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Interaction Effect of Pressurized Lamination Pipe by using 2D Finite Element Analysis

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Abstract. The availability of the multiple sites is often observed in pipeline and their interaction and coalescence may significantly affect their life. In this paper the finite element method has been used to study the effect of pressure defect on the stress field and their interaction in the interlaminar region. The effect of the crack size and the pressure defect will be investigated. The results are presented as the evolution of the stress field in the interlaminar region as a function of the pressure defect. It is observed that for two cracks with equal length, the pressure inside the lamination give greater value than those for unequal length

1. Introduction

There are many ways of practical application in which the pipe experience complicated loading. In general, cracks may be found on either the inner surface or the outer surface of a pipeline, which are called internal and external cracks or surface cracks, respectively. The surface cracks can be generated by different reasons, for instance the corrosion in the case of chemically corrosive fluid outside the pipe such as in presence of wet hydrogen sulphide. The hydrogen atoms attempted to attack the metal matrix in pipeline and join together to form hydrogen molecules. The accumulations of hydrogen molecules can cause the buildup of internal pressure at this site thus forming a larger crack.

Zacaria [1] proposed the pressure mechanism; where the incremental of the internal pressure in the lamination which leads to the interaction of the stress field as shown in Figure 1. Iino [2] reported that the formation of internal blister caused by the hydrogen precipitation at an inclusion interface. This followed by the formation of the blister crack array by cracking the region connecting the blister through the action of internal and the external pressure.

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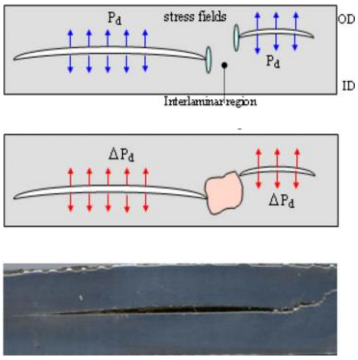

Figure 1: Schematic representation of the formation of a step wise cracks by pressure mechanism. (P_d = Pressure on defect)

This situation when there exist the pressure defect in the crack may increase the risk of unexpected and catastrophic failure during their nominal services. Furthermore the available design code may not reliable to assess these multiple cracks due to conservative method.

There are several methods for assessing the structural integrity of structural component that exist multiple cracks. These include body force method, boundary element method and. finite element method. Murakami [3] and Miyazaki [4] were among the first researcher who presented the stress intensity factor for coplanar surface cracks. Later, Jiang [5], Raju [6] and Moussa [7] employed the 3D finite element method to calculate the stress intensity factor for finite plate. Kirkhope [8] studied the stress intensity factor of coplanar cracks in cylindrical configuration. In this present paper, finite element method will be used to analyze the multiple non coplanar cracks in cylindrical configuration by considering the pressure on defect. The interaction effect in the interlaminar region will be investigated.

2. Material Properties

The material used for this paper was API X65. A true stress strain curve for this API X65 is shown in Figure 2 and the mechanical properties are tabulated in Table 1.

Table 1: Mechanical Properties of API X 65

	465 MPa
Ultimate strength	563 MPa
Elastic modulus	210 GPa
Poisson ratio	0.3

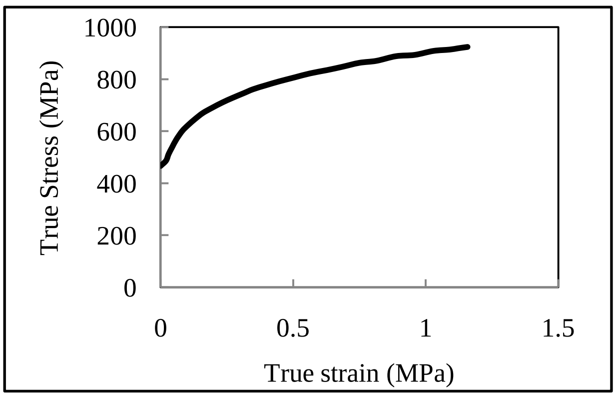

Figure 2: True stress strain curve for API X65

3. FE Modeling Conditions

In this study one quarter of the pipe was model due to an advantage of the symmetrical and to reduce the computation time. Two non-coplanar cracks was model by using MSc Marc. The pipe diameter was 610 mm and the wall thickness was 25.4 mm. The geometrical model was shown in figure 3 including the detail refinement mesh in the interlaminar region.

