Theoretical and Experimental Determination of the Fracture-Risk Areas on the Electrofusion Socket Made of High Density Polyethylene

EUGEN AVRIGEAN[1], MIRCEA STETIU[1], MIHAELA EMILIA OLEKSIK[1], ANDREEA ANGELA STETIU[2]*, CIPRIAN HORATIU ANTONIU TANASESCU[2], RADU CHICEA[2], HORATIU DURA[2], ADRIAN BOICEAN[2]

[1] Lucian Blaga University of Sibiu, Faculty of Engineering, 4 Emil Cioran Str., 550025, Sibiu, Romania

[2] Lucian Blaga University of Sibiu, Faculty of Medicine, 2A Lucian Blaga Str., Sibiu, Romania

The paper aims to approach a problem which occurs when welding the high density polyethylene fittings and pipes used in the natural gas distribution networks. The work presents a finite element numerical analysis of the polyethylene fitting. 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. There is presented, in parallel, the thermal analysis of the polyethylene fitting employing an infrared camera. Reading both, finite element analysis and thermal analysis conclusions may lead to the solution that should be taken in order to avoid the fracture of the polyethylene fittings during welding or immediately after that.

Keywords: polyethylene socket, temperature field, dangerous area, finite element method

The basic materials for manufacturing plastic products are natural materials like cellulose, resins, oil and natural gas [1]. 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 shape of their molecules.

The most important faction for producing plastic objects is the primary distillery gasoline. Most plastics are based on *the hydrocarbons* from which derive the individual combinations of plastics, called *monomers*, namely the monomer molecules of the same kind.

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 with the existing fittings;

-the increased speed of installing the networks involve reduced costs of execution;

-the variety of dyes allows a precise marking and identification;

-there is a variety of sizes in terms of fitting, of approximately 32,000 units;

-the high corrosion resistance, which leads to the elimination of 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.

The assembling through welding procedure is based on the use of a part which will be assembled through welding, called the electrofitting (fig. 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 socket) 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 heating at an optimal melting temperature of about 220 °C until 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 parts which are in contact (fig.1).

Figu.1. Threaded assembly consisting of 32 D diameter polyethylene fitting and Dn 32 PE 100 pipe; and polyethylenene fittings

The welding parameters and the intensity of the current necessary to the electro socket 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 [VJ] and R – the electrical resistance, [Ohm].

The fitting heats first at the ends, then towards the interior (the center), so that the melt mass solidifies without leaking outside the welded area .

* email: andreea.stetiu@ulbsibiu.ro; Phone: (+40)744869075

Only the same type of materials can be welded through electrofusion. The melt flow index of the electrosockets ranges between 0.7 and 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 electrosockets which sets the parameters of the welding. Some manufacturers also provide a magnetic card with the electrosocket 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.

The stages of electrofusion welding are:

-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 0.1 mm, 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 the fixing mechanism is set;

-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 binding 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.

Preparation of the welding consists in adjusting the size of the pipe. The pipe is cut perpendicularly on the axis. It is recommended to use a polyethylene pipe cutter (fig. 2) or a saw with teeth suitable for plastic material.

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 film will be removed (fig. 3).

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

Fig. 2. Pipe cutter for different size pipes

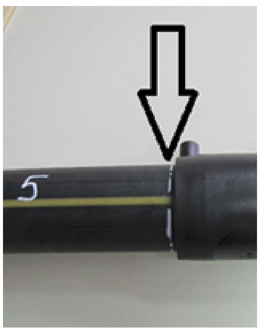

Fig. 3. Marking the length of the socket on the pipe

If the oxidized film 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 film, the areas to be cut will be marked with a marker.

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.

The end of the pipe is cut at the marked dimension by means of a special cutting device (using a chainsaw or hacksaw must be avoided).

The inner and outer seams, the cut edges of the pipe, will be removed. It is recommended to use a deburring device fitted with a cutting tool which will facilitate the fining of the sharp inner and outer edges of the polyethylene pipe.

Correcting the ovality – The pipes stored, particularly in coils and rolled up, may become oval. If in the area to be welded the ovality of the pipe exceeds 1.5% of the nominal outside diameter, the pipe should be rounded (corrected) in this area. This operation is performed by using devices for correcting the ovality appropriate for the nominal outside diameters of the pipes.

Degreasing the surfaces to be welded – In order to achieve welded joints with good mechanical resistance, it is mandatory to perform the degreasing operation on the surfaces which come into contact. Immediately after scraping, before assembling them, we use for degreasing a cloth soaked in etching solution (e.g. based on isopropyl alcohol with 99% purity), with which we remove the impurities.

Introducing the ends of the pipe in the socket of the fitting – When joining the pipes in the fitting, we should pay attention that the connection sockets of the fitting should allow the attachment of the connecting cables to the welding machine. It is not allowed to join the pipes into the fitting by force.

If necessary, the outside of the pipe will be scraped until it fits easily into the electrically weldable fitting or, where appropriate, the ovality correction device will be used. The processed end of the pipe must be inserted into the fitting to the stop in the middle area.

All the joints prepared for welding will be mounted without straining, 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).

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-center 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.

Experimental part

The Finite Element Analysis on the Dn32 mm Polyethylene Socket

The assembly polyethylene socket - 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.

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 this:

-to create a simplified model of the real model (fig. 4) and solve the differential equations on that model, obtaining the exact solution on the simplified model;

-to obtain an approximate solution to the real problem.

Determining the temperature distribution for the welded assemblies: polyethylene pipe – polyethylene fitting

The conducted study required the following equipment (fig.5):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 ThermoVision A320 which ensures the measurement and recording of temperatures both on a broad area and on a focused 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 DN 32 in diameter, SDR11, used in natural gas distribution and polyethylene pipe elbows 32 mm in size.

