Numerical/Experimental Analysis of the Deformation of Tubes under Concentrated Load

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Abstract
Distortion and deformation of tubes during machining operations are very important. In this study, a tube used in magnetic drum separator under concentrated load (machining load) is considered. Using finite element simulation, deformities and their dependence on parameters such as the thickness of the tube and the place of concentrated force are observed and predicted. To compare and confirm the results, some experimental tests are considered. The results show that there is good agreement between the numerical and experimental data. The results of this study indicate the amount of residual stress in the tube by changing the location of the load, the effect of residual stresses in the tube, indentations at different levels of thickness and location of the load. Results show that the values and location of force affect the stress and residual stress in the thickness of tube. In addition, increasing the thickness of tube decreases the residual stress area in longitudinal and circumferential direction of tube. Also, the maximum residual stress in tube is occurring under the force area and by increasing the thickness of tube, the displacements of area under the force is decreased.

Keywords
Tube, Finite Element, Plastic Deformation, Residual Stress, Machining Force

1. Introduction

The deformation of tubes, rod and cylindrical shapes under machining force is very important for precision device such as magnetic drum separator used in mines. Many studies have been conducted by various researchers on the deformation and stress in tubes. Such studies have been performed in analytical or experimental method or with simulation method by finite elements software. Dvorkin and Toscano [1] analyzed the behavior of pipes in industry by finite element modeling. Tang [2] worked on further researches in this field and investigated the relationships between various parameters of the pipe in its plastic deformation. Elchalakani et al. [3] studied the analysis of the tubular rotational plastic deformation. Toscano et al. [4] investigated the pipe failure under an intense external pressure by practical tests and the finite element simulation. Yoshida and Kuwabara [5] worked on the critical stress in the steel pipes exposed to the loading direction and found out that the critical stress is completely independent of the direction of loading. Zeinoddini et al. [6, 7] examined a numerical method on the effects of the pipe's failure and exposure with the preload, and also they investigated the same effects experimentally. Ozkan and Mohareb [8] investigated the deformation of the thick steel pipe under various loads including biaxial bending force, biaxial shear force, rotational force, axial force, and internal/external pressure, and the results they obtained were in good agreement with the peak load obtained from the analytical results. Mohareb et al. [9] studied the behavior of the steel pipes under different loads. They conducted these studies using Abaqus software and the obtained results were in good accordance with their experimental results. Liu and Francis [10] investigated quasi statically the denting effect of pipe caused by external forces. They found out a simple relation between the external force and the maximum depth of the dent. They proved these results both in an analytical and finite element method. Al-Qureshi [11] worked on the analysis of the elastic and plastic deviation of the pipe and introduced an equation to predict the residual stress. Hyde et al. [12] investigated the analysis of the stress in pipe due to the large fluctuations in the external pressure and the observations of residual stress. The effects of the backup situations, the amount of pressure, and the wedge radius of the finite element method were investigated resulting in a semi-empirical formula developed to predict the residual stress changes in the pipe. In another study, Hyde et al. [13] completed the formula to predict the stress and studied the effect of the residual depth of dent, the internal pressure, the wedge size and various materials' properties on the residual stress for different pipe with greater parameter sensitivity. In a numerical study by Brooker [14], the pipe under lateral force was investigated In this paper, it was dealt with a parametric study on the effect of the wall thickness, the pipe's length and diameter, and the stress, and it was introduced an equation to predict the depth of the dent. They also presented a finite element model to be compared with the numerical results. Karamanos and Andreadakis [15] studied the synchronic effect of the internal and external pressure. They showed that the internal pressure significantly increases the strength of the denting force. Kyriakides and Lee [16] examined the effect of the long-term residual stress on the collapse of the flawless plastic pipes under the pressure.

In this paper considering a tube under machining concentrated force such as the lathe force, the residual stress and the effects of the force concentrated on the steel tube, and its relation with the parameters such as tube thickness and the location of the loading are investigated.

