International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Numerical Analysis on Polyethylene Insulation of Steel Pipelines

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Abstract: ***This paper aims to tackle a sensitive issue related to the corrosion of steels and the measures to avoid it by applying polyethylene strips on the pipelines used in the natural gas sector in order to increase their durability. The paper focuses on the finite element analysis of the accidental breakage of the polyethylene insulation on the steel pipelines.***

Keywords: corrosion, protective insulation, polyethylene.

1. Introduction

Manufacturing, operating and maintaining in good condition the pipelines used for natural gas transportation require a thorough knowledge of both the phenomena occurring during the operation and the causes that have generated them. As a result, we studied the causes that induced the breakage of the polyethylene, more precisely a rock of a certain size and the strain produced by this. [5]

2. Analysis Conditions Taken into Consideration

The electrical resistance of the insulation is dependent on several factors, including the nature and the thickness of the coating, the nature of the environment where it performs its insulating function, the degree of degradation due to the imprint of hard bodies in the soil cover, etc. The experimental research observed the change of the insulation resistivity due to imprinting a spherical mandrel that simulates the case of a stone acting on the insulation.

The paper aims to create a simulation of a real situation, the imprint used on the surface of the polyethylene insulation being similar to the physical mandrel (figure 1).

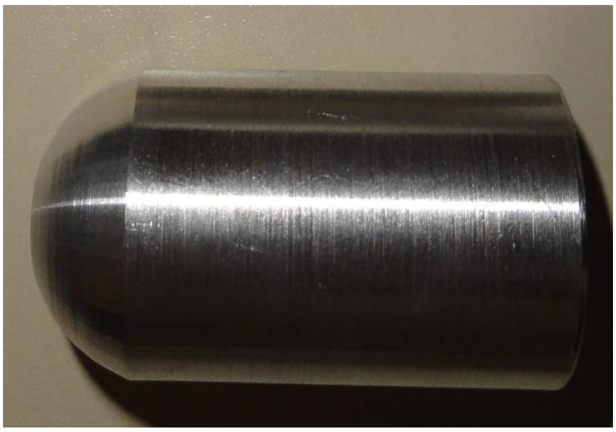

Figure 1: The shape of the mandrel which deforms the polyethylene [6]

3. The Finite Element Analysis of the Cold-Applied Insulation

In the finite element method a full model of the phenomenon being studied is used as a starting point. This model can be obtained directly by calculation or it can be derived from the corresponding differential model by means of the calculus of variations or of the weighted residuals method. Unlike the finite difference method, this method is based on local approximation or on sub-domains of the field variables. [3] Due to using an integral model as a starting point, and sets of piecewise continuous functions, the finite element method is no longer dependant on a rectangular network. By means of this method we can practically mesh any geometric body. [3] The input data are related to the constructional and technological information, depending on the conditions under which the part will function, in other words, they represent the different dimension parts from the database and the database of methods, containing optimization or engineering calculations software. From this database are extracted the constructional variants for which the finite element method analysis is conducted. [3]

One very important material hypothesis is that to consider the analyzed body as a continuous medium. This medium is considered to be locally homogeneous, meaning that a material inhomogeneity is allowed only up to a finite element level. [3]

Therefore, some finite elements may have physical properties different from those of the neighboring elements. In the case of the insulating materials, which typically have air inclusions, it is considered that the analysis field consists of a single homogenous material, with average physical properties obtained from those of the constituent elements. [3]

Regarding the considered operating mode, the work hypotheses lead to two major categories of problems: static and dynamic in the case of solid materials, or stationary and transient in the case of fluid media. [3]

The process of meshing the analysis field is physically supported by the possibility of breaking down the analyzed body in its components. In a first phase, the mashing process leads to the transformation of the analysis domain in a set of finite elements. Then, the finite elements and the nodes are numbered and the connections matrices are established. [4]

When the parts are highly complex, the meshing phase is preceded by a breakdown of the analysis domain in sub-domains and sub-bodies. The process is commonly used to automatically generate the finite element networks, within the propagation systems for research and computer-aided design.
Shaping the product consists of describing an object not only from a purely geometrical point of view, but also in terms of a certain number of characteristics, either functional or related to its manufacture, etc. Therefore, a product model contains:

- geometric information, which may correspond to what it is being used in solid models;
- technological information, e.g. machining operations (turning, drilling, milling, threading, tapping) that provide more complete information on the entire geometric shape or on parts of it;
- precision information, explaining the manufacturing tolerances related to the ideal shape;
- material information that give the type of material and its properties;
- administrative information that facilitate the object management (reference, suppliers, in stock)[4].

