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Determination of the Fracture-Risk Areas on the Electrofusion Elbow Made of High Density Polyethylene

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Abstract: ***The paper aims to determine the fracture area on the polyethylene elbows when welded to high density polyethylene pipes. Modern analysis methods are being used for the study, among which the specific numerical analysis and the study of the thermal area by means of thermal cameras. The drawn conclusions fall within the range of the initially recommended problem solving method.***

Keywords: polyethylene elbow, numerical analysis, temperature field.

1. Introduction

The basic materials for manufacturing plastic products are natural materials like cellulose, resins, oil and natural gas. Oil and natural gases are the most important raw materials. In refineries, crude oil is distilled into several factions. Depending on the range of boiling temperatures, there are different stages of distillation - gas, gasoline, kerosene, black oil and, as residues, bitumen. All these constituents are composed of hydrocarbons which differ only in the size and the shape of their molecules.

The most important faction for producing plastic objects is the straight-run gasoline. Most plastics are basically made of *hydrocarbons* from which the individual combinations of plastics, called *monomers*, or monomer molecules of the same kind are derived.

The advantages and the disadvantages of using polyethylene:

- The possibility of coupling pipes through welding at low temperatures (compared to the temperatures required for welding steel) through simple technology, and through mechanically assembled fittings, as applicable;
- The possibility of combining the polyethylene networks with the already existing steel networks or fittings;
- The increased speed of installing the networks involves reduced costs of execution;
- The variety of dyes allows a precise marking and identification;
- There is a variety of sizes in terms of fittings, of approximately 32,000 units;
- The high corrosion resistance, which leads to eliminating the need for the cathodic protection, a very important advantage for the natural gas distribution networks in urban areas as the soil aggressiveness is considerably higher than outside the settlements;
- The possibility of using very long pipes, by delivering them in coils;
- Good chemical resistance to the gas components;
- Good environmental protection, due to its feature as recyclable material.

2. The Finite Element Analysis on the Dn32 mm Polyethylene Elbow

The assembly polyethylene elbow - polyethylene pipe was chosen for the present research, and the conducted investigation can be easily adapted to other sizes of the same category.

As mentioned before, the geometric modeling was performed using the Catia software, which includes the finite element module, and thus eliminating the risk of the possible inconsistencies between the Catia files and other finite element software products.

The CAE Module (Computer Aided Engineering) was introduced in the composition of CIM systems (Computer Integrated Manufacturing) after the development of the CAD module (Computer Aided Design); it actually appeared with the emergence of the finite element method. The method was originally used in the mechanical calculation of the airplane structures but later it expanded widely to all the material continuum problems. These problems seek to determine, in a considered area, the values of one or more unknown functions such as: displacements, velocities, temperatures, stresses, strains, etc., depending on the nature of the tackled problem.

The natural phenomena of this kind are described by differential equations, and, by integrating them under given limiting-conditions, we obtain the exact solution. In this way we can calculate the value of the unknown function or functions at any point in the studied area. This is the analytical method, the common way of solving the problem, which is applicable only to the simple problems. However, the problems that arise in the practical engineering activity are not simple but often complex, both in terms of physical construction, the geometry of the part, and in terms of the stress and strain conditions, called the limiting-conditions. In this situation, solving differential equations is no longer possible. At this point, there are two ways of solving the problem:

- to create a simplified model of the real model and solve the differential equations on that model, thus obtaining the exact solution on a simplified model;

- to obtain an approximate solution to the real problem.

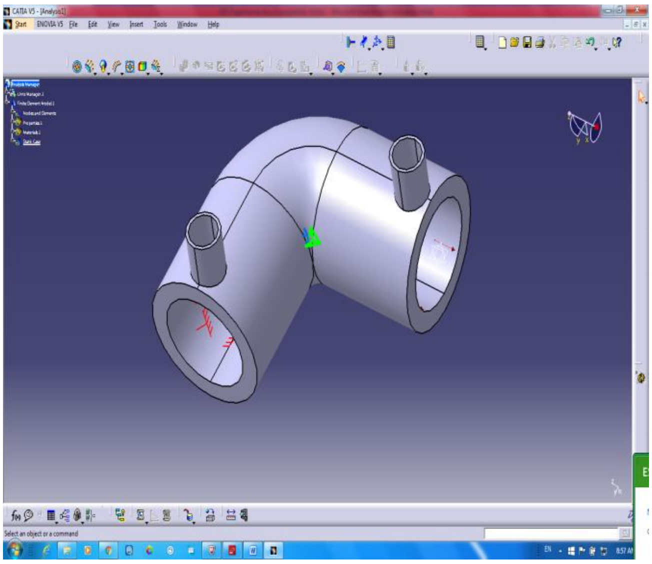

Figure 1: Designing the 3D model of the 32 mm electrofusion fitting, by means of Catia software

