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Identifying the Necessary Solutions to Prevent the Fracture of the Polyethylene Pipe undergoing a Squeeze-off Procedure

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Abstract: ***The present paper aims to observe the way in which the polyethylene pipe is deformed when acted upon by a radial stress caused by a mechanical squeeze-off tool, in order to avoid that the thickness reduction in the contact area causes a fracture in the future. Several possible solutions to increase the safety in operation are suggested.***

Keywords: polyethylene, stresses and strains

1. Introduction

Types of materials and procedures used in polyethylene pipe manufacturing

The cellulose, the resins, the oil and the natural gas are the raw materials used in the production of plastics. The oil and the natural gas are the most important raw materials. In refineries, the crude oil is separated by distillation into several components. Depending on the range of the boiling temperatures, various distillation phases are obtained, such as gas, gasoline, kerosene, fuel, leaving bitumen as a residue. All these components contain hydrocarbons which are different only in the size and configuration of their molecules. The most important fraction in plastic manufacturing is the straight-run gasoline. [2, 3]

This gasoline is further cut and transformed through a thermal cracking process (steam cracking) into ethylene, propylene, butylene and other hydrocarbons.

Therefore, plastics are materials obtained through the chemical transformation of the natural products, or through synthesizing the organic compounds whose main components are carbon (C) and hydrogen **(H)**.

The *hydrocarbons* are the core of most plastic materials. They create the individual combinations of plastics, called *monomers*, namely monomer molecules of the same type.

The basic chemical processes used in plastic production are the following:

Polymerization is the most widely used process for the synthesis of plastics, connecting the monomers into macromolecular chains, without dissociating the extraneous matter.

This process is used to obtain polyethylene, whose raw material (the monomer) is an unsaturated hydrocarbon, either the ethene or the ethylene, which is industrially obtained from petroleum gases of up to 98% purity.

Polycondensation consists of the set of reactions by which monomers of the same or different type connect and combine with each other in macromolecular chains, simultaneously releasing a secondary substance such as water, hydrochloric acid, or other. Polycondensation is used, for example, to produce phenol formaldehyde resins and polyamides. Certain additions and substitutions in which a product of the *carbonyl* group (a carbon component) binds to substances containing the CH, CH_2 or CH_3 group, creating a new C-C bond are defined as polycondensation reactions of aldehydes and ketones.

A better known example of a polycondensation reaction is the way the bakelites (discovered by A. Baeyer in 1872) are obtained by the condensation of phenol with formaldehyde. [2,3]

The analytical calculation of the radial stresses acting upon polyethylene pipes [1.4]

If a tubular pipe is stressed by an internal pressure p_i and an external pressure p_e (Figure 1), a three-dimensional stress occurs. Thus, three different types of stress act in the pipe's wall [1]:

- A radial stress:

$$\Sigma_I = \frac{1}{R_E^2 - R_I^2}\left[P_I R_I^2 - P_E R_E^2 + (P_E - P_I)\frac{R_E^2 R_I^2}{R^2}\right] \tag{1}$$

- A tangential stress:

$$\Sigma_I = \frac{1}{R_E^2 - R_I^2}\left[P_I R_I^2 - P_E R_E^2 - (P_E - P_I)\frac{R_E^2 R_I^2}{R^2}\right] \tag{2}$$

-> An axial stress:

$$\sigma_{ax} = \frac{p_i r_i^2 - p_e r_e^2}{r_e^2 - r_i^2} \tag{3}$$

In relations 1 and 2, $r_e = D/2$ is the outer radius of the pipe, and $r_i = d/2$ is its inner radius. It may be noticed that if r = r_i, the radial stress will be:

$$\sigma_r = -p_i \tag{4}$$

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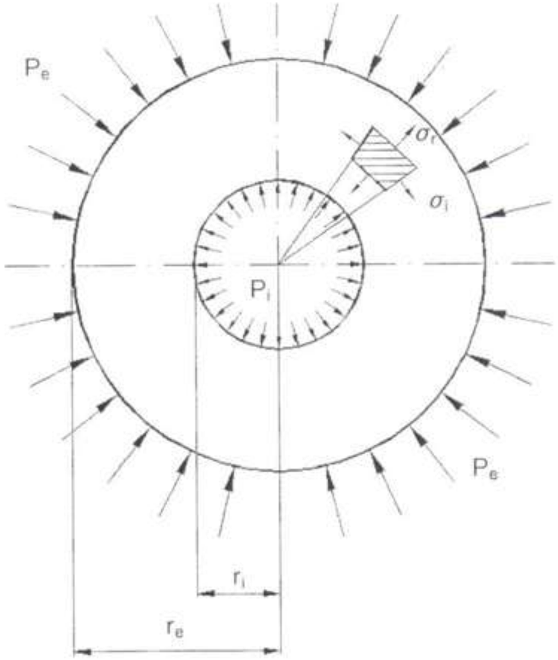

Figure 1: Distribution of stresses on the polyethylene pipe according to the application of the external and internal pressures

In the situation when r = r_e, the radial stress will have the following value:

$$\sigma_r = -p_e \tag{5}$$

If r = r_i, the tangential stress will be calculated with the following formula:

$$\sigma_i = \frac{r_e^2+r_i^2}{r_e^2-r_i^2}p_i - \frac{2r_e^2}{r_e^2-r_i^2}p_e \tag{6}$$

And if r = r_e, the following relation is obtained:

$$\sigma_i = \frac{2r_i^2}{r_e^2-r_i^2}p_i - \frac{r_e^2+r_i^2}{r_e^2-r_i^2}p_e \tag{7}$$

These mathematical expressions can also be written in the following form:

$$\sigma_i = \frac{D^2+d^2}{D^2-d^2}p_i - \frac{2D^2}{D^2-d^2}p_e \tag{8}$$

Respectively, the external stress σ_e, is:

$$\sigma_i = \frac{2d^2}{D^2-d^2}p_i - \frac{D^2-d^2}{D^2+d^2}p_e \tag{9}$$

where D and d are the outer diameter and the inner diameter of the pipe.

The internal pressure is caused by the fluid flowing through the polyethylene pipe. If $p_{e=0}$, which means that the external pressure is neglected in the calculation, the formula for the radial stress (relation 2.1) is as follows:

$$\sigma_r = \frac{r_i^2}{r_e^2-r_i^2}\left(1-\frac{r_e^2}{r^2}\right)p \tag{10}$$

where p =p_i.

If $r = r_i$, σ_r it has the same value given by relation (2.4), and if r = r_e, then $\sigma_r = o$

In a similar manner, the formula of the tangential stress is:

$$\sigma_i = \frac{r_i^2}{r_e^2-r_i^2}\left(1+\frac{r_e^2}{r^2}\right) \tag{11}$$

For $r = r_i$, this stress reaches the maximum value, with the following expression:

$$\sigma_i = \frac{r_e^2+r_i^2}{r_e^2-r_i^2}p \tag{12}$$

or

$$\sigma_i = \frac{D^2+d^2}{D^2-d^2}p \tag{13}$$

as it directly results from relation (8).

If in relation (13) we replace D with $D = d + e_n$, (e_n being the thickness of the pipe's wall) and omit the term which contains e_n^2, the following expression results:

$$\sigma_i = \frac{p*D}{2e_n} \tag{14}$$

if a term containing e_n^2 is omitted.

The previous formula usually serves at calculating size, because the tangential stress is the most important.

By applying the same calculation algorithm, the axial stress becomes:

$$\sigma_{ax} = \frac{r_i^2}{r_e^2-r_i^2}p \tag{15}$$

or it is:

$$\sigma_{ax} = \frac{d^2}{D^2-d^2}p \tag{16}$$

Using the same approximation of e_n^2 the axial stress is deduced with the following relation:

$$\sigma_{ax} = \frac{pd}{4e_n} \tag{17}$$

Applying the squeeze off tool on the polyethylene pipes with diameter of 63 MM

There are situations in every day practice when the couplings to the natural gas distribution pipes must be done under pressure (at the free end of the pipe or through multiple squeeze-off tools) being required to use different size tools (Figure 2).