2. Problem and Material Definition

In the production process of the magnetic drum separator with tube machining, it is important that the tube under machining force has least permanent deformation. This deformation is important because the gap between the tube and magnetic parts has more influence on the power of drum separator in separation the iron from the material in iron ore mines. This gap and its effect on separation are presented in Figure 1.

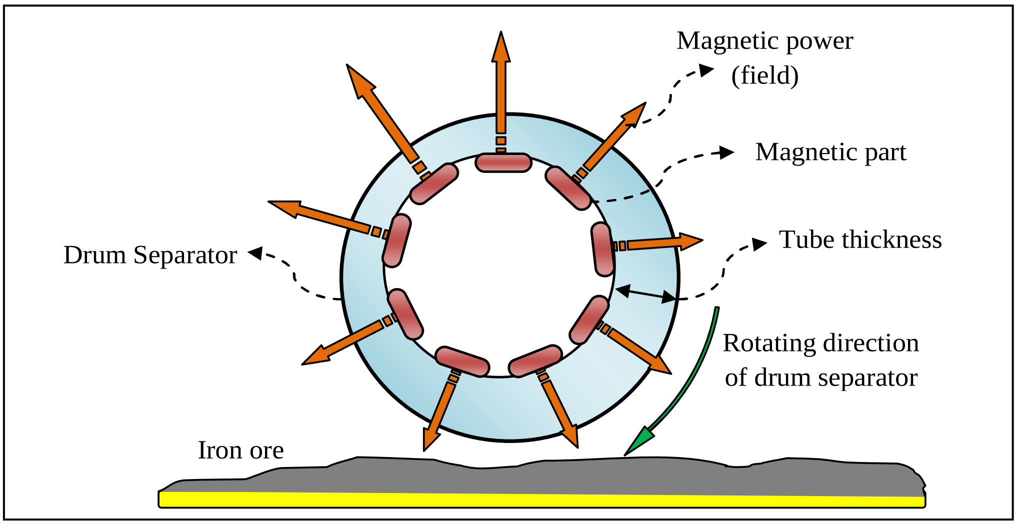

Figure1. The effect of magnetic gap on separation the iron from iron ore

So, it is very important to study the applied changes and the residual stress after machining operations on the tube. In this paper, one type of tube subjected to concentrated load along the length of tube is considered. The dimension of tube is presented in Table 1. All tubes have the same outer diameter and length and the inner (thickness) of tubes are varied.

Table1. Dimensional models analyzed

No.	Tube length(mm)	Outer radius(mm)	Internal radius(mm)
1	1000	114.3	53.15
2	1000	114.3	52.15
3	1000	114.3	50.85
4	1000	114.3	49.15

For material property, the SS-316 is considered for tubes and the mechanical properties are listed in Table 2. The material properties are considered independent in temperature. This kind of steel is commonly used for magnetic drum separator. In Figure 2 schematic of the model and loading areas mesh size in ABAQUS software can be observed. In finite element formulation, the element ‘‘C3D8R: An 8-node linear brick’’ is considered for plates. The boundary condition is considered as fix-fix at end of the cylinder.

Table2. The mechanical properties of the tube

Property	Value
Yield strength(MPa)	170
Density(Kg/m^3)	8000
Modulus of elasticity(GPa)	193
hardness (HB)	217