The boundary condition was applied both at the end of the pipe to allow free expansion. The operational pressure of 1.72 MPa was applied to the inner surface of the pipe. The load defect, P_d was pressurized until the interlaminar region become fully yielding. The dimensions of the pipe and the cracks are summarized in Table 2.The parameter varied in the model are shown in figure 5 and described as follows:

- Curvature of the defect on the right side, r_r
- Curvature of the defect on the left side, r_l
- Vertical separation, d_y
- Horizontal separation, d_x
- Pressure on defect, P_d
- Operational pressure, P_o

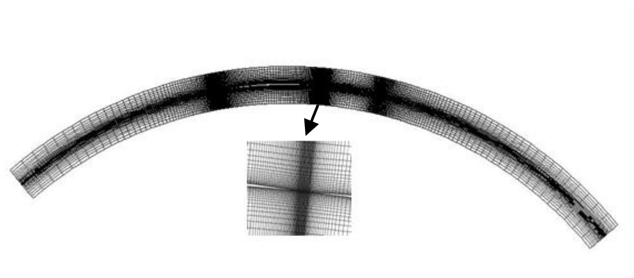

Figure 3: Geometrical modelling and mesh refinement in the interlaminar region

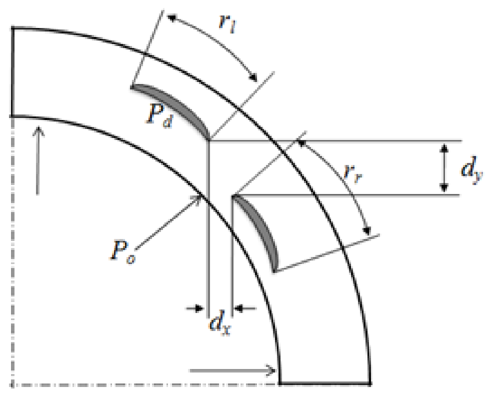

Figure 4: Variables of the model

Table 2: The crack geometry and parameter of the crack

Case number (CN)	r_l (mm)	r_r(mm)	d_x (mm)	d_y (mm)
1	6.35	6.35	0.7937	0.7937
2	38.1	19		
3		38.1		
4		63.5		
5	63.5	19		
6		38.1		
7		63.5		
8	89	19		
9		38.1		
10		63.5		

4. Results and Analysis

All the cases of study behaved in similar fashion. Due to that, the results of stress distribution for one case study are presented and described. The case described is CN 2, with dimensions given in Table 2.

4.1Effect of pressure defect and operational pressure along the crack path

The effect of zero pressure defects was shown in figure 5. It is observed that as the operational pressure increase the stress increases. The maximum stress occurs at the inner and outer crack tip and it was reduced at the midpoint. Figure 6 shows the similar fashion with the presence of pressure defect.

