Study of the influence of thermal factors on the welding process of polyethylene gas pipelines

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Abstract

A one-dimensional calculation scheme is proposed with the help of which it is possible to determine and set the technological parameters with the accuracy to be realized in production conditions: the temperature of the heating element and the heating time, which allows maximum mechanization of the technological operations of polyethylene gas pipelines welding. The numerical value of the coefficient of temperature for polyethylene grade PE-80 is determined and it is found that the presence of molten polymer mass at the ends of pipes is an additional source of their heating and a significant factor in obtaining high quality and reliable welds.

Keywords: *coefficient of temperature conductivity, technological parameters, welding of polyethylene gas pipelines.*

In the territory of Ukraine, in addition to the unique system of main gas pipelines, there is a much longer system of gas networks of settlements. With its help, they supply natural gas to domestic, communal and industrial consumers. This system has a complex geometric configuration, runs in a variety of topographical conditions, is characterized by different values of working pressure, involves the use of pipes, made from different materials [1].

Since 1985, polyethylene has become widely used in Ukraine for the construction of gas pipelines. During this period, more than 13 thousand kilometers of gas pipelines made from polyethylene pipes were built in different regions of our state. Successful exploitation of such gas pipelines and the absence of accidents confirm their high efficiency and expediency [2].

In the European Union, the use of polyethylene pipes in the construction of new distribution pipelines is 95 %, and in Japan, for example, legally, steel pipes are replaced by polyethylene pipes [3]. A rather important feature of the use of polyethylene pipes is their high resistance to various types of electrochemical corrosion. The cost of corrosion protection is practically zero.

At the moment, for the construction of distribution pipelines in Ukraine, polyethylene pipes PE-80 and PE-100 are used, which are manufactured in accordance with DSTU B.2.7-73-98 "Polyethylene pipes for combustible gases supply. Specifications". This standard provides for the manufacture of pipes with an external diameter of 16 to 400 mm, a standard size ratio of SDR 17.6 (for gas pipelines with the operating pressure of up to 0.3 MPa) and SDR 11 (up to 0.6 MPa).

Quality of welding by rheological processes occurring in the field of welded joints. The kinetic regularities of these processes and their final results naturally depend on the basic parameters of welding, in particular temperature on one side and the properties of polyethylene on the other.

In literature you can find various recommendations on the choice of technological parameters of welding [4–7]. They indicate that nowadays the mechanism of formation of a welded joint during the contact welding of polymers by fusion and the influence on it of temperature factors, in particular has not been studied yet.

Peculiarities of the technological process of polyethylene pipeline welding

Welding of polyethylene pipes is a technological process of melting of the surfaces of two elements with the help of a heating element, also called a mirror, and then compressing them further to form a non-detachable connection (Fig. 1).

While contacting the ends of the pipes it turns out that even a carefully prepared surface is far from the ideal plane. The surface of the heating element also has a corresponding roughness. The thin air gap between the end of the pipe and the heating element is a serious

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obstacle for the transfer of heat from the heater to the welding surface.

To achieve a quick complete thermal contact it is necessary to press the end of the pipe to the heater with a great effort at the beginning of the heating. Then the protrusions on the surface of the end face will be molded and extruded outward in the form of a uniform circular roller, while filling the inequalities on the surface of the heater. This preparatory process is called melting, and the molded material being extruded is called weld flash. The operator is always determining the time of weld flash formation visually, even in the case of automated welding.

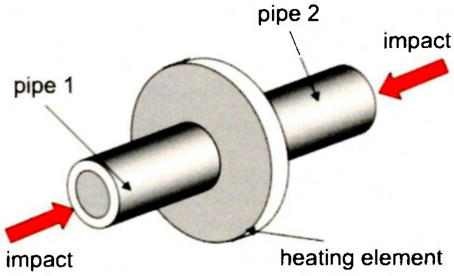


Figure 1 – Scheme of technological process of welding of polyethylene pipelines

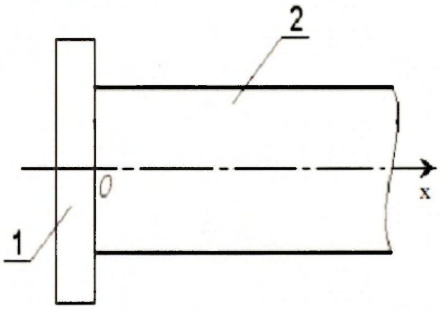
During a heating period which begins immediately after the appearance of a weld flash of a given height, the pipe surfaces are in close contact with the heating element for a certain amount of time required for pipe walls melting. This process mainly determines the quality of welded joints.