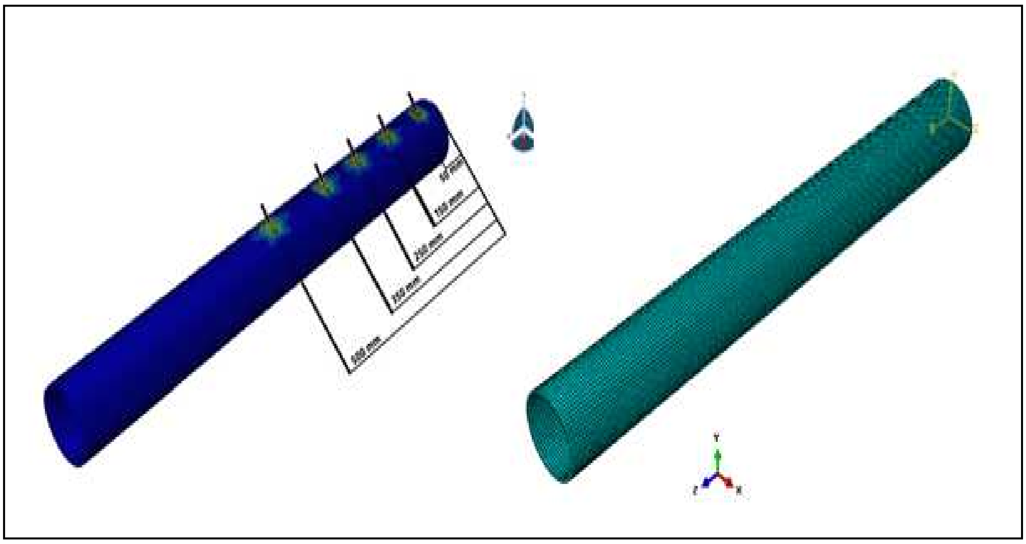

Figure2. Schematic of model and mesh model

To simulate the steel tube under concentrated load with finite element, using three-dimensional modeling, the forces were applied up to the half-length of the tube because of the symmetric of the model. In this simulation, the two sides of the model are quite constrained. The force was applied to five points of the tube, with the distances 50, 150, 250, 350 and 500 mm from the head of the tube. The forces were applied in all four models as follows: the force applied to the distance of 50 mm, from the head of the tube, transformed the model into a plastic status, and then the same force was applied to other points. Also, the simulation was performed in two steps because of the examination of the residual stress in the tube, loading/unloading.

3. Results and Discussion

After the steps of the simulation, the results are presented as applicable diagrams. The changes in the stress along the tube are showed in Figure 2. It can be seen from this figure that by moving the loading point away from the support, the residual stress is increased. Also by increasing the thickness of tube, the residual stress is decreased.

It is observed also from Figure 3 that the residual stress is less at the point under the force applied on than the surrounding of the loading point and the amount of this stress differs further from its surrounding by the increase in the tube thickness.

