DEFECT ASSESSMENT IN CLADDED SEAMLESS PIPE UNDER TENSILE AND PRESSURE LOADING VIA FINITE ELEMENT METHOD

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ABSTRACT

Pipes are present in all sectors of society, including primary, genetic, extractive, manufacturing, construction, and service industries. Because of this massive presence worldwide, their importance is remarkable. In the oil and gas industry, one of their applications requires the cladding process, such that it is obligatory to inspect them in order to check if they are useful for performing their design functions. When defects are produced due to this process, it is advisable to measure and evaluate if they can be put into service or not. The general objective of this paper is to check the mechanical response of a cladded seamless pipe under tensile and pressure loading in the presence of defects due to the process of welding deposition. This research has practical character with quantitative approach (using Finite Element Method), making use of literature review, resulting in presenting von Mises stresses under the abovementioned conditions.

Keywords: Pipe; Cladding; Defect.

1. INTRODUCTION

1.1. Context

The manufacturing of iron pipes has probably begun in Central Europe in the fifteenth century. With the improvement of existing manufacturing processes and the advent of others, the first steel pipe became in an application where high-pressure resistance was required in the beginning of the nineteenth century (8).

Pipes are part of many crucial activities performed currently, including industries, houses, platforms, etc. (5). Thereby, as their branches of application are present worldwide, related researches have been performed in order to gain knowledge about the parameters that do influence their performance under certain service conditions.

In oil and gas applications, pipes in contact with these fluids are required to resist to corrosion for their operation life. Due to this requirement, cladding process has been used as a solution that provides economy compared to a completely Corrosion Resistant Alloy (CRA) pipe (4). However, as cladding process inherently implies defects, a decision turns out to be necessary in order to accept or reject pipes with defects for service execution.

1.2. Importance

In this context, pipes are important due to their role of conducting oil and gas through all their extracting and production chain, from the field to the customer. In general, specifically at industries that make use of pipes to transport products, this system represents 50 to 70% of financial value of all equipment involved (7).

Inserted in the universe of pipes, cladded pipes are mainly used when corrosion protection is a requirement. Up to now, they are an economical alternative to avoid the use of noble materials (CRA) with structural function, applying them only in regions where strictly necessary, thus making the least costly project ([3]).

Therefore, a small defect in the clad layer of a pipe will generate a stress concentration region and a localized corrosion area, probably causing rupture or premature pipe wall perforation in a corrosive ambient through time. In addition, depending on magnitude, disposition and form of defect, it may come to have an efficiency even lower than that presented by a pipe without deposition and a reduced expected lifetime.

1.3. Objectives

The general objective of this paper is to check the mechanical response of a cladded seamless pipe under pressure and tensile loading in the presence of defects related to the CRA layer due to the process of deposition.

The general objective yields into the following specific objectives:

- To obtain von Mises stress at defect region.
- To determine the critical point of the critical defect.
- To simulate different types of defects related to the CRA layer and analyze the effect of each one concerning to stresses.

2. MATERIALS AND METHODS

2.1. Cladding

Fundamentally, it is a process in which a layer of one material covers a layer of another by welding (6). It is commonly used when neither material by itself can provide the desired physical and chemical (deteriorative) properties and/or the cost of applying or manufacturing the pipe of just one material is infeasible.

One of the materials is the base metal, which is primarily selected for low cost and/or structural purposes. The choice of the other metal (layer) is due to provide properties such as corrosion protection, electrical conductivity, magnetic conductivity, etc., which are not present in the desired magnitude on base metal.

2.2. Defects

During cladding process on a pipe, defects appear in an uncontrolled and unorganized way, including different locations, sizes, orientations and densities. API 5LD standard considers that an approximated elliptical defect must:

- Be greater in size than an approximate ellipsoid of minor axis of 1/16 inch and major axis of 1/8 inch.
- Have a minimum separation to its adjacent defect of 2 inches.
- Present a maximum number of three unities in any 6 inches.
- Not exceed (in length) one-half the pipe diameter in any direction.

Standard defects are categorized due to their causes into three types: lack of complete penetration of fusion material, cracks and incomplete fusion (the most common cause in this type of process) (1) (2). Their localization can be inside, outside and mid-wall according to Figure 1.

