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# Comparative Study of Stresses and Strains Occurring at Accidentally Loading Tapping Tees Welded with and without Under Clamp

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**Abstract:** ***The present paper is a comparative study of two polyethylene fittings used for coupling pressurized natural gas pipes, namely two tapping tees, one welded with an under clamp and the other one without. The aim of the paper is to observe the state of stress and strain in the two cases, highlighting the differences between them.***

**Keywords:** insulation, polyethylene, mechanical action**.**

## 1. Introduction

The raw materials for the production of plastics are natural materials such as the cellulose, the resins, the oil and the natural gas. The oil and the natural gas are the most important raw materials. In refineries, the crude oil is separated into several components through distillation. 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 fraction for producing plastics is straight-run gasoline. This gasoline is further fractioned and transformed through a thermal cracking process (vapour cracking) into ethylene, propylene, butylene and other hydrocarbons. Therefore, we can say that plastics are materials obtained through the chemical transformation of the natural products, or by means of synthesis, starting from organic compounds having carbon (C) and hydrogen **(H)** as main components. Most plastics are based on *the hydrocarbons* from which the *monomers* are derived, which are individual combinations of plastics, namely monomer molecules of the same type. [2]

The advantages of using polyethylene fittings and pipes:

- It is possible to join them by welding at low temperatures (compared to the high temperatures required for steel), by means of simple technology, as well as by mechanically assembled fittings, as appropriate;
- It is possible to combine the polyethylene networks with the already existing steel networks or with the existing fixtures;
- The increased speed of installing the networks leads to lower execution costs;
- The large variety of dyes allows a precise marking and identification;
- A large variety ofdimensions of the pipe fittings of approximately 32,000 units;
- The high resistance to corrosion eliminates the need for the cathodic protection, a very important advantage for the gas distribution networks because the aggression of the soil in the urban environment is significantly higher than outside the localities;
- The possibility to use longer pipes by delivering them in coils;
- Good chemical resistance to the gas components;
- Environmental protection, being a recyclable material. [4]

## 2. The current stage of obtaining the polyethylene fittings

***Polymerization* -** is the most widely used process for the synthesis of plastics; that is the reaction of linking monomers in macromolecular chains, without loss or gain of material [1].

This process is used to obtain polyethylene, the raw material (the monomer) being an unsaturated hydrocarbon **-** ethene or ethylene and it is obtained industrially from petroleum gases up to 98% pure. The isolation of alkenes (another name for the class containing the ethylene) from oil has led to the definition of an important industrial branch: *the petrochemistry*.

The molecules of the alkenes and of other unsaturated substances have the property of combining by means of double bonds, forming polymers.

The number of molecules of the monomer, i.e. the molecules that combine in order to form the polymer, is called the degree of polymerization (n).

There are two types of polymerization reactions. Some lead to the formation of polymers with low degrees of polymerization: *dimers*, *trimers*, *tetramers*, while from others *high polymers* or *macromolecular polymers* (n = several hundred thousand) are born. These two types of polymerization reactions show different mechanisms. [1]

The simplest mechanism for a polymerization reaction is that in which the molecules of the dimer are formed by the collision of two monomer molecules (after the usual pattern of the bimolecular reactions). The molecules of the trimer are formed by the bimolecular association between a dimer molecule and a monomer molecule. This mechanism


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(through trimolecular collisions) is the real one; the formation of the trimer can only be noticed when the concentration of the dimer in the mixture reaches appreciable values (the reaction rate is proportional to the concentration of the reactants). Also, the tetramer does not begin to form until the mixture contains a certain amount of trimer, etc. [3]

As the concentration of these polymers increases, the concentration of the monomers from which they originate decreases. It is obvious that by this mechanism of *step growth polymerization* or *chain reaction polymerization* does not create a macromolecular polymer. Assuming that the velocity of the formation of the trimer is equal to that of the dimer, it is estimated by analytical calculation that the decamer would appear in a concentration of only 0.5%, a point where the monomer has practically disappeared. In reality, in many polymerizations of this type the dimer and the trimer predominate and only a few polymers are formed having the degree of polymerization n = 5 to 6 [1].