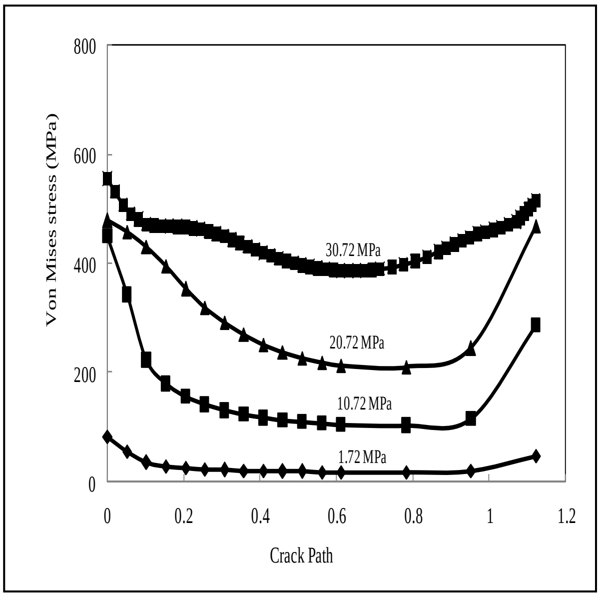

Figure 5: Stress distribution along the crack path without pressure defect in the interlaminar region

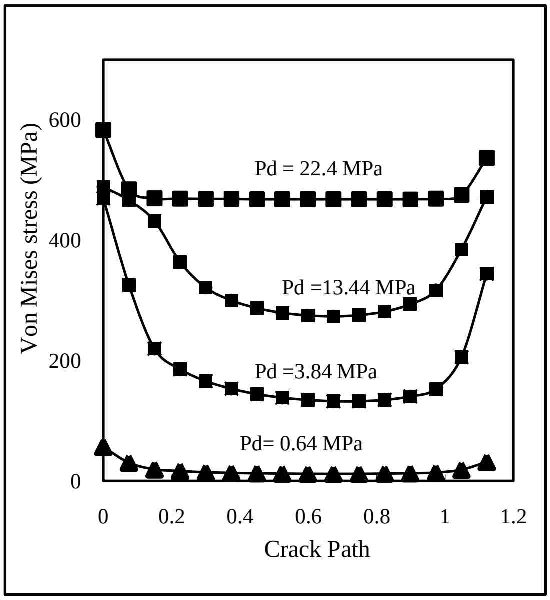

Figure 6: Stress distribution along the crack path with pressure defect in the interlaminar region .Operational pressure = 1.72 MPa

4.2 Stress field in the interlaminar region

The von Mises stress distribution for various pressure steps are shown in Figure 7(a-f). The maximum stress occurred at the internal tip, i.e in the interlaminar region, because this stress is higher than at the external tip. This indicates that there is an interaction of the stress field since the first pressure step. Figure 7(a) shows that at a pressure on defect of 3.82, MPa, there is a noticeable yielding in the at the internal crack tip. The von Mises stress increased when the pressure on the defect increased as shown in Figure 2(b and c) but not the entire interlaminar region.

As the pressure on defect increase to 23.04 MPa as shown in Figure 2(d), the von mises stress in the interlaminar region are above yield strength of the material. This region considered fully plastic. Finally, as shown in Figure 2(f), at the pressure on defect equal to 32 MPa, the von mises stress in the interlaminar region passes the ultimate strength of the material.