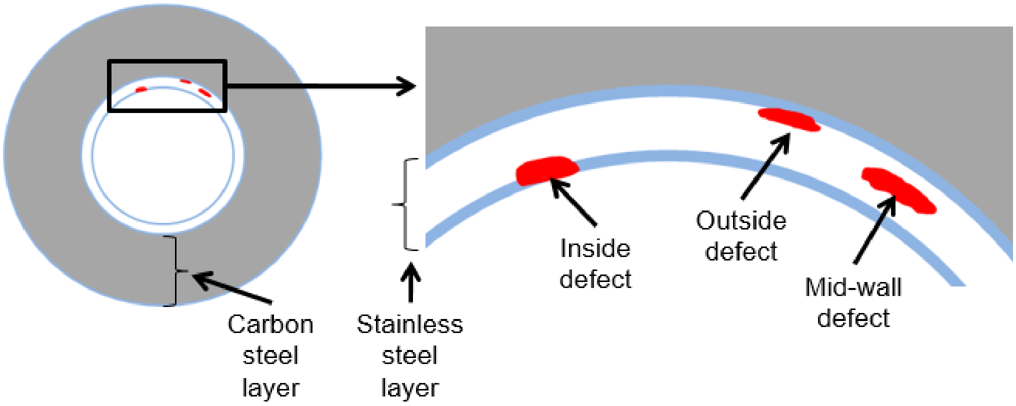

Figure 1 – Localization of defects.

2.3. CAD and FEM Modeling

Figure 2 was generated in Solidworks® software, and represents a half of a cladded seamless pipe (due to symmetry of loading and geometry) with the three types of defect localization (shown in enlarged detail view). The welding deposition (yellow part) has an internal diameter of 13 5/8 inches and a thickness of 1/4 inch and it is constituted of AISI 316L material, which yield strength is 290 MPa. The carbon steel pipe (the green one) has, respectively, internal and external diameter of 14 1/8 inches and 16 5/8 inches and it is made of AISI 8630 material, which yield strength is 385 MPa. The length of both parts is 31 1/2 inches and the materials behave as an elastoplastic model with an elastic modulus of 210 GPa and a tangent modulus of 10 GPa presenting kinematic hardening, i.e., the material becomes anisotropic as a result of the hardening process.

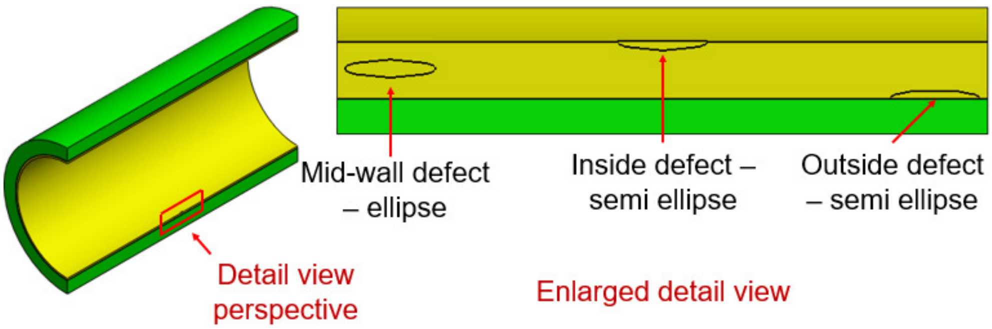

Figure 2 – Localization of defects.

The three defects were modeled as ellipsoids and semi ellipsoids, having major axis of 10 mm (greater than the maximum allowed of 1/8 inch) and a minor axis of 2 mm. They are contained within 2 3/8 inches length (lower than the minimum allowed of 6 inches). In addition, the distance between them is 1 3/16 inches (lower than the minimum allowed of 2 inches). Thus, according to API 5LD standard, for these three reasons these are considered defects.

The problem, modeled in accordance with the boundary conditions, is solved using the Finite Element Method (FEM). Figure 3 illustrates meshes performed along structural pipe and layer, using the tetrahedral element in the entire model with refinement at the edges (stress concentrators) of defects.