The mechanism of the reactions forming macromolecular polymers is defined by its own characteristic reactions. Thus, in the spontaneous polymerization of the system (without promoter), at 100° C, the polymer formed after the first hour of heating (when only 2% of the monomer has been converted) and the polymer isolated near the end of the reaction (when 80% of monomer has been converted), have practically the same degree of polymerization. Therefore, the monomer is definitively transformed into a polymer. There is no formation of polymers with intermediate degrees of polymerization throughout the polymerization process; the system which does not participate to the reaction is considered a pure monomer.

On the other hand, such polymerizations can be initiated by ultraviolet light or promoters and can be stopped by inhibitors.

The sulfuric acid polymerization reaction of the alkenes (the case of the isobutene) was discovered by A.M. Butleron (1873). The macromolecular structure of high polymers was recognized by H. Standinger (1925) who proved that the molecules of the monomer are linked together in the polymer by covalence and not by undefined physical forces of attraction, as previously thought. The mechanism of the chain reaction of the macromolecular polymerization of the alkenes was defined in 1930.

These fundamental theoretical discoveries made possible the development and the magnitude of the plastics industry in the following years. [5]

## 3. Welding and the welded assemblies

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 interior of the electrofusion coupler) 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, an expansion of the material will occur, pre-calculated by taking into account the gap between the two parts and then, by heating it until it reaches an optimal melting temperature of about 220°C, a homogeneous molten mass is obtained. Upon cessation of the electric current in the electric resistance, the process of solidification of the molten mass begins, thus welding the two connected parts (Figure 1).


**Figure 1:** Electrofusion welded polyethylene coupler

The welding parameters and the current intensity necessary to the electrofusion coupler for plasticizing the contact surfaces are monitored and registered automatically by the welding machine by means of a control processor.

The intensity of the current flowing through the coil of the electro fitting is determined by the relation I-U/R where: I is the current intensity, *[A];U* is the voltage in the welding terminals [V] and R is the electrical resistance, *[Ohm]*.

The fitting heats first at the ends then towards the interior (the center) so that the molten 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 electrofusion coupler 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 electrofusion couplers which sets the welding parameters. Some manufacturers also provide a magnetic card with the electrofusion coupler that is inserted into the welding machine. When the welding is completed, the technical data contained therein referring to setting the welding parameters are *deleted*, therefore it can be used only once.

**The stages of Electrofusion Welding are the following:**

- 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);


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- After scraping, the surfaces of the pipes are cleaned with a cotton cloth soaked in an etching liquid (methylene chloride, isopropyl alcohol, ethyl alcohol over 99% pure);
- The inside of the fitting is cleaned with the same etching liquid;
- The pipes are introduced into the electrofitting and into 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 starting command 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.


**Figure 2:** Polyethylene fitting 63-32 mm indiameter before welding


**Figure 3:** Polyethylene coupler - Dn63-32pipe assembly resulting from electrofusion welding


**Figure 4:** Polyethylene coupler - Dn63-32 pipe assembly resulting from electrofusion welding

## 4. Numerical analysis on the tapping tees

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. Such software that allows the accomplishment of a finite element analysis is Catia.

One of the modules of this software is the structural one which, due to its extensive capabilities, was chosen for the study of the static and dynamic behavior of the polyethylene parts. Among the most important facilities underlying geometrical modeling, we mention:

- Parametrizing the model of the part in order to optimize it;
- Building the model through Boolean operations, which is possible by using the Solidworks model maker that allows such operations;
- The compatibility with CAD assisted design software that allow us to import the model of a structure made in a different software;
- The existence of a sufficient finite element data base;
- The optimization module that makes possible to define the design and status variables and the objective function within the optimization algorithm.

For the present research, the polyethylene coupler - polyethylene pipe assembly was chosen, 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, 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 at the same time with 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


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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 the real problem.

The two models were made, the one with and the one without a clamp, in the same working conditions and applying a force of 1 kN on the end of the tee, the most unfavorable area.