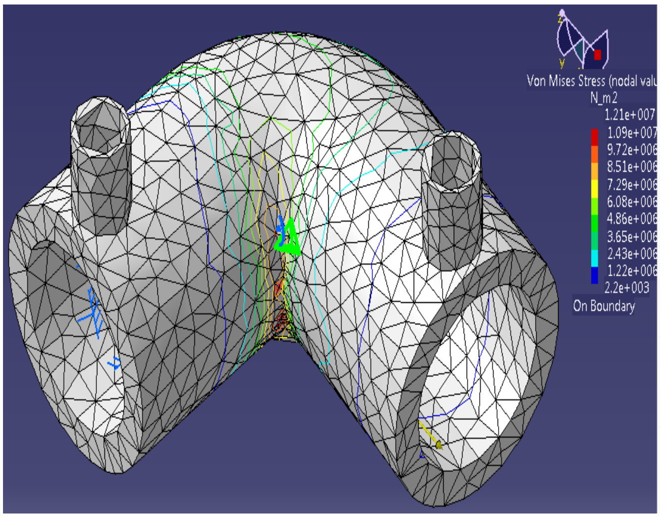

Figure 2: Stresses appeared in the electrofusion fitting (the 32 mm elbow), following accidental tensile stresses

Following this finite element analysis, one can observe that the most stressed area is the central one, which in terms of the thickness of the material is thinner and must be protected from tensile or bending stresses during welding.

3. Welding Polyethylene Materials and Elbows

3.1 General issues

The procedure is based on the use of a part which will be assembled through welding, called *the electrofitting* (Figure 1). It consists of the basic body, injection molded from high density polyethylene, having different geometric shapes depending on the purpose of the assembly (pipe joints, pipe branching, diameter change, etc.) provided internally with an electrical resistance, welding indicators (control) and electrical connectors that can be linked to the welding machine.

The surfaces to be welded (the exterior of the pipe and the inside of the electro elbow) are heated to the plasticizing temperature, due to the electrical resistance immersed in the inner surface of the electrofitting. By heating the pipe-fitting assembly, there is a swelling of the material, pre-calculated by taking into account the gap between the two parts and then, by heating until it reaches an optimal melting temperature of about 220 °C, we obtain a molten homogenous mass. Upon cessation of the electric current in the electric resistance, the process of solidification of the melted mass begins, thus welding the two connected parts (Figure 3).

Figure 3: Threaded assembly consisting of 32 D diameter polyethylene fitting and 32 Dn PE 100 pipe

The welding parameters and the intensity of the current necessary to the electro elbow for the plasticization of the contact surfaces are monitored and registered automatically by the welding machine via a control processor.

The intensity of the current flowing through the coil of the electro fitting is determined by the relationship I-U/R where: I – the intensity of the current, *[A]; U* – the voltage in the welding terminals [V] and R – the electrical resistance, *[Ohm]*. The fitting heats first at the ends, then towards the interior (the center), so that the melted mass solidifies without leaking outside the welded area.

Only the same type of materials can be welded through electrofusion. The melt flow index of the electroelbow ranges between 0.7 1.3 *g/10 min*, and allows the welding of pipes and fittings that have a melt flow index ranging between 0.4 - 1.3 *g/10 min*.

There is a bar code on the electroelbows which sets the parameters of the welding. Some manufacturers also provide a magnetic card with the electroelbow that is inserted into the welding machine. After the welding, the technical data contained therein relating to the setting of the welding process parameters are *removed*, therefore it can be used only once.

3.2 Stages of Electrofusion Welding

- The pipes are cut to size and the ends are straightened;
- The outer surface of the pipe is scraped in the area where it will be joined to the electrofitting, at a depth of at least

0.1mm, by means of a special device (removal of the oxide layer);

- After scraping them, the surfaces of the pipes are cleaned with a cotton cloth soaked in an etching liquid (methylene chloride, isopropyl alcohol, ethyl alcohol of over 99% purity);
- The inside of the fitting is cleaned with the same etching liquid;
- The pipes are placed in the electrofitting and in the fixing mechanism;
- The terminals of the welding machine are connected and the necessary data for the dimensions to be welded are introduced into its processor (manually or automatically), and the command *start* of the welding process is activated;
- After completing the welding cycle (assisted by the machine), we wait for the welded joint to cool down to the ambient temperature, and then remove the joined pipes from the fixture,
- The welding temperatures and times are recommended by the producers of pipes and welding machines.

3.3 Description of the Procedure

The procedure is based on using a part which will be welded, called *electrofitting* (Figure 4). It consists of the basic body, molded by high density polyethylene injection, with different geometric shapes depending on the purpose of the assembly (pipe joining, pipe branching, diameter change, etc.) internally provided with an electrical resistance, welding indicators (controls) and electrical connectors that can be linked to the welding machine.