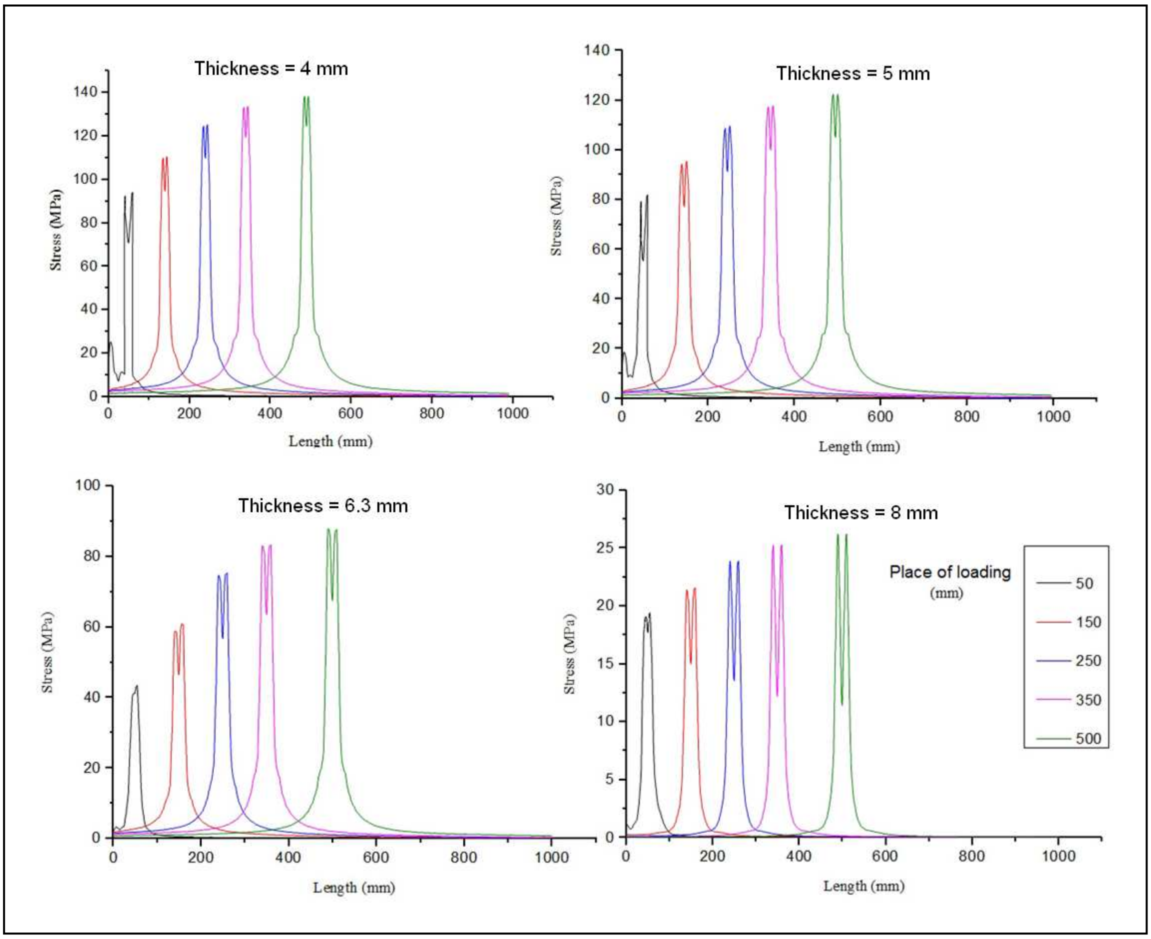

Figure3. changes in residual stress in tubes with diferent thickness

Figure 4 shows the permanent displacements in tubes by various loading point. It can be seen from this Figure that the permanent displacements are increased by moving the force away from the supports. Also in low values for thickness of tube, the permanent displacements increased with a constant force, and by moving the force far away from supports the displacements values are increased rapidly.