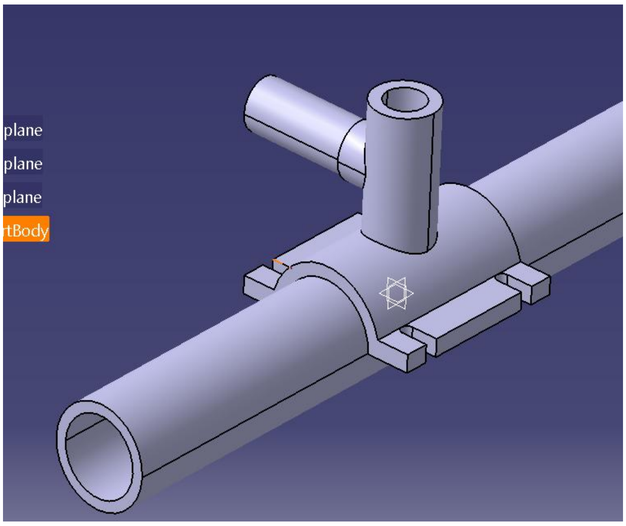


**Figure 5:** Model of a tapping tee without under clamp

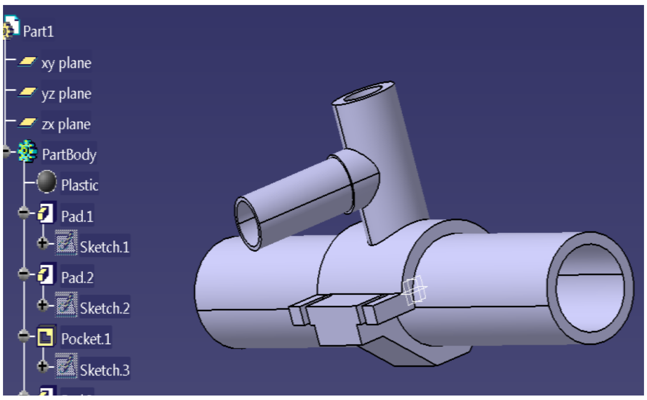


**Figure 6:** Model of a tapping tee with under clamp

## 5. Determination of stress and strain in the fittings

After building the three-dimensional model, real loading conditions were simulated by applying a 1 kN force perpendicular to the axis of the polyethylene pipe for the two cases, figures 7 and 8.

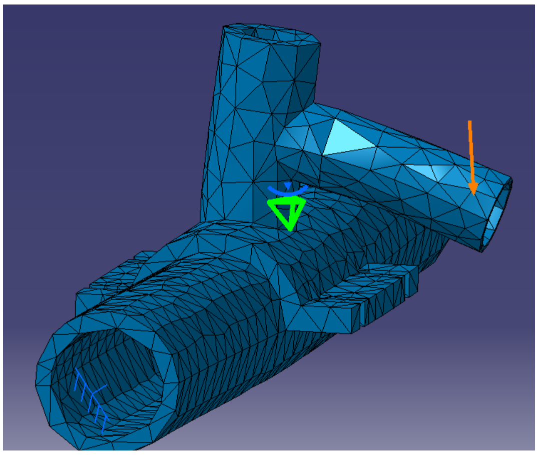

**Figure 7:** Applying the 1 kN load on the polyethylene tee without under clamp

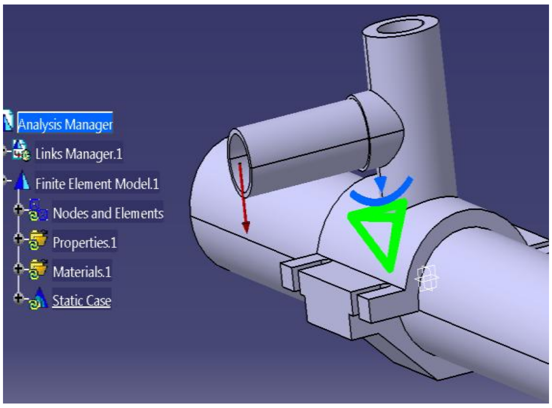


**Figure 8:** Applying the 1 kN load on the polyethylene tee with under clamp

After conducting the analysis, the following values of the stress and strain for the required load were obtained, as shown in figures 9 and 10.