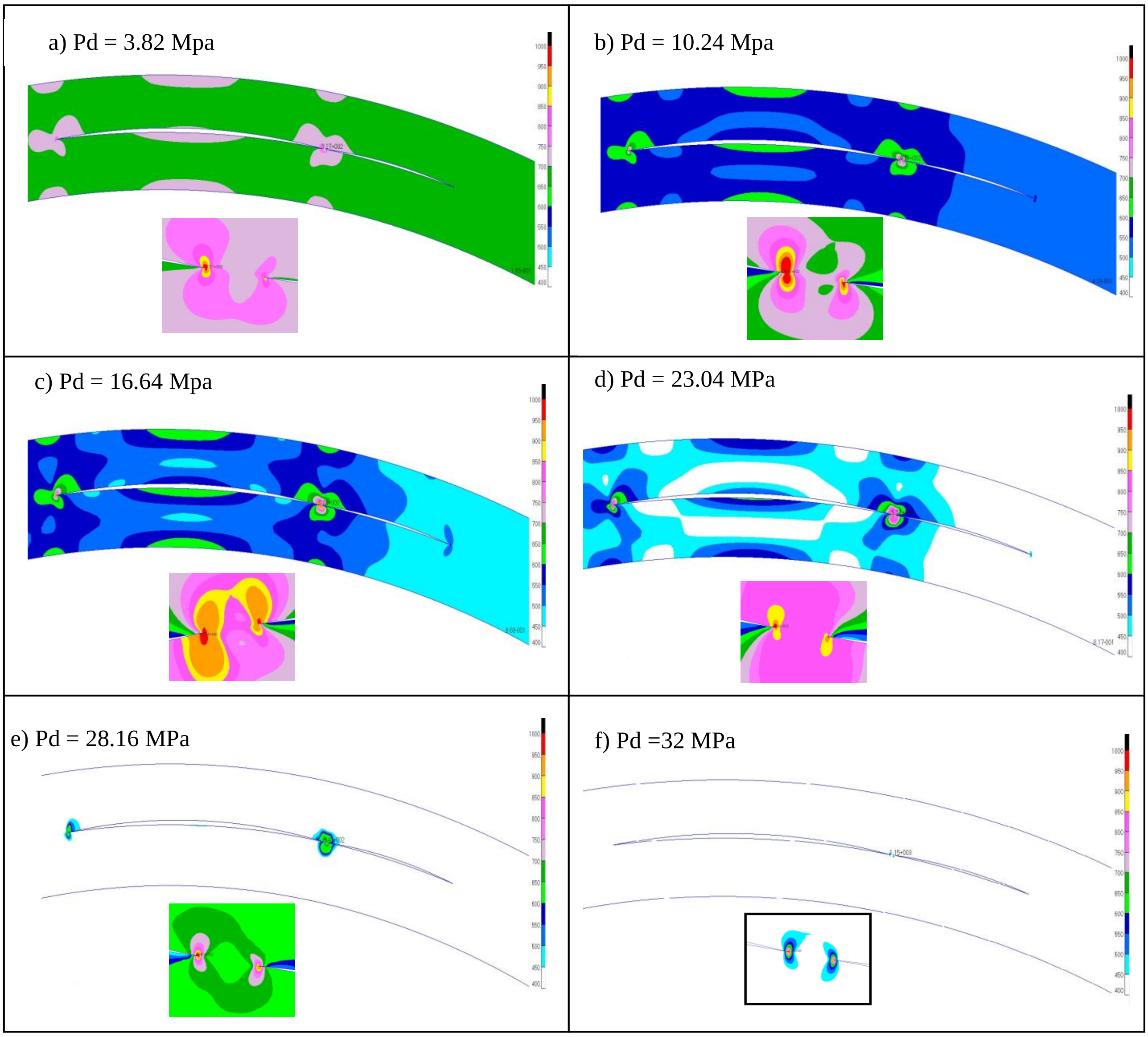

Figure 7: Von Mises stress distribution for various pressure steps

4.3 Variation of Pressure on defect and Von Mises stress

The maximum von mises stress were plotted to determine and analyze the mechanical behaviors of the material the in the region where the crack interact. By doing this, the transitions from linear to nonlinear behavior, i.e. the onset of the plastic deformation and the value of the critical lamination pressure can be observed. The critical lamination pressure is defines as the pressure in the interlaminar region when the von mises stress in the interlaminar region reach or surpass the ultimate strength of the material.

Figure 8 shows the maximum von Mises stress in the interlaminar region as a function of the pressure on defect for case 1 where the r_l is equal to r_r. In this case, the pressure that causes the interlaminar region reach or surpasses the ultimate strength of the material was 148 MPa. Figure 9 shows a reduction of pressure on defect almost 86%. For case 2, 3 and 4, the $r_l$was 38.1 mm and r_r increase from 19 to 63.5. It is shown that in case 3 where the radius of defect is similar, the pressure on defect slightly increases. The pressure on defect in case 4 is reduced to 14.72 MPa as the radius of crack become greater.