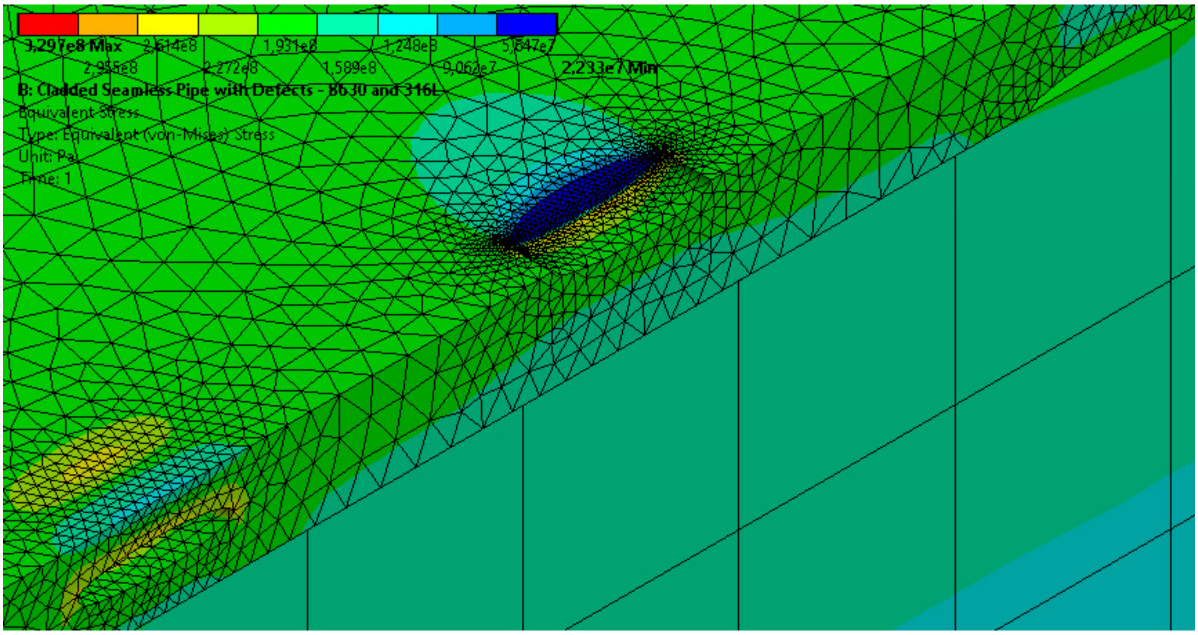

Figure 3 – Discretization of assembly.

Figure 4 shows the components, pointing out the restrictions and the applied loading. The assembly is subjected to 5ksi internal pressure and a 15 kips tensile load. The cladded seamless pipe is free to displace along the longitudinal z-axis and transversal y-axis and is fixed related to transversal x-axis.

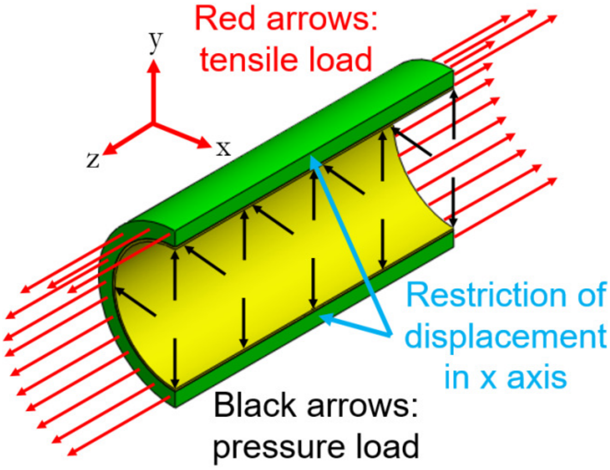

Figure 4 – Restriction and loading of assembly.

3. RESULTS AND DISCUSSION

Von Mises stress results are shown for the assembly in Figure 5, obtained from ANSYS® software. Defect region is augmented in order to show the distribution behavior. By analyzing this region, it is possible to determine its critical points (that reflect the stress concentration phenomenon) and quantify the responses of inside, outside, and mid-wall defects.