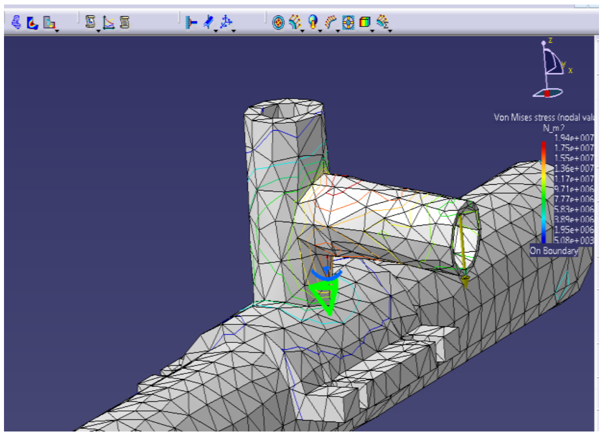

**Figure 9:** Von Mises stress obtained in the tapping tee without under clamp, 19.4 MPa


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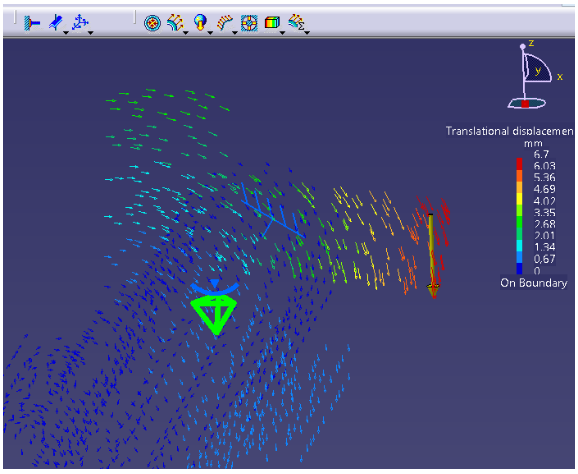


**Figure 10:** Maximum displacement obtained in the tapping tee without under clamp, 6.7 mm

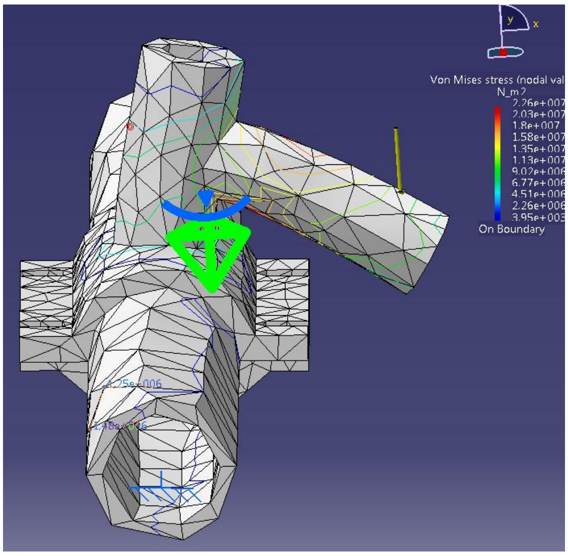


**Figure 11:** Von Mises stress obtained in the tapping tee without under clamp, 22.6 MPa

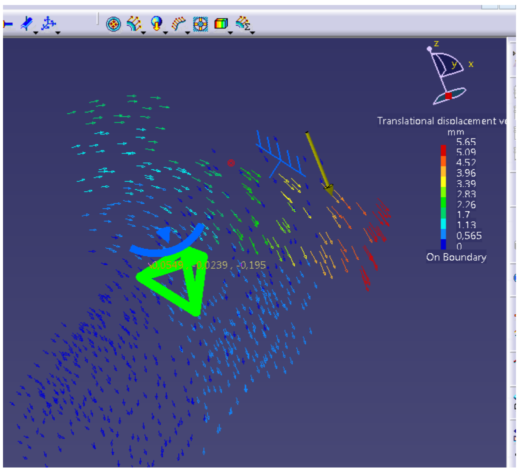


**Figure 12:** Maximum displacement obtained in the tapping tee without under clamp, 6.7 mm

## 6. Remarks and Conclusions

Following the conducted bibliographic and analytical research, it was observed that the two tapping tees differ in terms of the supplementary under clamp that helps fix the tapping tea on the pipe and ensures an additional resistance to the tapping tea without under clamp.

It was noticed that in the case of the tapping tee provided with an under clamp there is an additional rigidity, which ensures a better resistance over time, but at the same time a higher risk of fracture as proven by the values of the two obtained displacements.

The state of stress in the tapping tee is also higher in the case of the tapping tee having the under clamp due to the lack of flexibility on the polyethylene pipe.

After analyzing the displacements, the strains and the stresses, but also taking into consideration the endurance of the welding over time, it is recommended to use the tapping tee with under clamp, although the price is higher.

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## Author Profile

**Avrigean Eugen** - holder of a Ph.D. title in Mechanical Engineering, specialty Strength of Materials, higher education faculty member (Lucian Blaga University - Engineering Faculty) and researcher for 20 years. He has conducted work on numerous research books and articles, on laboratory studies, numerical analysis and computer aided design.


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