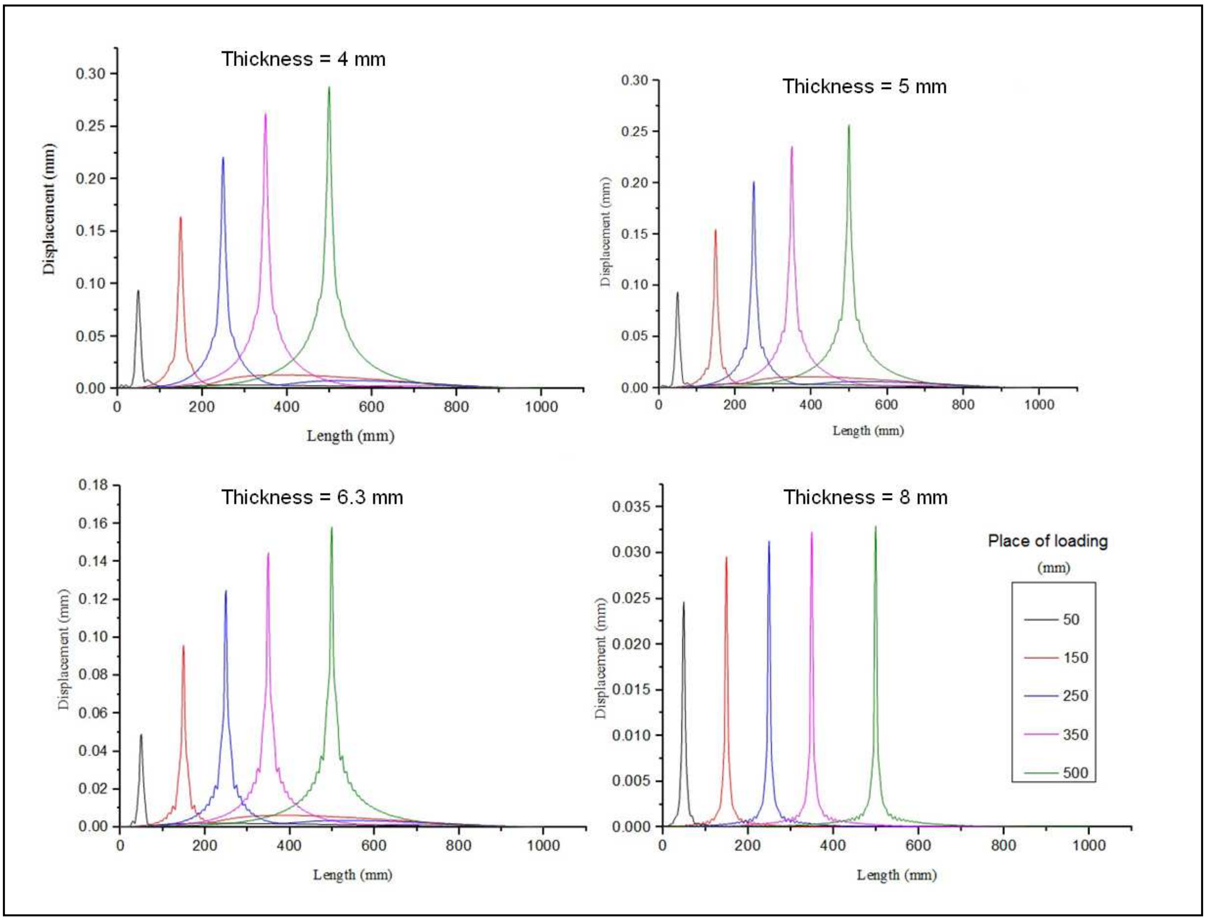

Figure4. changes in permanent displacement in tubes with diferent thickness

To consider exactly the values of the residual stress and the displacement in the tube, these values were also calculated at the tube circumference direction where the force is applied and to understand more accurate and better, the diagrams were drawn in polar form.

Figures 5 to 8 show the changes in residual stress at the circumferential direction of tube at load location where the force is applied. As shown in Figure 5, at the thickness 4 mm. the peak of the residual stress is at the point where the force is applied, and by moving away from the support at an angle of 10 degree along circumference direction, the residual stress is increased. This event is occurred for each tube with various thicknesses as shown in Figures 5 to 8. Figure 6 shows also that the maximum of the residual stress effect is at the degree of 10 along the circumference direction from the loading point.

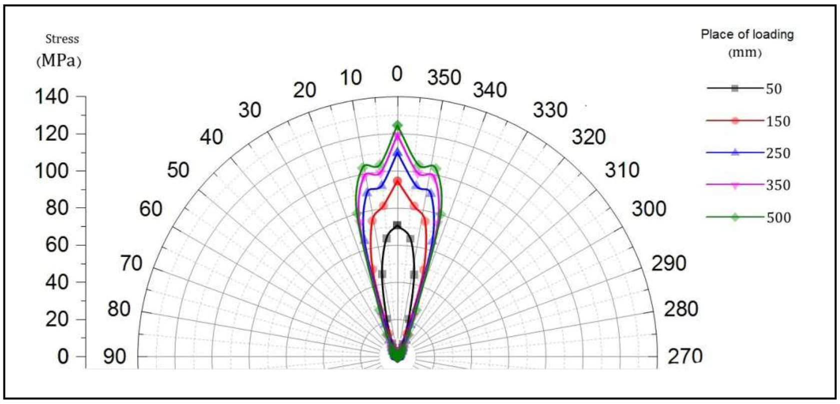

Figure5. residual stress changes in the circumferental of tube - thickness of 4 mm