In case 7, it is obvious that the pressure on the defect was greater than in case 5 and 6. This is because the radius of defect on the right side becomes similar with the left side which is 63.5 mm. The pressure on defect decrease from 9.6 MPa to 7.4 MPa when the r_r increase. However for case 7 and 10, the pressure on defect reduces from 16.8 MPa to 9.6 Mpa. Figure 11 shows the variation of pressure on defect for ri equal to 6.35, 38.1 and 63.5. Obviously, the crack with size 6.53 mm, has greater pressure in defect as compared to the others. When the crack length increase from 38.1 mm to 63.5 mm, the pressure on defect reduce from 22.3 to 16.8 MPa. In reality, it difficult to have the crack with similar size.

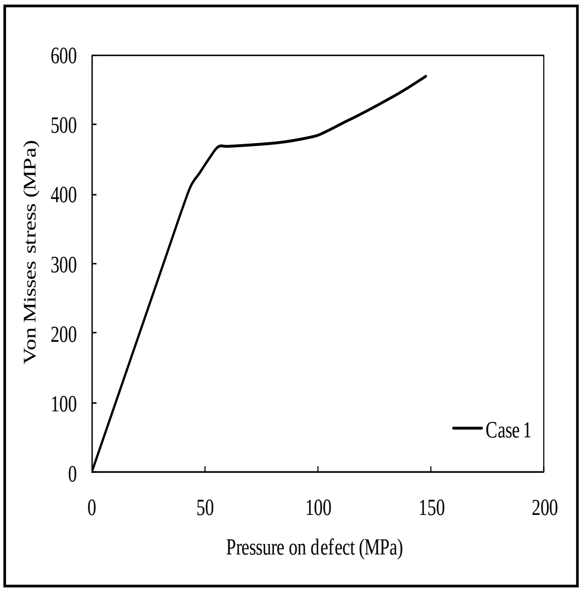

Figure 8: Maximum von Mises stress in the interlaminar region as a function of the pressure on the defect for Case 1, r_l = 6.35 mm

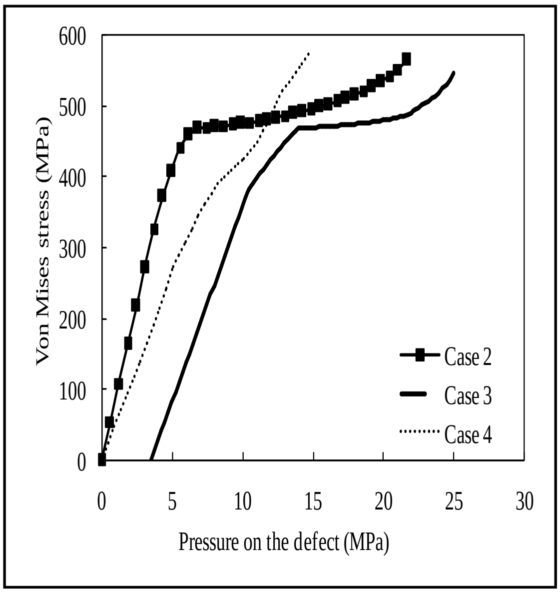

Figure 9: Maximum von Mises stress in the interlaminar region as a function of the pressure on the defect for r_l=38 mm

Figure 13 shows the maximum von mises stress in the interlaminar region for three equal crack length, 6.35 mm, 38.1 mm and 63.5 mm. The pressure defect for r_i equal to 6.35 mm, gives the higher value than larger cracks.