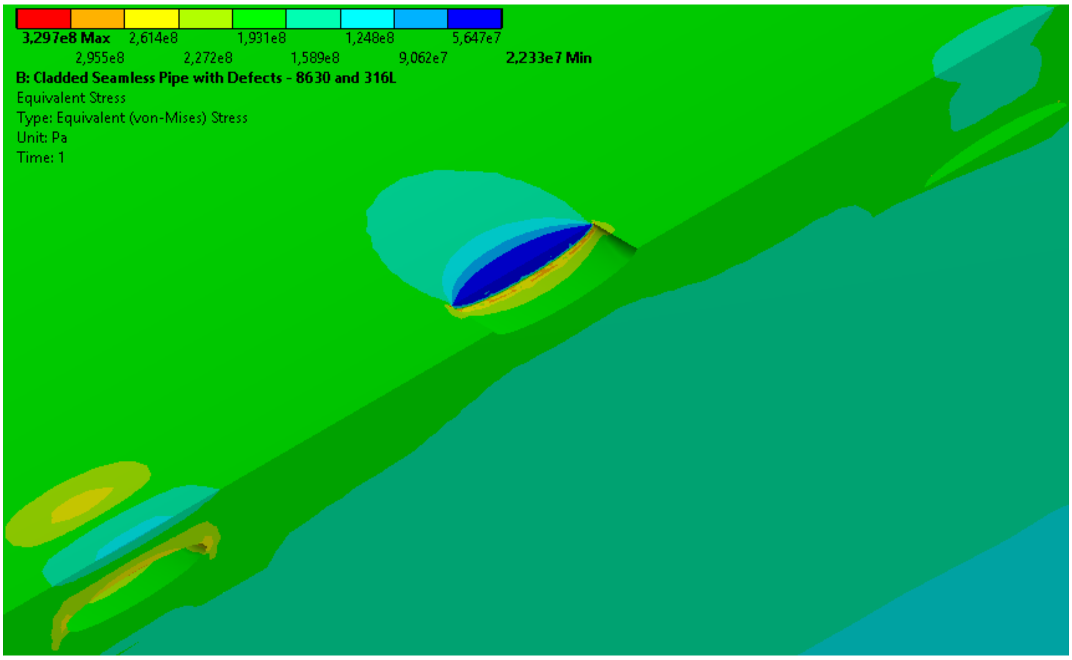

Figure 5 – Von Mises stress at defect region.

The distribution of stress in the course of each defect edge is given, respectively, by figures 6, 7, and 8.

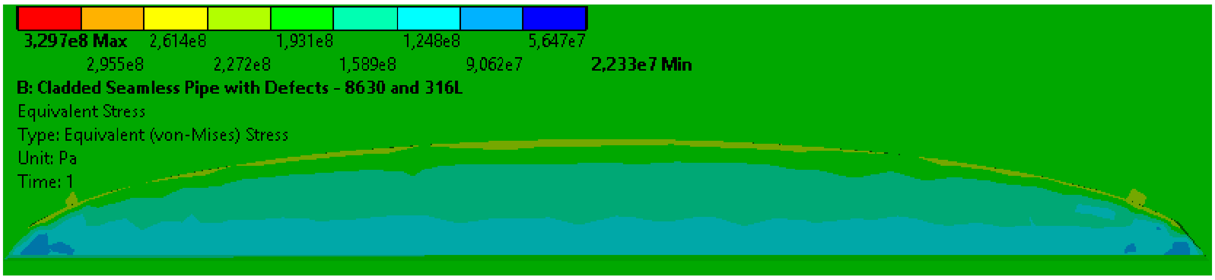

Figure 6 – Distribution of stress on outside defect

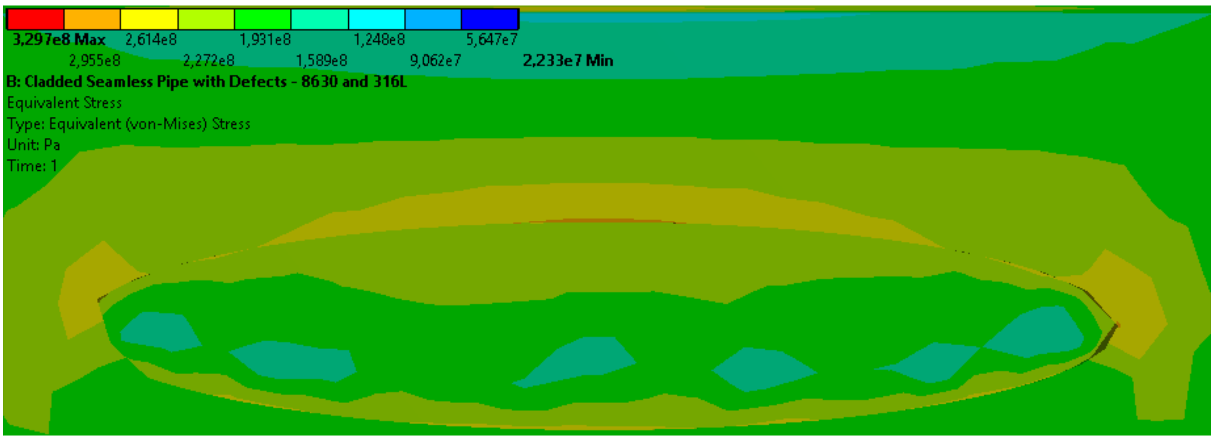

Figure 7 – Distribution of stress on mid-wall defect.