The optimization takes into account both the constructional elements and the technological ones required for designing the product. It has the effect of producing optimal parts in terms of construction (shape, resistance), material savings and high technologicity. [4]

The modified (optimized) shapes and dimensions are saved in the graphical database. The drawings saved in the database are customized so that for every measurement change in the optimization process, the design drawing of the part in question can be performed automatically.

The database created is used both in the design-redesign phase and in the phase of developing the manufacturing technological processes. [4]

In order to integrate the computer aided constructional design in a CIM system it is important to find opportunities for the electronic processing of information in this field towards the computer aided technological design and computer aided manufacture.

It is therefore necessary to create a database that contains the constructional elements obtained from the optimization process, but, at the same time, the technological information, which are further used for the information flow integration. [4]

In the present case, an analysis was performed on pipelines insulated with 1, 2 and 3 layers of insulation which were kept in the atmospheric environment.

Due to the significant differences of the value of the applied forces for the samples insulated by extrusion, these results were not included in the determination of the finite element.
Figure 9 shows the technology used for conducting the constructional and functional optimization steps, by applying FEM (the finite element method), based in this case on a simulation in Catia.

Catia (Generative Structural Analysis) was developed by IMB and Dassault Systems and it is a design and manufacture software - CAD/CAE/CAM, representing the world leader in CAD/CAE/CAM software.

The Catia platform reaches a total of 60 software programs. These applications can be used in mechanical design, the analysis of parts' behavior, equipment design, simulating various movement processes, studying the behavior of the parts under various environmental factors. With these new facilities, Catia v.5 covers all the stages of design and production of equipment. Ensuring maximum productivity, this product with unique modeling capabilities can integrate related applications. For these reasons Catia is used as a standard platform in several fields. [4]

3.1 Achieving Tridimensional Models

The shapes and sizes of a piece of insulation for the 2" steel pipeline were modeled (see Figure 2. a. b. b.) for three different thickness layers used in insulation.