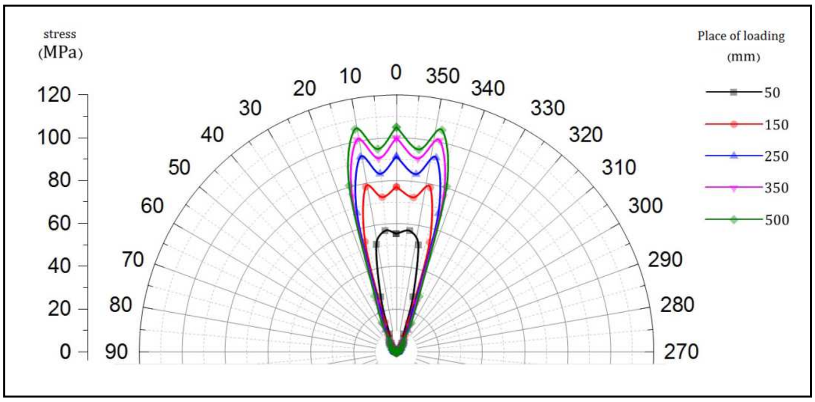

Figure6. residual stress changes in the circumferental of tube - thickness of 5 mm

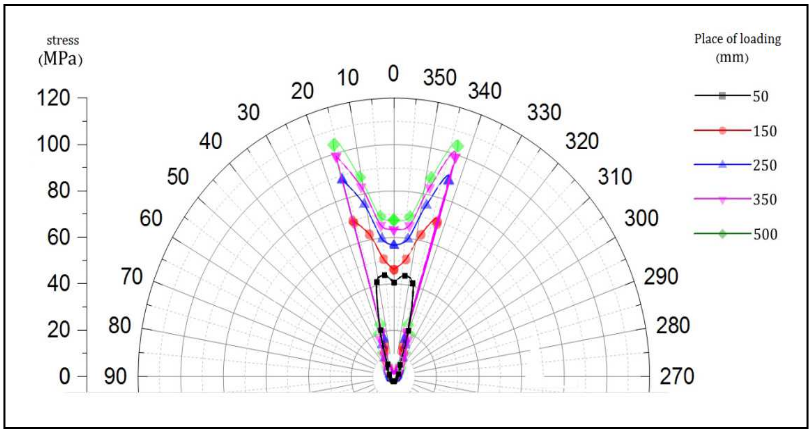

Figure7. residual stress changes in the circumferental of tube - thickness of 6.3 mm

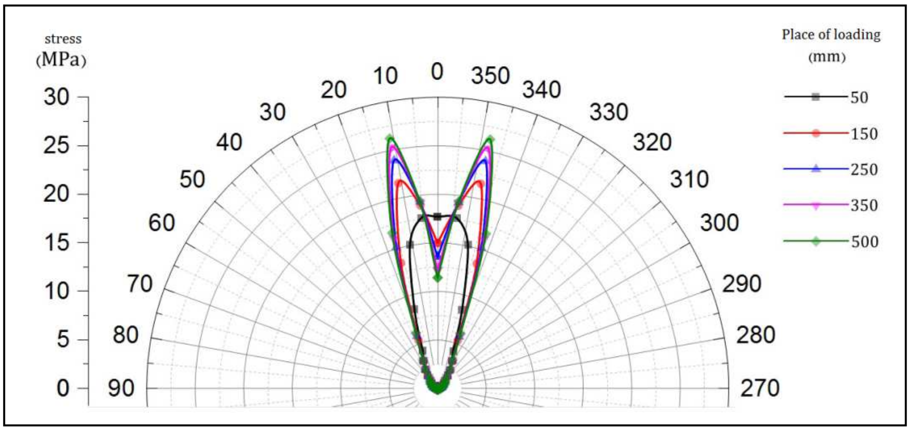

Figure8. residual stress changes in the circumferental of tube - thickness of 8 mm