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.

Results and discussions

Most of the problems of modern engineering are solved using numerical methods [8, 9]. Following the finite element analysis, widely used since the 1960's with applications in the fields of engineering and bioengineering

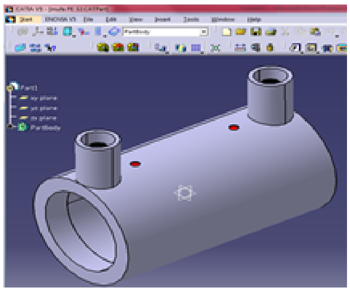

Fig. 4. Designing the 3D model of the 32 mm electrofusion socket, by means of Catia software

Fig. 5. System for welding and measuring temperatures

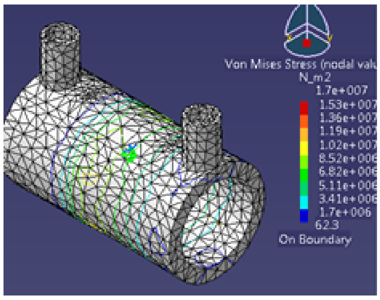

Fig. 6. Stresses appeared in the electrofusion fitting (the 32 mm socket), following accidental tensile stresses

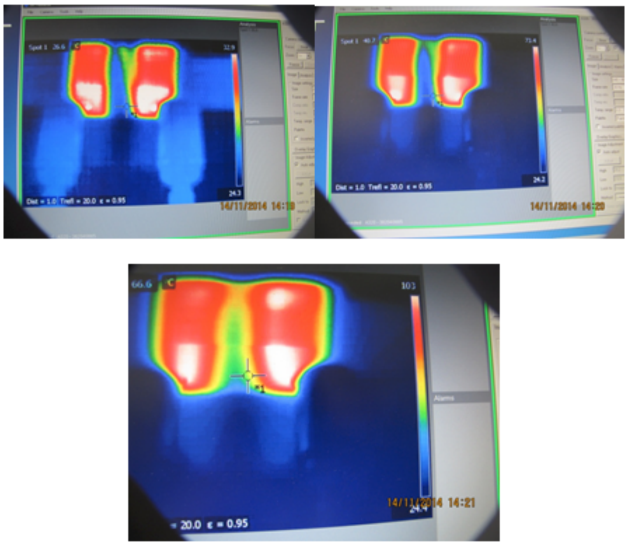

Fig. 7. Different stages of temperature measured at the beginning of the welding, halfway through and at the end of the procedure

[10], one can observe in figure 6 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, as other authors confirm this [11]. An important issue in the Finite Element Analysys is the precision of the three dimensional finite element model that is used in the simulation [12].

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 (fig. 7). The study was done for highlighting the welding for pipes with the diameter of Dn 32 mm [13, 14].

Conclusions

After modeling the polyethylene fitting with the diameter of Dn 32, we could observe the spot where the polyethylene fitting is under the maximum stress and strain (fig. 6);

We thus identified the area of the dangerous section; it is recommended that this area should be subjected to zero force, which means 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.

References

1.LUPU N.I. Conducte din polietilena in sistemele de distributie. Editura Universitatii Lucian Blaga din Sibiu, 2000.

2.*** SR ISO 3501 1995 Asamblari intre fitinguri si tevi de polietilena sub presiune. Incercarea la rezistenta prin smulgere

3.*** SR ISO 3459 1995. Tevi de polietilena sub presiune. Asamblari cu fitinguri mecanice.

4.BALAN M.L. Contributii la utilizarea procedeului de sudare cap la cap a tevilor de polietilena destinate transportului si distributiei gazelor naturale. Doctoral thesis. Sibiu 2009.

5.*** SR ISO 3609 1996. Tevi de polietilena si polipropilena. Tolerante la diametrul exterior si la grosimea peretelui.

6.*** SR ISO3607 1995. Tevi de polietilena. Tolerante la diametrele exterioare si grosimile de perete.

7.MURARIU C. Influenta imperfectiunilor imbinarilor sudate ale structurilor din polietilena de inalta densitate asupra comportarilor mecanice. Teza de doctorat. Timisoara. 2008.

8.TAMAS V., MARTIN R.R., JORDAN C. Reverse Engineering of Geometric Models - An Introduction. Computer Aided Design vol. 29, no. 4, pp. 255-268, (1997).

9.TABACU, S., HADAR, A., STANESCU, N.D., ILIE, S., TUDOR, D.I.. Hexahedral Finite Elements Mesh Generation Method with Applications to Plastics Parts., Mat. Plast., **47**, no. 1, 2010, p. 94

10.COMAN, C., GHERGIC, D.L., PATROI, D.N., TARCOLEA, M., COMANEANU, R.M., BARBU, H.M. Comparative Assessment of Resistance Against Experimental Forces of Mixed Prosthetic Restorations, Mat. Plast., **53**, no. 1, 2016, p. 91

11.J. SCHIJVE. Fatigue of Structures and Materials. Editia 2, 2009:60-264.

12.BORTUN, C.M., ARDELEAN, L., RUSU, L.C., MARCAUTEANU, C. Importance of Modern Light-curing Resins in the Design of Removable Partial Dentures. Rev. Chim. (Bucharest), **63**, no. 4, 2012, p. 428

13.AVRIGEAN E., HUNYADI L. Study on Temperature Distribution in the Jointing Fittings for Polyethylene Natural Gas Pipes. 3rd International Conference on Recent Trends in Materials and Mechanical Engineering (ICRTMME 2015) Auckland, New Zealand, January 15-16, 2015.

14.OLEKSIK V., PASCU A.M. Proiectarea optimala a maºinilor si utilajelor. Editura Universitatii Lucian Blaga din Sibiu 2007.

Manuscript received: 3.06.2016