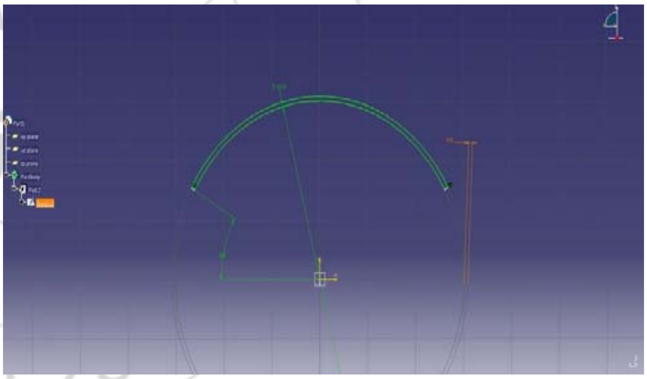

Figure 1: (a) Thickness 0.8 mm

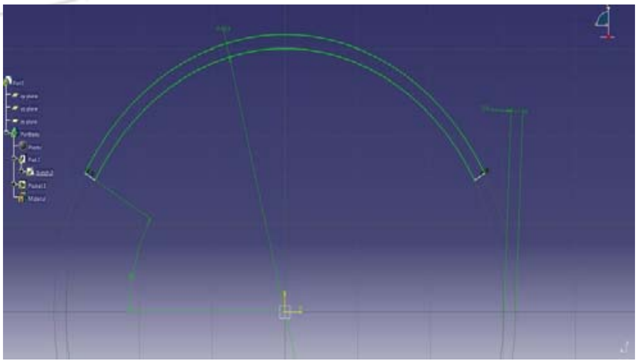

Figure 1: (a) Thickness 1.6 mm

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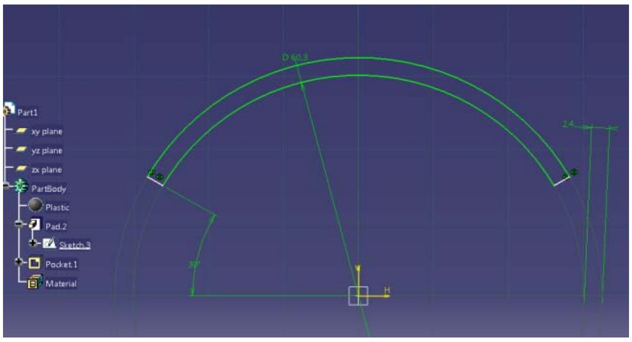

Figure 1: (a) Thickness 2.4 mm

The resulted surface has the shape shown in figure 3 bearing the imprint of the mandrel used for the testing.

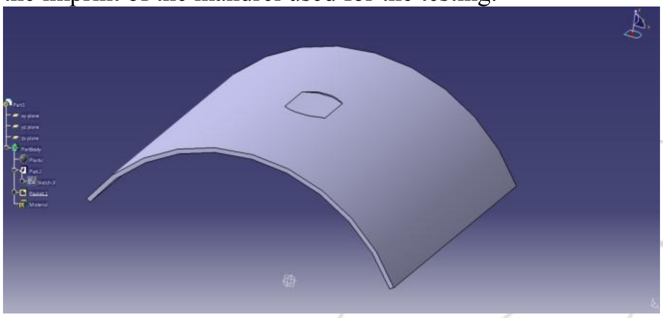

Figure 3: Applying the mandrel imprint on the insulation surface

The mechanical and elastic properties of the analyzed part are introduced in the finite element analysis program (fig. 4).

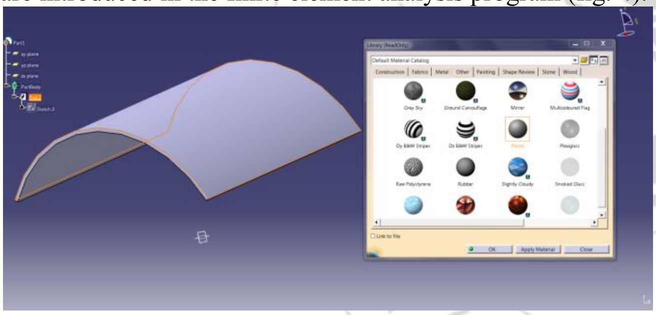

Figure 4: Loading the properties of the material for the finite element analysis in Catia software [1,2]

After loading the specific material properties, the insulation will be sent in the analysis module of CATIA, and constraints will be applied (a clamp) which simulates the adhesion of this insulation to the Ø2" steel pipeline (Figure 5).