The changes in the permanent displacements at the circumferential direction of tube are shown in Figures 9 to 12. Figure 9 shows the changes in the displacement at the thickness of 4 mm. It is observed that the displacements are decreased and approached together by increasing the distance from the support up to the middle point of the tube. At all distances in these changes, the maximum displacement is observed at the point applied the force. The displacements are decreased by increasing the angle, however, the displacements are increased at the angles of 15 to 20 degrees, and thereafter the amount of displacements is decreased. The range of the increase in the displacement is negligible at the distance of 50 mm, and this manner is the same for every thicknesses considered for tubes.

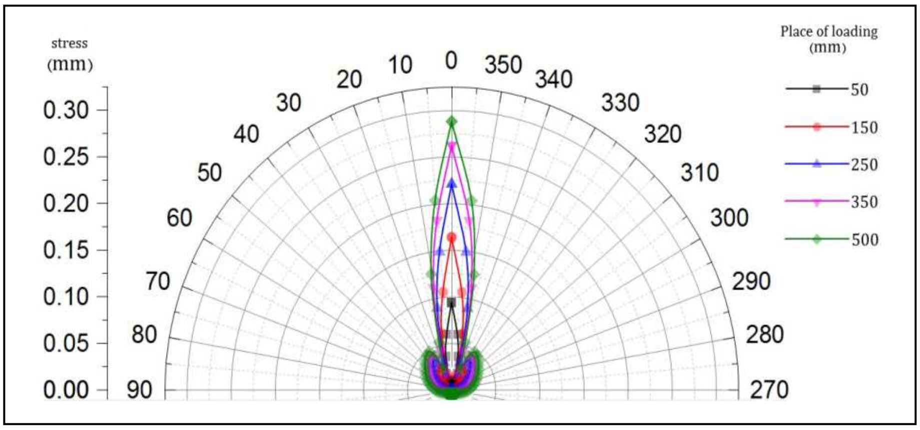

Figure9. Permanent displacement at circumferential direction of tube - thickness of 4 mm

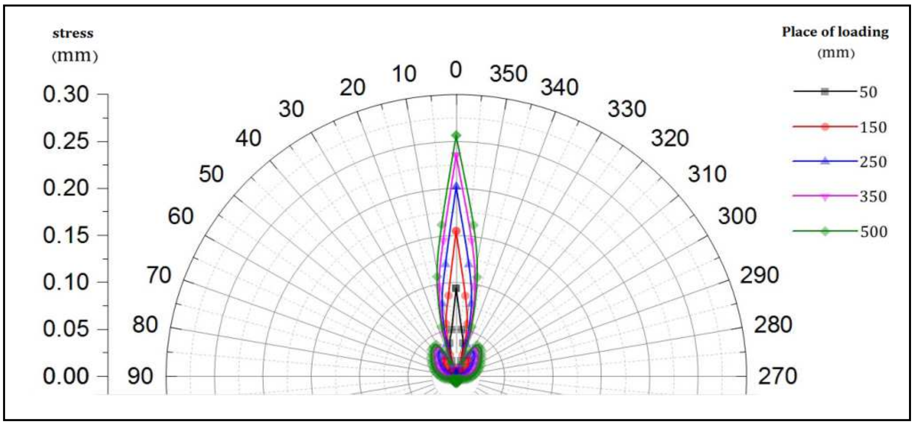

Figure 10. Permanent displacement at circumferential direction of tube - thickness of 5 mm

