curves in Figures 4 and 6 showed the same effect of both gasoline and diesel fuel on the studied mechanical properties over an extended period of immersion time, despite the different absorption. Based on the above, it was necessary to study the effect of motor oils W10 and W40 on characteristic values of the curves (strength - tensile strain) in order to show their significance for the materials under study.

Figure 8 shows the force development curves of yield strength, ultimate strength and fracture depending on the time of immersion in motor oil W10, and then the distinguished values of stability were studied.

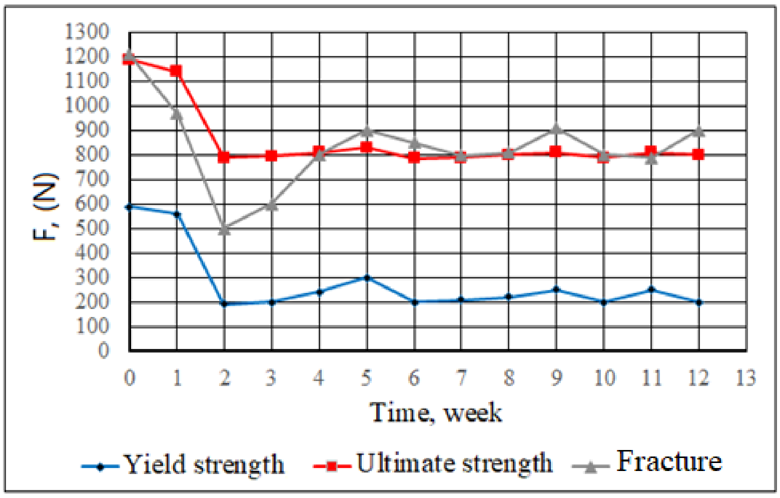

Figure 8. Force development curves of yield strength, ultimate strength and fracture depending on the time of immersion in motor oil W10

The obtained results in Figure 8 prove that the studied characteristic values decrease greatly and, despite the large difference in the absorbance values, they are approximately equal to a decrease in these values when immersed in gasoline and diesel fuel, which is confirmed by the results in Figures 3 and 7.

The result shown in Figure 7 is of great importance from a technical point of view, as it proves a significant influence of motor oil W10 effect on the characteristic values, despite the very low values of absorption as a time-varying function compared to the materials with a high degree of the ability to absorb.

To confirm influence of motor oils on the characteristic values of the curve (strength-tensile strain), the other type of motor oil 40 was studied. Figure 9 shows the force development curves of yield strength, ultimate strength and fracture depending on the time of immersion in motor oil W40.

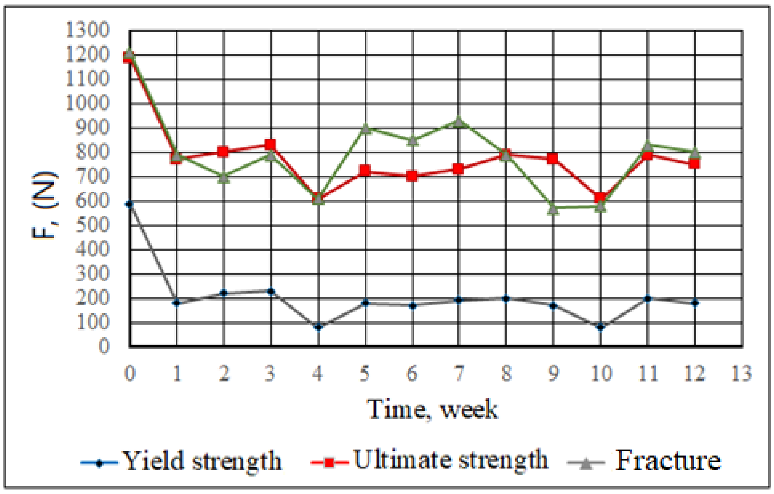

Figure 9. Force development curves of yield strength, ultimate strength and fracture depending on the time of immersion in motor oil W40

According to Figure 9, the curves show the effect similar to the effect obtained with motor oil W10, shown in Figure 8, where it was noted that the maximum decrease in the values of the studied characteristics had occurred after three weeks since immersion, after which almost all values had stabilized at the average values. This result is of great importance as it confirms the aforementioned concerning a significant effect of motor oils on the distinctive characteristics.