After the heating is completed, the quick removal of the heated tool and the alignment of the welding surfaces are of great importance. The maximum allowable time for the removal of a moving pipe, the removal of the welding mirror and the alignment of the ends of the pipes is called a technological pause. Upon completion of the technological pause, the precipitation and shuttering process takes place when the surfaces must be pressed again to one another, causing the plastic material in the contact area to flow, squeezing out the contamination and air bubbles. The macromolecules of the welding surfaces are mixed, the boundary between the objects being welded disappears. After cooling and cooling the polymer, the thermal motion of the molecules weakens and the Van der Waals forces re-bind them to the solid.

It is known that the strength of the connection to a large extent depends on the temperature field, provided in the process of welding. It is required to obtain a layer of molten material in the welding zone [8].

Mathematical model of heating process

To calculate the temperature field, we used a one-dimensional design scheme (Fig. 2). Let's assume that in the process of melting the surface of pipes walls are insulated, their movement and movement of the heating element along the axis of the pipe does not occur and let's neglect the hidden heat of pipe material melting. Then the given problem is reduced to the determination of the temperature field in a half-limited rod with a heat-insulated lateral surface, the initial temperature of which is equal to the ambient temperature. At the end of the rod there is a maintained temperature that corresponds to the temperature of the heating instrument.



1 – heating element; 2 – rod

Figure 2 – Scheme of a one-dimensional model of the heating process during welding

In the cartesian reference system, the heat flow can be considered as propagating only along one x-axis, perpendicular to the plane of the melted edges:

$$C_V \rho \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right), \qquad (1)$$

where T (x, t) is the temperature of the point at an x distance from the end at a t time; λ, Cv, ρ are the coefficient of thermal conductivity, specific heat capacity and density; t is the heating time.

By denoting T_0 the temperature of the points at the end of the workpiece before heating (the ambient temperature), and assuming that T_f is the temperature of the heating instrument (the temperature of the welding), we can formulate boundary conditions

$$T(x,0) = T_0;\; T(0,t) = T_f;\; T(\infty,t) = T_0\,. \qquad (2)$$

Equation (2) can be solved by various methods, for example, the Laplace operation method. After correspondent transformations, we get the solution in the form of the expression:

$$T(x,t) = T_m + (T_0 - T_m)\, erf\left(\frac{x}{2\sqrt{at}}\right), \qquad (3)$$

where a is the coefficient of thermal conductivity of material; $erf\left(\frac{x}{2\sqrt{at}}\right)$ is the probability integral.

Experimental study of the influence of temperature factors on the welding process

The coefficient of temperature conductivity for the polyethylene pipe was determined experimentally by the method [9], the calculations were carried out by the formula (4):

$$a = b\, R^2/2K\Delta T\,, \qquad (4)$$

where b is the velocity of heating; R is the thickness of the studied material; K is the form coefficient; ΔT is the temperature difference between the test points of the sample.

For our studies, the coefficient of thermal conductivity was $a = 8 \cdot 10^{-8}\ m^2/s$.

To verify the reliability of the calculated temperature distribution, experimental studies were carried out in which the temperature change along the

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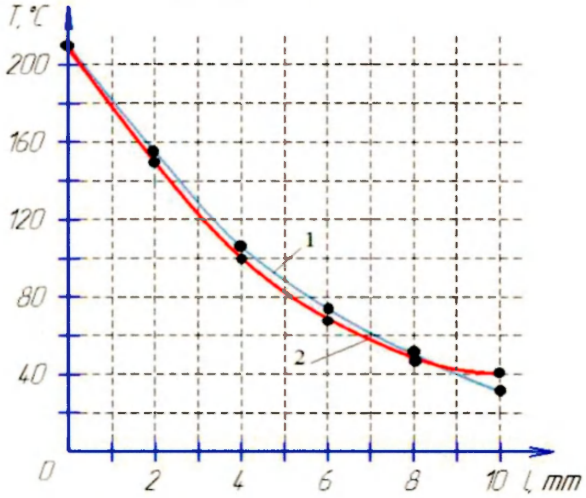
length of the pipe was recorded using the installed thermocouples.

The tests were carried out using a polyethylene pipe PE-80, with a diameter of 160 mm, a wall thickness of 9.1 mm, SDR 17.6, according to the following technological parameters: ambient temperature – 200 °C, heating time – 90 seconds, heating element temperature – 2100 °C.