Figure 2: Squeeze-off tool used for shutting off polyethylene pipes with diameter of 63 to 160 mm

The adjustment of this squeeze-off tool is done by means of a limit stop, a rotating knob which selects the diameter and the thickness of the pipe.

The problem which occurs in such cases is related to the radial compression of the polyethylene pipes and the behavior of the material, therefore we shall closely monitor the squeezed-off area of the pipe.

Figure 3

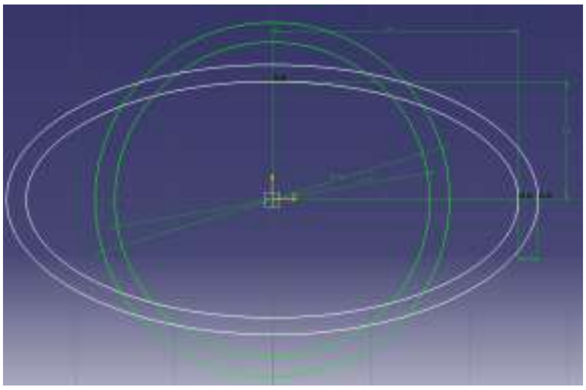

Figure 4: The difference between the unsqueezed pipe (green) and the one that does not have a full rebound (white)

The model of the pipe which was subjected to the squeeze – off tool and which underwent the maximum allowable deformation of 15%, is shown in the following figure:

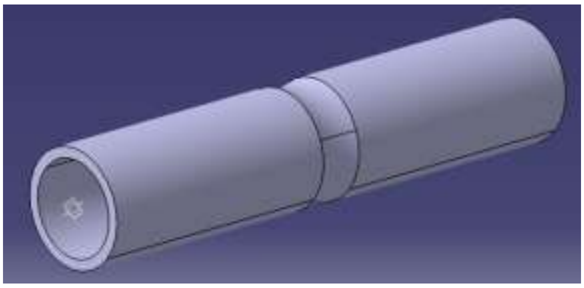

Figure 5: Deformation caused by the squeeze-off tool on the polyethylene pipe with a diameter of 63 mm

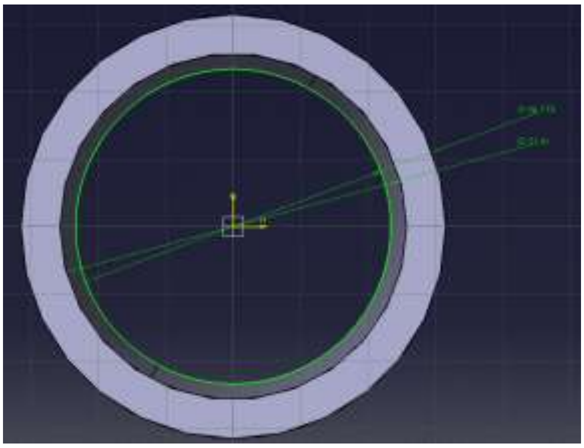

Figure 6: The difference between the initial state and the one after the deformation is 9%

The study indicates that in the work area the polyethylene pipe is throttled by 9%, which prevents the gas flow to some extent, its friction against the wall of the polyethylene pipe can create turbulence in the natural gas pipeline. In such a situation, it should be noted that in certain areas and under certain conditions (river crossings, railways, etc.) the pipe may contain water and mechanical elements that have been accidentally introduced inside during couplings or defects (pieces of metal, stones, sand) which are carried over by the natural gas flowing under pressure and may hit the pipe in the obstructed area, thus representing a danger for the integrity of the natural gas pipeline.

Another aspect to be noted here is the thickness reduction of the pipe in the work area, so that the value of the wall of the polyethylene pipe will be lower than the designed one. To this respect, a fitting will be made that will be welded in two parts to increase its strength in the actuation area.

In order to rebound in proportion of up to 98% under high temperature conditions, a double welding socket can be mounted which is different from the existing ones and is of our own design.

Figure 7: The upper part of a Dn 63 socket with welding terminals.

The upper and lower sockets will be identical and will be joined to each other by means of four screws, each one allowing the welding. The advantage of using such a socket is the fact that it will increase the resistance in the work area

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and will stiffen an already weakened surface.

