Studies and Research on the Stress – Strain Analyses of the Polyethylene Pipe-Fitting Assemblies Accidentally Subjected to an External Force

E Avrigean¹* and S M Filip²

¹Faculty of Engineering, Lucian Blaga University, No. 4, Emil Cioran Street, Sibiu 550025, Romania
²Delgaz Grid S.A., No. 40, Rusciorului Street, Sibiu 550112, Romania

Email: eugen.avrigean@ulbsibiu.ro

Abstract. The paper aims at analyzing the behavior of the polyethylene pipe-fitting assembly in the case of accidental stress due to the accidentally occurring external forces (mechanized excavation in the assembly area). The study will identify the necessary computing relationships and the minimum value of the force to which the analyzed assembly breaks, as well as some solutions for avoiding these accidental stresses. A three-dimensional model of the assembly will be made by applying the external forces on three main directions, following the maximum stresses for the same value of the external force. Also, a welding of a polyethylene pipe-fitting assembly will be carried out and it will be subjected to three stresses on the three directions so that a parallel can be made between the results. The study will also observe the way in which the temperature is distributed throughout the assembly and the areas where the obtained temperature reaches the highest value during welding.

1. Introduction

The oil and the natural gas are the most important raw materials. In refineries, the crude oil is divided by distillation into several components. Depending on the range of the boiling temperatures, different stages of distillation are obtained: gas, gasoline, kerosene, black oil and, as residues, bitumen. All these constituents are composed of hydrocarbons which differ only in the size and the configuration of their molecules. The most important component for producing plastics is straight run gasoline. This gasoline is further cut and transformed by a thermal cracking process (vapour cracking) into ethylene, propylene, butylene and other hydrocarbons [1].

Therefore, it is safe to assert that plastics are materials obtained by chemically transforming natural products, or by means of synthesis, starting from organic compounds having carbon (C) and hydrogen (H) as main components. The hydrocarbons are at the core of most plastics and the individual combinations of plastics, called monomers namely monomer molecules of the same kind [1].

The electro fusion welding procedure is based on the use of a part which will be assembled through welding, called the electro fitting (figure 1). It consists of the basic body, injection molded from high density polyethylene, in 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 (for 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 electro fitting. By heating the pipe-fitting assembly, a swelling will appear on the material, which is pre-calculated by taking into account the gap between the two parts and then, by heating until an optimal melting temperature of about 220°C is reached, we obtain a homogeneous molten mass. After cutting the electric current in the electric resistance, the melted mass begins to solidify and, thus the two connected parts will be welded (figure 1) [2].

The welding parameters and the intensity of the current necessary to the electro sleeve for plasticizing the contact surfaces are monitored and registered automatically by the welding machine by means of a control processor. At the beginning the fitting heats at the ends and 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 electro fusion. The melt flow index of the electro socket 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 and 1.3 g/10 min. There is a bar code on the electro fusion sleeves which directs the welding parameters. Some manufacturers also provide a magnetic card with the electro fusion sleeve that has to be inserted into the welding machine. Once the welding is complete, the technical data contained therein referring to setting the welding parameters are deleted, which means that the card can be used only once [1].

Two types of tees used for branching polyethylene pipes to other polyethylene pipes were selected for the analysis, respectively the branch tee type T (Figure 2) and the tapping tee (Figure 3).
Thermal Study on the Welding Process [4]
The conducted study required the following equipment: 1 Polyethylene welding machine Sbox, manufactured by Fusion company England, which makes possible welding polyethylene fittings up to 180 mm in diameter and allows the 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 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, diameter 63SDR11, used in natural gas distribution and the analyzed polyethylene tees, 63 mm in size.

The welding technology is taken into consideration and the employed tools and machines are certified. The mark was made on the pipe, the coating on the DN63 mm pipe was removed in the welding area by means of the metallic scraper, the welding area was etched with a special etching solution and then the DN63 electro-fusion sockets were set and the welding procedure began.

a. The equal electro-fusion tee 63 mm in diameter was welded with a welding machine appropriate for polyethylene, called S-box and manufactured by Fusion company.