Figure 4: Polyethylene fittings

The areas to be welded (the outside of the pipe and the inside of the electroelbow) are heated to the plasticizing temperature due to the electrical resistance immersed in the inner surface of the electrofitting. By heating the assembly pipe-fitting, there is a pre-calculated swelling of the material, taking into account the gap between the two parts and then at the optimal melting temperature of about 220°C, a homogenous molten mass is formed. Upon turning off the electric current in the electric resistance, the process of solidification of the molten mass begins, thus concluding the welding of the two connected parts (figure 1).

Preparation of the welding:

1. Adjusting the size of the pipe

The pipe is cut perpendicularly on the axis of the pipe. It is recommended to use a polyethylene pipe cutter (Figure 5) or a saw with teeth suitable for plastic material.

Figure 5: Pipe cutter for different size pipes

The failure to fulfill these conditions leads to overheating and uncontrolled melting, because the pipe covers the heating resistance in the fitting only partially, due to cutting the pipe non-perpendicularly on the axis. The area to be welded will be measured, marked with a marker, and the oxidized layer will be removed (figure 6).

Figure 6: Marking the length of the Dn32 elbow on the pipe

The welding area in the fittings is generally the depth of penetration, i.e. the length between the edge of the elbow and the interior shoulder. For the elbows, this length is measured between the edge of the elbow and its 90 degrees axis. For the piercing saddle (the length is equal to the length of the weldable fitting's cap). Before the mounting, the oxidized layer produced during the storage of the pipes must be cleaned without abrasion, by using a self-propelled manual peeling device, or a pipe scraper (Figure 7).

Figure 7: Manual pipe scraper

If the oxidized layer is insufficiently cleaned, a leaking weld may result. A superficial cleaning is usually sufficient, through cutting or scraping with a thickness of at least 0.1 mm.

It is not advisable to use sandpaper or wire brushes, because impurities (foreign bodies) may penetrate the material. In order to obtain a complete removal of the oxidized layer, the areas to be cut will be marked with a marker.

Figure 8: Isopropyl alcohol used in degreasing surfaces

The processed area must be protected from being contaminated with impurities and by possible bad weather conditions (e.g.- moisture, frost). The fittings with embedded resistances will not have the area of the heating resistance cleaned by scraping.

1) The end of the pipe is cut at the marked dimension by means of a special cutting device.
2) The inner and outer seams, the cut edges of the pipe, will be removed.
3) Correcting the ovality of the pipes.
4) Degreasing the surfaces to be welded.
5) Introducing the ends of the pipe in the socket of the fitting.

All the joints prepared for welding will be mounted without straining them, the pipe not being allowed to hang inside the fittings under their own weight or to be folded. After mounting the electrofittings, we must check whether it is possible to easily twist them (without considerable effort).

Figure 9: Polyethylene machine used in electrofusion welding

If necessary, the pipe can be supported, or appropriate supporting devices may be used. The joint will remain in a fixed position, requiring a cooling time indicated on each fitting. An off-centered joining compared to the right position leads to a surplus of molten material, changing the inner section of the joint, the mechanical strength of the welded assembly. The time needed for cooling down the bounding areas with a resistive element differ according to the diameter.

3.4 Performing the electrofusion welding of Dn 32 polyethylene elbows and pipes

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4. Determining the temperature distribution for the welded polyethylene pipe – polyethylene fitting assemblies

The conducted study required the following equipment: 1. Polyethylene welding machine Sbox, manufactured by Fusion company in England, which makes possible to weld polyethylene fittings up to 180 mm in diameter and provides an observation of the welding cycle, so in case this is not completed correctly, the machine will record the error and will highlight this in the welding protocol; 2. High technology camera for recording the temperatures Thermo Vision A320 which ensures the measurement and recording of temperatures both on a broad area and on a specific area; 3. Software for acquiring the values measured by means of the thermal camera - allows us to create an overall or a detailed image. 4. The welding machine which consists of the high density polyethylene pipe 32 mm in diameter, SDR11, used in natural gas distribution and polyethylene pipe elbows 32 mm in size.

Figure 12: System for welding and measuring temperatures

The welding technology is followed, and approved machines and tools were used. The mark was made on the pipe, we used the metallic scraper to remove the coating on the DN32 mm pipe in the welding area, we etched the welding area with a special etching solution and then we fixed the DN32 electrofusion elbows and the welding procedure began.

The measurements on the working assembly (3 tests) were carried out at an ambient temperature of 22 degrees Celsius. The polyethylene welding machine Sbox allows the automatic adjustment of the operating voltage and the progressive increase of the welding temperature, a fact which is seen in the images taken during the measurements. The study was done for highlighting the welding for pipes with the diameter of 32 mm.