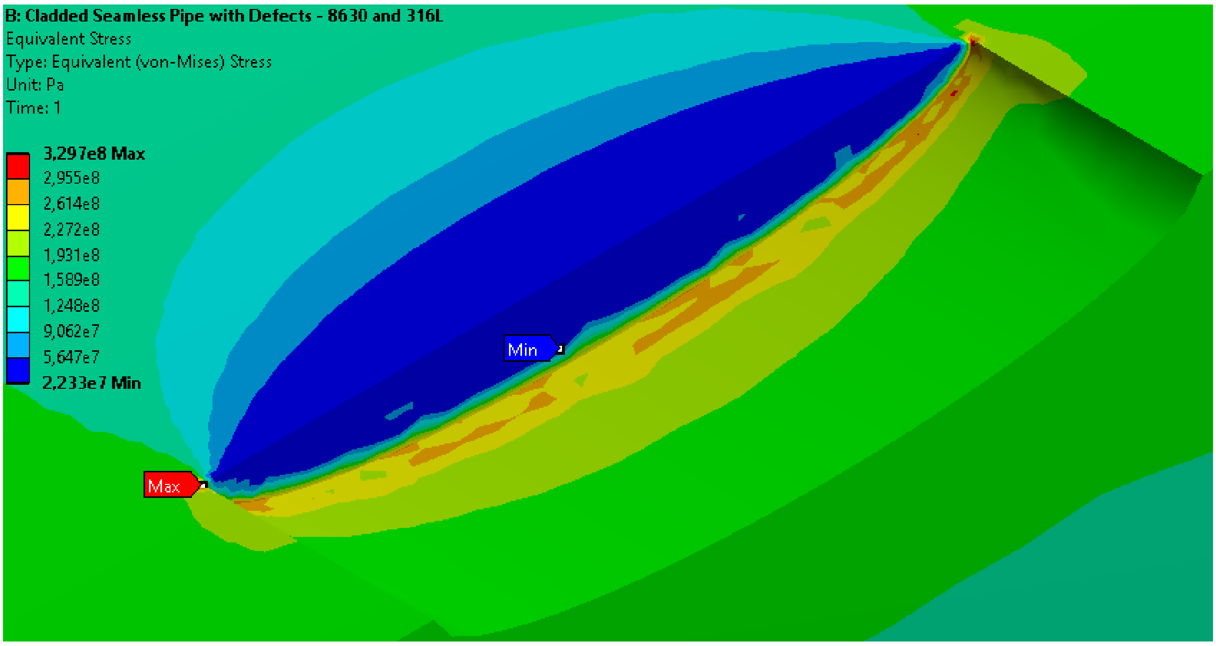

Figure 8 – Distribution of stress on inside defect.

As expected, it can be noticed that the inside defect, exposed directly to pressure, presents the greatest levels of stress (peak of 329,7 MPa), being its edges (red region around the "Max" label of Figure 8) the critical parts, surpassing the value corresponding to yield strength of cladding material (290 MPa). However, a simple visual inspection can detect this kind of defect and thus it can be repaired.

Different history occurs with the mid-wall defect (Figure 7). Although it does not have the same magnitude of stress, its peaks reach levels slightly higher than the yield strength of cladding material, i.e., the material plasticizes until it reaches a new condition of equilibrium. In addition, it is more difficult to identify, depending on its position. The case of outside defect is manageable because its stress levels do not reach considerable values when compared to the yield strength of cladding material, representing only a lack of adhesion between the carbon steel and the stainless steel.

4. CONCLUSIONS

According to what was presented in this paper, defects are inherent to cladding process and they may occur at internal diameter (inside defect), mid-wall and/or external diameter (outside defect) of CRA layer. The former, as expected, due to direct exposure to internal pressure, is the critical one concerning to stresses, besides being relatively easy to identify. Although the latter is also a stress concentrator, it presents the lowest levels of stress because of its localization related to the application of internal pressure. Among the three types of defect, mid-wall is the most alarming because it presents levels of stress that surpass the yield strength of CRA in regions shown and it is somewhat difficult to identify and localize.

The results point out that between tensile and pressure loadings, the most contributor to the stresses is the latter because CRA layer is in direct contact with pressure. The former loading does not influence much due to the fact that structural pipe carries most of the tensile load.

Thus, the conclusion is that defects located at mid-wall CRA are critical to the integrity of the assembly not only because of the stress levels involved, but also for the difficulty of inspection inherent to its localization. In addition, within the circumstances described in this paper, pressure loading is more significant than tensile loading due to the magnitude of stress at the defects in the cladded seamless pipe.

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