A similar effect of the studied hydrocarbon compounds on the curves characteristic values (force-tensile strain) shows that the material specificity influence is rather great, and the obtained curves trajectories of the studied parameters depending on the immersion time in gasoline show that, despite stable absorption, after the third week of characteristics` study, a process of instability occurs. Thus, due to the presence of gasoline in the material's structure of pipe samples, instability is observed, and it can be noted that the curves representing development in the studied characteristic values depending on the immersion time in diesel fuel tend to decrease throughout the immersion period relative to the matched weighted dimensions of the samples.

The most essential results, which can be received from the motor oils absorption curves, have proved the following:

-The investigated characteristic values are not affected by the amount of absorbed hydrocarbon.

-The relatively similar influence of all hydrocarbon compounds on the investigated characteristic values.

In order to determine the hydrocarbon compounds effect on the investigated characteristic values more precisely as well as to determine the values of their losses that occurred as an absorption result, Table 1 shows the values of the researched characteristics after 12 weeks of immersion in the above-mentioned hydrocarbon compounds.

Table 1. Peculiar peaks of the curve (strength-tensile strain) after 12 weeks of immersion in hydrocarbon environment used in the study

Used environment	Significant results after 12 weeks of immersion		
	F_y, N	F_n, N	F_b, N
Without immersion	1171	554	1246
Immersion in gasoline	763	232	919
Immersion in diesel fuel	860	334	1060
Immersion in motor oil W10	820	246	834
Immersion in motor oil W 40	770	160	734

where: F_y - yield strength, H; F_n - ultimate strength, H; F_b – fracture force, H.

As can be seen from Table 1, the studied indicators had an obvious decline in the values, and it is noted that yield strengths and ultimate strength formation do not depend on the difference in hydrocarbon environment and the adsorbed material amount, while an obvious fluctuation in the values of the fracture force can be noticed. In order to define the values decline under study precisely, Table 2 represents the relative losses of characteristic values after 12 weeks of immersion.

Table 2. Relative losses of characteristic values after 12 weeks immersion in various environments

Used environment	Significant results after 12 weeks of immersion		
	$\frac{\Delta F_y}{F_y} . 100\%$	$\frac{\Delta F_n}{F_n} . 100\%$	$\frac{\Delta F_b}{F_b} .100\%$
Immersion in gasoline	34.8	58	26.2
Immersion in diesel fuel	26.49	40	14.92
Immersion in motor oil 10	30	55.64	33.06
Immersion in motor oil 40	34.26	71	41

Table 2 shows that the percentage of the studied performance decline is large in case of immersion in motor oils in comparison with the effect of other environment, and the decline rate of the ultimate strength reaches 50% or more. Considering that the environment is absorbed by two surfaces of test samples, their full immersion in the above environment shows that such a decline takes twice the time, showing that the absorption increases linearly over time. Diffusion behavior study of the above-mentioned hydrocarbons actually requires the additional studies to achieve the effect of full saturation of sample materials, which was not achieved in our studies due to the process instability.

4. Conclusions

The experimental results have shown that when being immersed in diesel fuel, the absorption capacity reaches the saturation stage, and when immersed in hydrocarbons in various proportions, this stage is not reached, but there is a clear deterioration in mechanical properties (strength and elongation) despite the large difference in absorption values. The experimental results have also revealed a great influence of W10 and W40 motor oils on mechanical properties (strength and elongation), despite the low absorption capacity, therefore it is necessary to avoid sinking HDPE pipes into environments rich in hydrocarbon compounds, as this has a detrimental effect on their mechanical properties and leads to a decrease in service life. Investments in such pipes are estimated at 50 years.

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