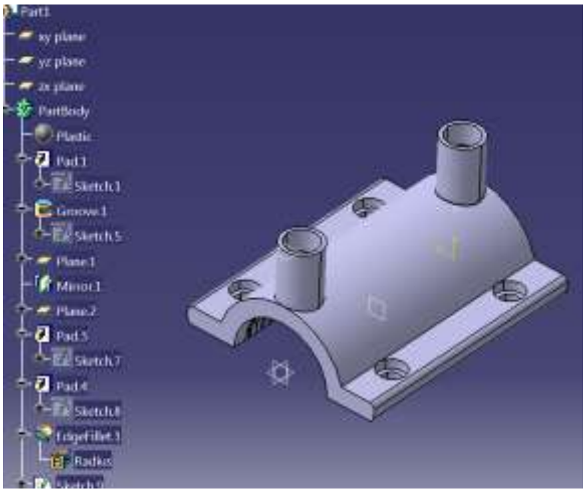

Figure 8: Execution of the electrofusion welding support socket

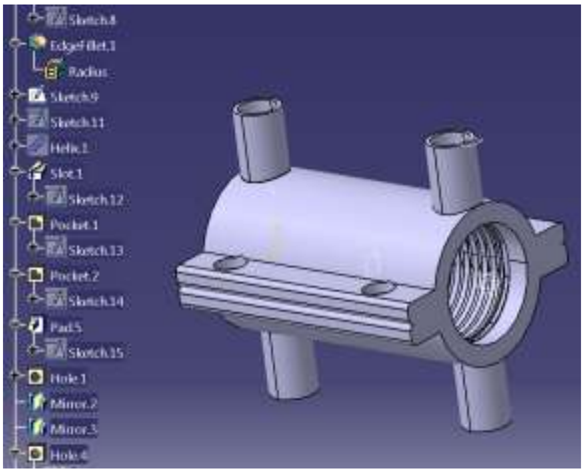

Figure 9: Execution of the complete electrofusion welding socket

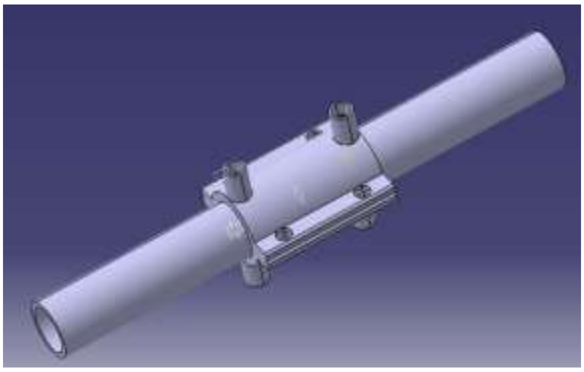

Figure 10: The polyethylene pipe - special socket assembly

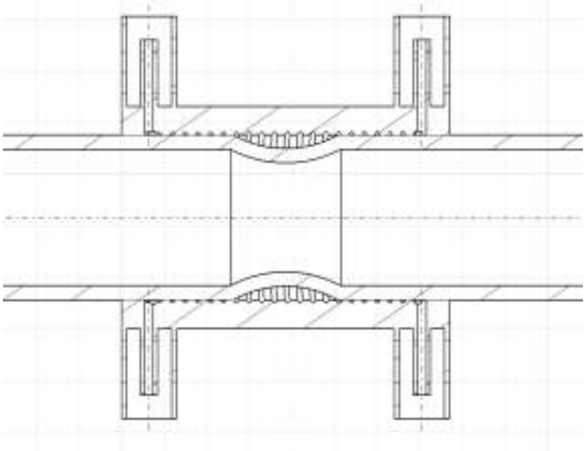

Figure 11: Section of the polyethylene pipe - special socket assembly

It is obvious from the drawing that the two electrofusion sockets must be welded independently, which requires a longer welding time and implicitly a longer time for the assembly to cool down.

Also, the two sockets must be fastened with the four screw-washer-nut systems, which require an extra working time. The surface layer will be removed from the pipe to be hardened only in the welding area, not exceeding the length of the socket, because the surface layer is resistant to the chemical attacks of the various substances that may be in the soil.