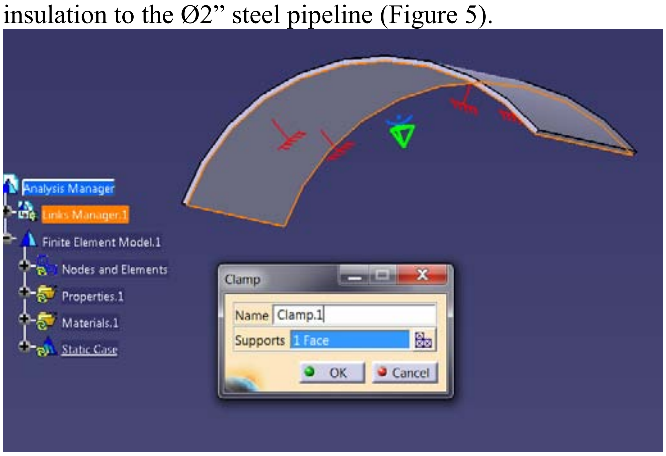

Figure 5: Applying constraints on the polyethylene insulation

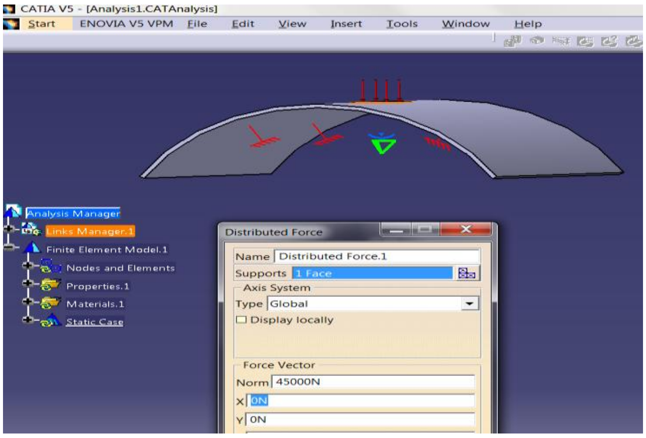

Figure 6: Applying the experimentally determined maximum force

3.2 Obtaining the Results

After applying the constraints and the forces acting on the insulation, the analysis program will be launched, resulting in the way in which the insulation was mashed (split) for the analysis (figure 7), the Von Mises stress (figure 8) and the maximum displacements (figure 9).

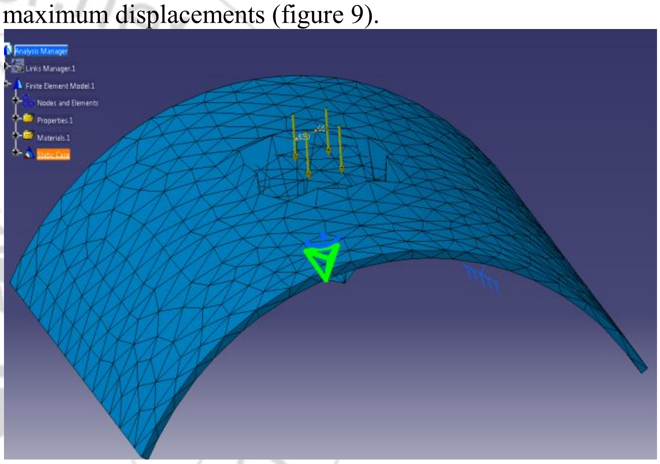

Figure 7: Mashing of the polyethylene insulation

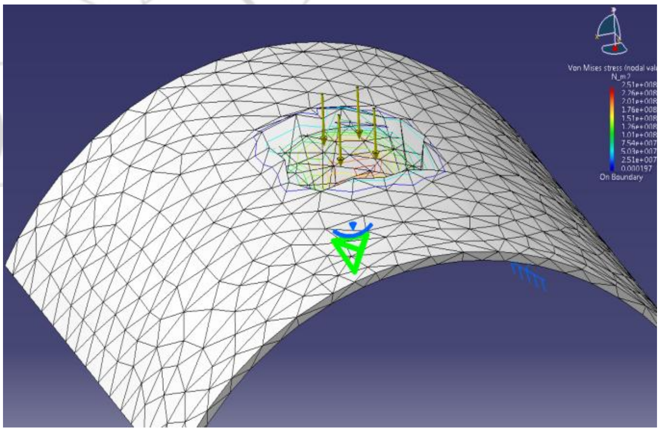

Figure 8: Von Mises stress on the contact area between the polyethylene insulation and the Ø2" steel pipeline

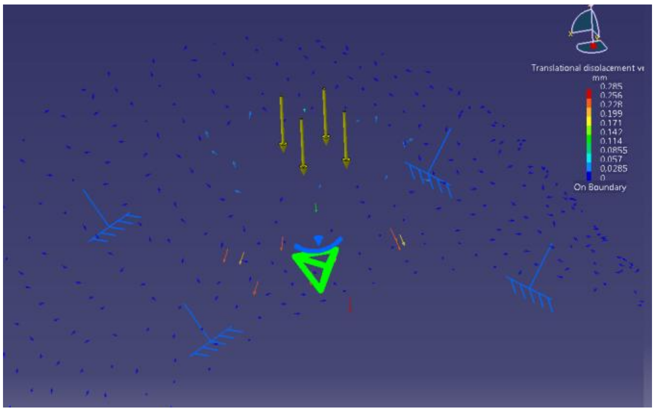

Figure 9: Displacements of the polyethylene on the mandrel application area

The measurements obtained from the simulation for the three types of applying the insulation (one, two or three layers) are shown in Table 1. Also, it contains the values of the displacement and the deformation of the insulation for the three measurements.