By observing the welding process, it was noted that the time required for welding this fitting was 40 seconds and the minimum cooling time was 5 minutes.

b. Welding the electro-fusion branch tee 63-32 mm in diameter
By observing the welding process, it was noted that the period of time required for welding this fitting was 80 seconds and the minimum cooling time was 12 minutes.

Measurements on the work assemblies (3 tests) were carried out at an ambient temperature of 22 degrees Celsius. The Sbox polyethylene welding machine allows the automatic adjustment of the operating voltage and the progressive increase of the welding temperature, which is noticeable in the following images taken during the measurements.
2. Justification for Conducting the Study
Because in daily practice various works are being done to modify and improve the routes of the utilities networks, this requires mechanical excavations, which sometimes lead to certain accidents, respectively defects, caused on the branch tee - polyethylene pipe assemblies. That is why the most influential area in terms of the maximum stresses will be studied for each individual tee.

3. Designing Physical Models in CAD Software
Such a program that allows the accomplishment of a finite element analysis is Catia. The issue of geometric modeling can currently be approached using assisted design software or modules incorporated into the finite element analysis software for assisted design.

The polyethylene sleeve - polyethylene pipe assembly was chosen for the present research; the conducted investigation being 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 the risk of the possible inconsistencies between the Catia files and other finite element software has been eliminated.

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 aircraft 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 in any point in the studied area. This is the analytical, classical solving method, which is applicable only to the simple problems. However, the problems that arise in the practical engineering activity are not simple but rather complex, both in terms of physical geometrical construction of the part, and in terms of the loading boundary conditions. In this situation, solving the differential equations is no longer possible. At this point, there are two solving options:

- creating a simplified model of the real one and solving the differential equations on the former, thus obtaining the exact solution on a simplified model;
- obtaining an approximate solution to a real problem.

In order to make a comparative study on the stresses and strains occurring in parts like these, they were modeled and analyzed by means of Catia software.

After obtaining the three-dimensional models, they were transferred to the finite element analysis
module and mechanical characteristics and constraints have been applied to them. (Figures 12 and 13)

Figure 9. Modeling the Dn 63 mm T-type branch tee

Figure 10. Modeling the Dn 63 mm branch tee

Figure 11. Applying constraints and forces to the Dn 63 T-type branch tee along the pipe (a), perpendicular to it (b) and at a 45 degrees angle

Figure 12. The maximum value of Von Mises stress for a 1 kN force on the T-type tee is 3.89 MPa for stress along the pipe (a), 4.37 MPa for stress perpendicular to the pipe (b) and 4.06 MPa for stress at a 45 degrees angle

Figure 13. The maximum value of Von Mises stress for a 1 kN force on the T-type tee is 0.57 MPa for stress along the pipe (a), 1.63 MPa for stress perpendicular to it (b) and 1.22 MPa for stress at a 45 degrees angle

The above variants have been similarly analyzed and applied to the tapping tee and the observed differences are listed in the graphs below.
Table 1. Distribution of Von Mises stress and displacements for the two studied cases

| Von Mises Stress [MPa]                     |
|-------------------------------------------|
| 1 kN force                                |
| Along the axis of the pipeline            |
| Perpendicular to the axis of the pipe.    |
| At a 45 degrees angle to the axis of the pipeline |
| T Branch Tee                              |
| 3.89                                      |
| 4.87                                      |
| 4.06                                      |
| Tapping Tee                               |
| 3.08                                      |
| 4.31                                      |
| 3.77                                      |

Figure 14. Von Mises stress [MPa] for the two models of tees and three types of forces

Figure 15. Von Mises stress [MPa] for the two models of tees and three types of forces

Using the same methods for the branch tee, it was observed that the values of the Von Mises stress were 32.2% lower and those of the displacements 37.4% lower.

4. Conclusions
Following the conducted studies, we have noticed that in terms of the fixed constraints, the values of Von Mises stresses resulted for the two models of tees were different, which proved that it is preferable to use the tapping tees, which were more rigid and registered lower measurement values than the equal tees.

In the future, mechanical tests will be carried out on these elements for a 1 kN force, and the behavior of these assemblies will be observed.

References

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