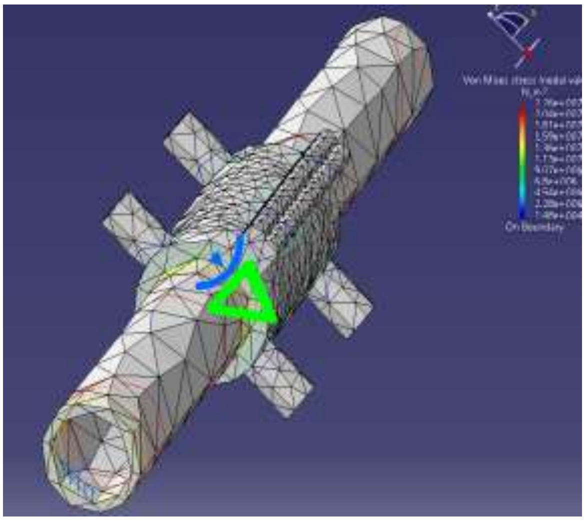

Figure 11: The von Mises stress of the assembly subjected to an axial stress is 22.6 MPa

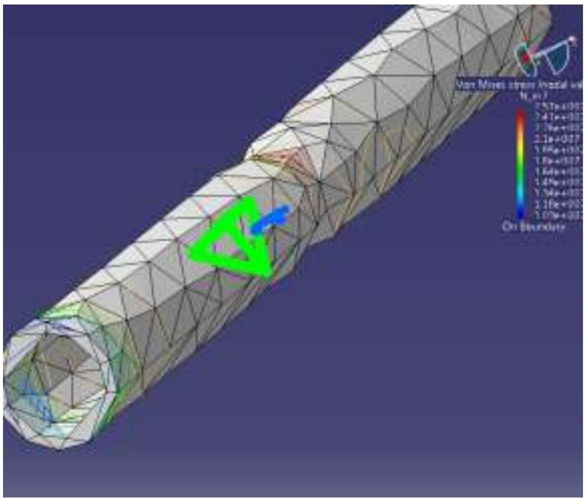

Figure 12: The Von Mises stress in the obstructed pipe subjected to an axial stress is 25.7 MPa

The difference between the Von Mises stresses shows that installing the specially designed socket improves the strength of the pipe by 14%, thus enhancing its safety in operation.

There is an additional aspect related to the fact that in the cold season the obstructed polyethylene pipes do not fully rebound after the release of the squeeze off tool. It is therefore recommended to construct the special parts by three-dimensionally scanning the area and printing the sockets according to the three-dimensional measurements (figure 13).

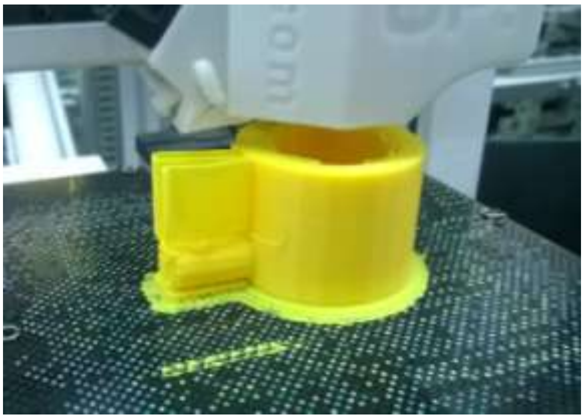

Figure 14: Constructing special sockets for stiffening the mechanically obstructed pipes.

2. Conclusions

The thickness reduction produced by the squeeze off tool may leave a deformation on the pipe and must be verified so that it does not cover an area larger than 15% of the thickness of the material.

The study indicates that the polyethylene pipe is obstructed by 9% in the work area, which prevents the gas flow to some extent. The friction of the gas to the wall of the polyethylene pipe can create turbulences in the natural gas pipeline.

The advantage of using this special socket is that it will increase the strength in the work area and will stiffen an already weakened surface.

The difference between the von Mises stresses proves that mounting the specially designed socket improves the strength of the pipe by 14%, increasing its safety in operation. At the same time, it involves costs related to the construction and installation of the special socket.

It is recommended to create the special sockets for the polyethylene pipes that remain obstructed after the 3D scanning.

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