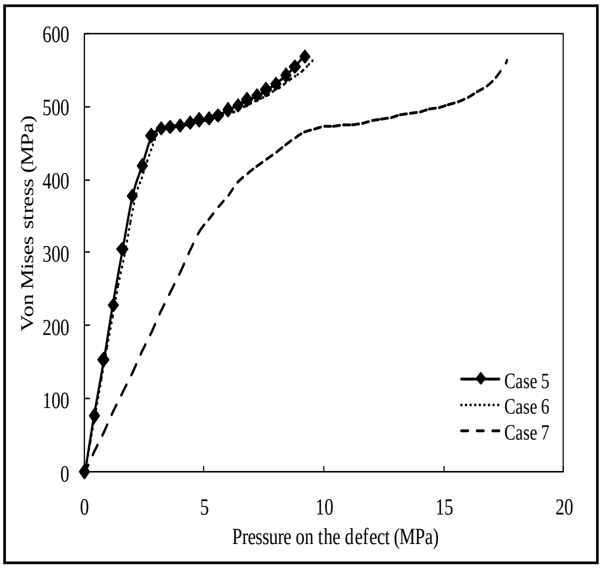

Figure 10. Maximum von Mises stress in the interlaminar region as a function of the pressure on the defect for r_l=63.5 mm

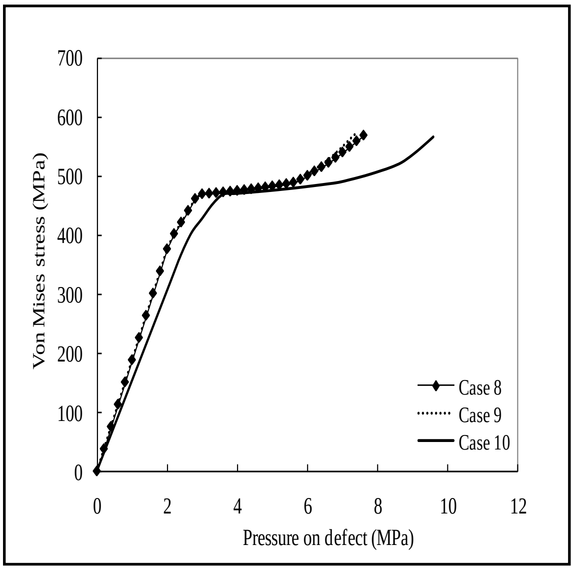

Figure 11. Maximum von Mises stress in the interlaminar region as a function of the pressure on the defect for r_l=89 mm

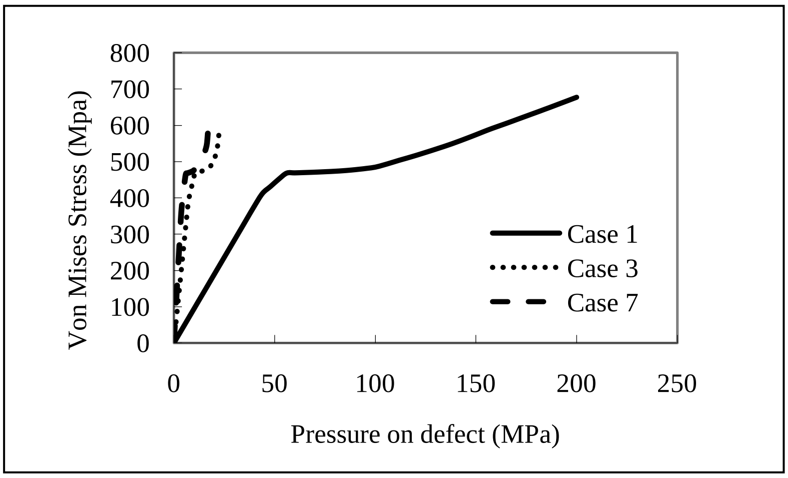

Figure 13. Maximum von Mises stress in the interlaminar region for three equal cracks.

5. Conclusion

The stresses at the internal crack tips are higher than at the external crack tip. This indicated that there is an interaction of the stress field since the first pressure step inside the lamination. The interaction of the stress field of two approaching non coplanar pressurized cracks will be higher and therefore will produce higher stresses as the cracks become similar size.

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