Table 1: Values obtained from the simulation in Catia

S. No	Type of Sample	Von Mises Stress	Polythylene Displacement
1	Layer of Insulation (0, 8mm)	227	0, 285
2	Layer of Insulation (1, 6mm)	251	0, 536
3	Layer of Insulation (2, 4 mm)	276	0, 866

The force of penetrating the insulation depending on the number of layers

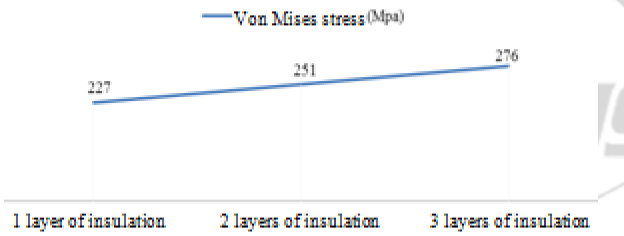

Figure 10: Values of the Von Mises stress when penetrating the cold-applied polyethylene insulation

The displacement of the polyethylene influenced by the compression force

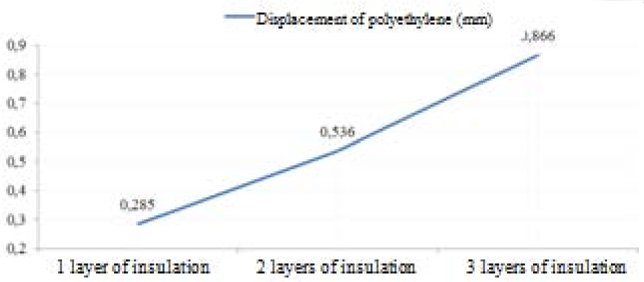

Figure 11: Values of the polyethylene displacement under compression forces

4. Observations and Conclusions

Following the finite element analysis, we noticed that the obtained values of the Von Mises stress in the contact area fall within the limit of steel deformation, which coincides with the experimentally obtained results (deformation of the steel pipeline), while regarding the deformation of the insulation, we observed that the displacement has a high value as compared to the original shape from which we started, reaching a maximum of 0.866 mm.

Taking into account all these determinations, tests and simulations, we conclude that the most vulnerable areas of the pipelines that make up an urban gas distribution network are the elements that are isolated after laying the network, as follows: butt welds, bends, branches (simple tees) reducers, the metallic part of the metal-polyethylene transition fittings, etc.

Also, we infer that laying the pipeline in a layer of sand where there are rocks or other foreign high asperity bodies, poses a greater risk of rapid deterioration of the insulation layer. Such effects can occur when not complying with the required thickness of the sand layer above the pipeline or below it. Another influential factor is the inadequate settlement of the sand layer and of the thereof upper layers, which, due to the vibrations of the soil resulting from heavy traffic, may allow the penetration of bodies that can damage the insulation, for example river or broken rocks, posing an even greater danger than all that has been presented in this chapter, but which is the subject of further scientific research.

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Author Profile

Stefan Mihai Filip has had an extensive and important training in the natural gas field, studying at the Petroleum-Gas University of Ploieşti and "Lucian Blaga" University in Sibiu, being awarded the title of Bachelor of Science in Engineering in the Petroleum and Gas Engineering Department. He has a rich practical experience in the natural gas distribution systems, occupying the position of project manager within the Eon Romania Distribuţie SA company, coordinating important works in the field, which allowed him to gain important knowledge and to detect certain problems the company has been dealing with, and, by performing such works, to try to find solutions for them.