Figure 3 displays a comparison of the distribution of temperature values along the length of the pipe, obtained by calculation and experimentally.



1 – calculated values; 2 – experimental values

Figure 3 – Distribution of temperature values along the length of the pipe

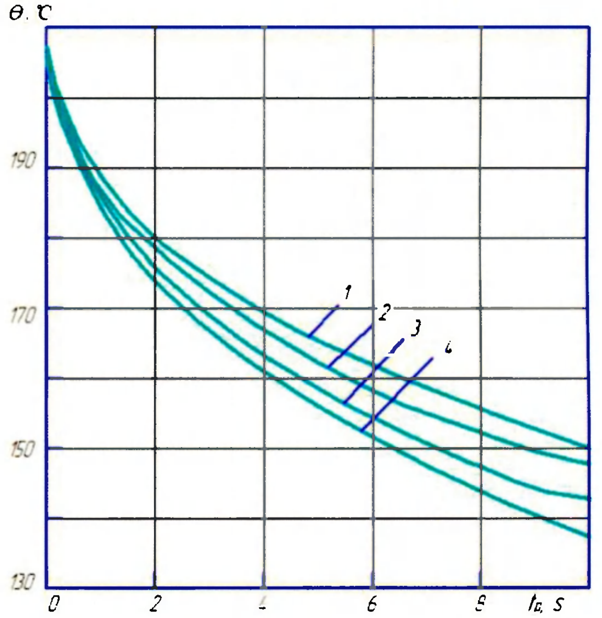
The comparison of temperature dependences shows a fairly close coincidence of the calculated and experimental values in the welding zone, which allows, with the sufficient accuracy to calculate and determine the basic technological parameters, such as the temperature of the heating element and the heating time depending on the ambient temperature.

An important technological operation in polyethylene pipelines welding is a technological pause, during which the melted edges, being in contact with air, are oxidized and cooled as a result of convective heat transfer, which significantly influences the quality of welded joints.

The processes of the nucleation and growth of crystalline formations in the joint, the type of the finite supramolecular structure and, as a result, the strength characteristics of the welded joint, depend on the rate of cooling of the melt. In addition, the speed of cooling the joints and the duration of the technological pause determine the temperature and the rate of fluidity of the melt at the time of the beginning of deposition. Therefore, considerable interest in the study is related to the effect of the duration of the technological pause on the temperature of the welded surfaces, taking into account external temperature factors.

We conducted experiments on determining the temperature of the welded surfaces during the duration of technological pauses, at different ambient temperatures. For the investigated polyethylene pipe with a diameter of 160 mm, wall thickness 9.1 mm, SDR 17.6. Technological pause is 5 seconds.

Measurements were made using an electronic thermometer DT-meter 400 with a contact probe. The data of studies on the temperature of the welded ends of the pipes from the time of technological pause for different values of the ambient temperature are given in Figure 4.



1 – T = 30 °C; 2 – T = 20 °C; 3 – T = 10 °C; 4 – T = 0 °C

Figure 4 – Dependence of the temperature of the ends on the duration of the technological pause

From the drawing it is clear that at this stage of the welding process there is intense cooling of the welding edges. So, for 5 seconds, the temperature of the end of the pipe decreases from 135 to 162 °C at ambient temperature T = 20 °C. However, given that the melting point of the polyethylene is about 125 °C, the molten mass at 162 °C can be considered an additional source of heating during the deposition and shutting process.

This phenomenon is a very important factor in preventing the formation of defects in welded joints of polyethylene pipes, in particular such as "mirror seam" (cold welding), when the weld seams are in line with the requirements of the normative requirements, but their mechanical strength is clearly insufficient. These defects are usually formed with insufficient thermal action on the surface of the ends of the pipes being welded.

This assumption is confirmed by the fact that the width of the weld flash l (Fig. 5) in our experiments was 6.0–9.5 mm, while during the heating process (Fig. 3) the melting depth of one end of the pipe reached about 2.5 mm.

To determine the strength of the test tube PE-80, 160 mm in diameter, wall thickness 9.1 mm, SDR 17.6, according to the above technological parameters: ambient temperature 200 °C, heating time 90 seconds, temperature of the heating element 2100S was welded to welding machine R 160 of the firm Rosenberger (Fig. 6).