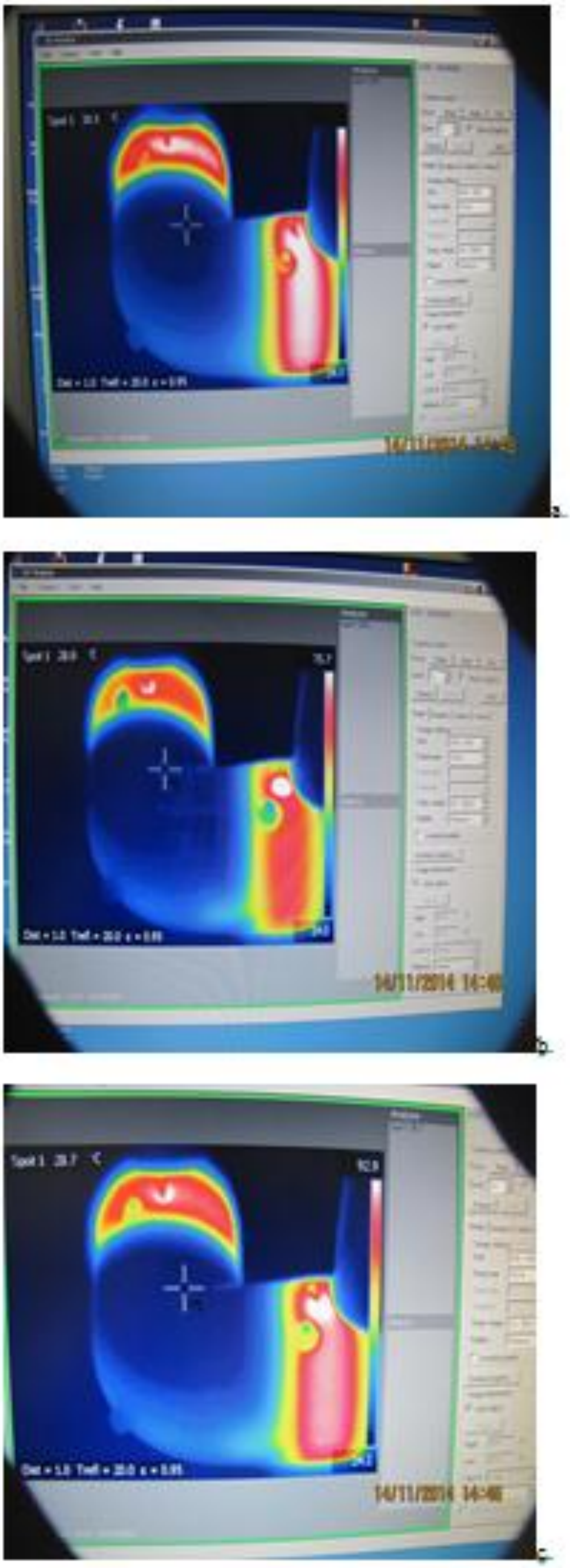

Figure 13: Different stages of temperature measured at the beginning of the welding, halfway through and at the end of the procedure.

5. Conclusions and Recommendations

The conduct of these studies led us to observing some important elements that may extend to other diameters of pipe delivered in coils.

The elements resulting from these studies can be identified as follows:

- After modeling the polyethylene fitting with the diameter of 32 mm, we could observe the area where the polyethylene fitting is under the maximum stress and strain;
- We thus identified the area of the dangerous section; it is recommended that this area should be subjected to zero force, which means that a device should be used during welding which will prevent the appearance of the tensile or compressive stress, or the bending of the wall socket;
- The operations which should be followed during the welding process have been identified, as well as the fact that the welders should use appropriate equipment for preparing the welding which has been approved according to the appropriate work stage;
- We performed the welding of the assembly: fitting - polyethylene pipe 32 mm in diameter, according to the standing technical norms in the field;
- A thermal study was conducted on the welding process, this operation being monitored both in terms of the heating - cooling times, and of the temperatures registered throughout the welding process.
- All the welding operations were performed by a company authorized in welding polyethylene pipes and fittings, which is an important aspect in validating the results and the conclusions, the standard welding procedure following the standing norms and regulations.
- The reached conclusions were presented during a meeting with some of the companies involved in conducting the studies in the suggested domain, the latter making the proper observations to the working procedure they apply, so they could make certain corrections to their working method.

A future direction of research can be the broadening of these studies to a mechanism to fix the fittings and the pipes, which will allow us to block the elements to be welded until they have cooled, thus ensuring an increased safety of welding as well as of operating the gas distribution pipes.

The results are important and lead to an extension of the research on other forms of fittings in the field of welding polyethylene pipes and fittings.

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