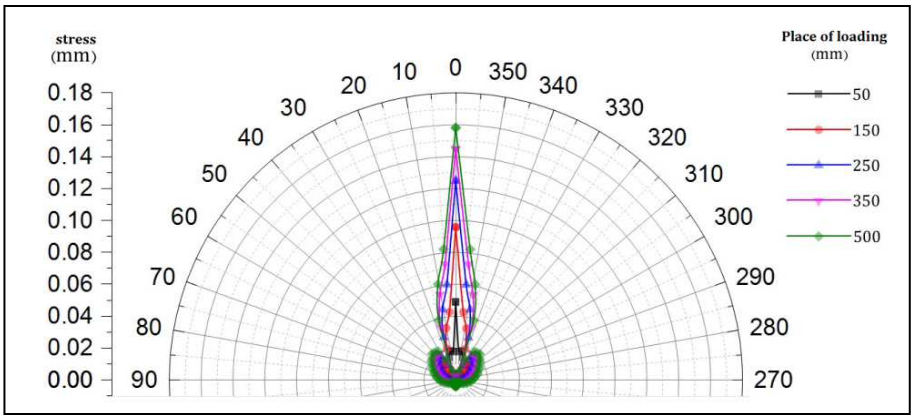

Figure 11. Permanent displacement at circumferential direction of tube - thickness of 6.3 mm

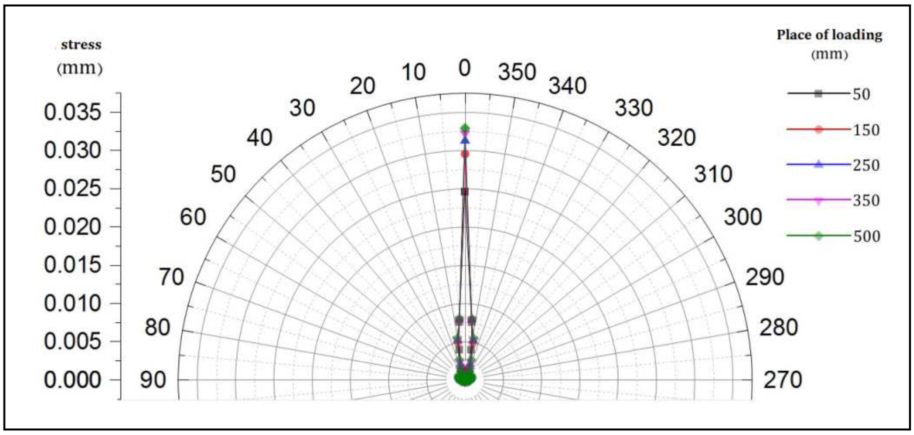

Figure 12. Permanent displacement at circumferential direction of tube - thickness of 8 mm

4. Validating Data Experimental Results

To compare the previous results, some experimental tests are considered for tube of magnetic drum separator. The sample (drum separator) is shown in Figure 13 and is completely bounded in the lathing machine and the force indicated in the software is applied to the experimental model. The strain created in the piece is derivative with strain gauges after applying the force and removing the load. Dynamometer is used to measure the force and the strain of the tube. Moreover, strain gauge and data logger are used. The results compared with FE simulation are shown in Table 3. The results show that there was an acceptable agreement between the results from the software and the experimental test.

Figure20. Magnetic drum seperator tube - Experimental sample

Table3. Comparison of theoretical and experimental results

Strain	Analysis	Test	Error(%)
With force	3.62e-4	3.35e-4	7.34%
Without the force	8.03e-6	7e-6	12.8%

5. Conclusions

This paper investigated the effect of the force concentrated on the tubes and it was observed and examined the effects of parameters such as the thickness of the tube and the point the force applied on, the amount of residual stress and the displacement caused in the tube. These effects were obtained by using finite element and validating by experimental tests. The results and the diagrams also show that the effectiveness of the residual stress is reduced at the length and the circumference of the tube by increasing the thickness of the tube. Also, the maximum of residual stress is created in the tube about the point the force applied. The displacement caused by the force is decreased considerably by increasing the thickness. Also, in addition to the point the force applied, the circumferential displacement starts to grow in the range varying depending on the thickness of the tube.

6. References

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