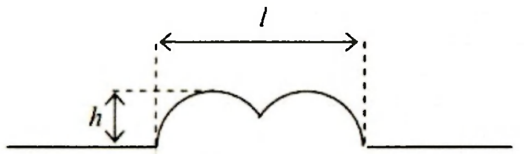


Figure 5 – The width of the external weld flash

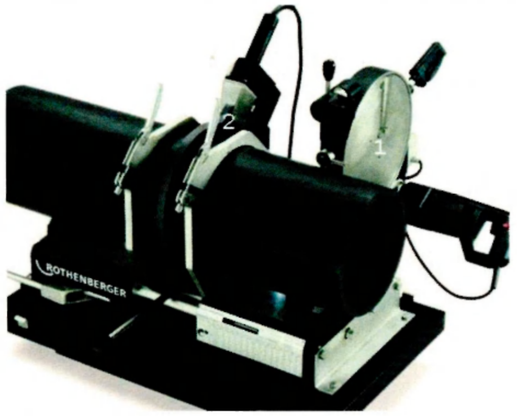


Figure 6 – Abutting welding machine P 160

Determination of the strength of the samples obtained was carried out on a universal tensile testing machine P-50, in accordance with the requirements of DBN V.2.5-41:2009. It was established that during axial tensile testing, all the samples examined, conformed to the requirements of the normative documents, had a plastic nature of the destruction and the line of rupture was behind the limits of the weld.

Conclusions

According to the results of analytical and experimental studies a one-dimensional calculation model for the determination of technological parameters of the process, which will allow to mechanize the technological operations of welding of polyethylene gas pipelines, is suggested. It has been established that the size of the molten polymer layer at the end of the heating is about 2.5 mm for the selected test conditions, while the weld flash formed during the heating stage contributes to increasing the temperature of the interconnected surfaces during the setting process and is an important factor in the quality of the weld.

References:

[1] Panchuk, MV, Shlapak, LS & Hrytsenko, MD 2009, 'Polymer materials for the construction of piping systems', *Scientific bulletin of the IFNTUOG*, no. 4, pp. 119–124. [in Ukrainian]

[2] Shlapak, LS, Panchuk, MV, Senych, OO & Vereeke, P 2009, 'Evolution of polyethylene materials during the construction of gas pipelines', *Scientific bulletin of the IFNTUOG*, no. 2, pp. 113–116. [in Ukrainian]

[3] Kovringa, V 2007, 'Polyethylene pipes withstand earthquakes', *Polymer pipes*, no. 5, pp. 58–59. [in Russian]

[4] Shlapak, LS, Panchuk, MV, Dranchuk, SM & Kliupa, A 2010, 'Intensification of polyethylene pipelines welding for the construction of gas networks', *Oil and gas industry*, no. 2, pp. 30–33. [in Ukrainian]

[5] Panchuk, M, Shlapak, L, Panchuk, A, Szkodo, M & Kiełczyński, W 2016, 'Perspectives of use of nanocellulose in oil and gas industry', *Journal of Hydrocarbon Power Engineering*, vol. 3, iss. 2, pp. 79–84.

[6] Szewczyk, P 2012, 'Badania odpornosci na oddzialywania punktowe rur polietylenowych warstwowych ukladanych w gruncie rodzimym, przeznaczonych do przesylania gazu', *Nafta-Gaz*, tom 68 , zeszyt 9, s. 611–616. [in Poland]

[7] Wroblewska, A 2013, 'Szybka propagacja pęknięc w sieciach gazowych z rur polietylenowych', *Nafta-Gaz*, tom 69 zeszyt 10, s. 788–793. [in Poland]

[8] Starostin, NP & Amosova, OA 2006, 'The choice of the welding mode of polyethylene pipes at low temperatures on the basis of modeling of the thermal process', *Bulletin of the YGU*, vol. 3, no. 1, pp. 63–66. [in Russian]

[9] Fokin, VM & Chernyshov, VN 2004, *Non-destructive control of the thermophysical properties of building materials*, Moscow, Mechanical engineering. [in Russian]

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Вивчення впливу теплових факторів на процес зварювання поліетиленових газопроводів

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Запропоновано одновимірну розрахункову схему оцінювання технологічних параметрів зварювання поліетиленових газопроводів: температуру нагрівального елемента та час нагрівання. Експериментально оцінено коефіцієнт температуропровідності поліетилена ПЕ-80. Встановлено, що наявність розплавленого полімеру на кінцях труб є додатковим джерелом їх нагрівання та важливим чинником отримання високоякісних і надійних зварних швів.

Ключові слова: *зварювання поліетиленових газопроводів, коефіцієнт теплопровідності, технологічні параметри.*