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ANALYSIS OF FITNESS FOR SERVICE IN DENTED PIPES BY MEANS OF FINITE ELEMENTS: STUDY CASE

Edwin Torres Díaz[1], Saúl Andrés Hernández Moreno[1], Edwin Rúa Ramírez[1], Bladimir Ramon Valencia[2] and Gonzalo G. Moreno-Contreras[2]
[1]Research and Development Group on Engineering in New Technologies, GIDINT, Santo Tomas University, Tunja Section, Colombia
[2]Department of Mechanical Engineering, University of Pamplona, Pamplona, Colombia
E-Mail: gmoren@hotmail.com

ABSTRACT

The oil and gas transmission pipelines used in the petrochemical industry are a very important asset but are in turn exposed to a very high risk due to the various threats to which they are subjected, one of these is third party damage to these pipelines, because the pipes suffer fracture or deformation that affect the integrity of the asset in mechanical characteristics such as strength and hardness among others and operational conditions such as fluid pressure and flow, causing deformations, leaks or in the worst case a break, delays in transport and therefore an increase in the costs of the same This is how the need arose to analyze the suitability for service according to API 579 by means of finite elements in a pipe with dent failure API 5L x70 of 42" diameter, belonging to a pipeline. To this end, the mechanical and operational conditions of the dent failure pipe were defined, the boundary conditions were established in a pipe model and finally the behavior of the pipe was resolved and analyzed by means of finite elements in a non-linear static regime.

Keywords: pipelines, buckling damage, thicknesses.

1. INTRODUCTION

Colombia is the fourth Latin American producer of crude oil and must evacuate some oil it pumps in its fields. According to the above, the oil industry uses different means of transportation of Crude, according to Ballou (2004) cited by Almanza and Pulido. (2009), there are five basic models of simple transport, these are: sea, rail, lorry, air and pipeline.

Nevertheless, pipelines are pipes that carry thick liquids over the ground and, if necessary, under it. It consists of welded sections covered with protectors to prevent premature deterioration and filtration of unwanted materials, (Colpetrol, 2007 cited by Almanza and Pulido, 2009). Products transported by pipelines are limited to liquids, gases and semi-solids; crude and refined oil, petroleum derivatives and dense liquids are currently transported. The capacity of this means of transport is high and can be used 24 hours a day 7 days a week making it an efficient means of transport despite its low speed (approximately 5 to 6.5 kilometers per hour). Installing ducts is costly and makes installation more difficult when they have to cross rivers and mountains. (Almanza and Pulido, 2009, p, 27). On the contrary, as a consequence of third parties the pipes suffer fracture or deformation that affects the integrity of the asset in mechanical characteristics such as strength and hardness among others and operational conditions such as fluid pressure and flow, causing deformation, leakage or, in the worst case, a breakdown, delays in transport and hence an increase in transport costs; This is how the need arises to evaluate these anomalies by applying mathematical models that allow to analyze the suitability for service for the pipe. Jaimes Garcia, M. L., (2017) indicate that in the last 20 years a series of mathematical and analytical methods have been developed to assess pipeline damage. In addition, pipelines are also exposed to time-independent damage, which means that there is no way to predict when an unfortunate event will occur that will affect the integrity of the structure, such as environmental damage, such as tell uric movements, earthquakes, thunderstorms, among others.

Therefore, this investigation is intended to analyze a deformation pipeline for crude oil transport which has a 42" diameter API 5L x70 dent fault pipe, using the recommended practice API 579/ASME FFS-1 Fitness for Service, by means of finite elements, considering the definition of the mechanical and operational conditions of the deformed pipe, the establishment of boundary conditions in a CAD model and finally the calculation and analysis by means of finite elements of the behavior of the pipe in linear static regime and fatigue. SAVIDIS, et. Al, (2011) recommends the use of the finite element method to introduce a diversity of material properties and plasticity effects both in the duct and in the ground, as well as possible non-linear geometric effects. Saúl Hernández et. By (2019) simulation under adjusted parameters as experimental test, allows to see deformations graphically and facilitates engineering analysis.

2. MECHANICAL AND OPERATIONAL CONDITIONS OF THE PIPE

2.1 Visual Assessment

The section of the pipeline shows a length of 5.79 m, with a dent of approximately 200 cm and 120 cm long and wide respectively. The section has a diameter of 42 inches and a wall thickness of 17.74 mm. On the other hand, it has a 4.50 mm thick coating, which is affected by the dent generated by the explosive charge. The hourly position of the pipe is not indicated; the longitudinal welding cord is located 63 cm from shoulder 1 of the dent. The following additional data are described below in the visual inspection:

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Table-1. Results of visual assessment.

Pipe of 42" t= 17,42 mm buckling length = 2700 mm buckling width =1200 mm	% buckling = 45,23% Max diameter= 1250 mm Min diameter= 530 mm depth <= 482,26 mm

Figure-1. Pipe with buckling damage.

2.2 Measurement of Thicknesses

It is performed in the deformed area, measuring thickness by ultrasound, in a grid of 0.39" (10 mm) by 0.39" (10 mm) on the entire deformed surface of the Figure-1 pipe, including the shoulders. The grid of thicknesses shown in Figure-2 is obtained. Three thicknesses are recorded that show a variation of up to 10% of thickness loss in relation to the healthy zone. The thicknesses of zones 1, 2 and 3 with their respective minimum, maximum and average values are presented in Figure-3.

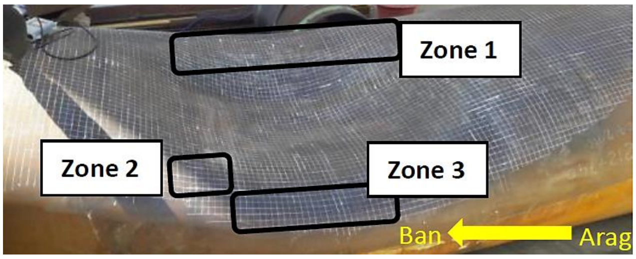

Figure-2. Thickness measuring grid.

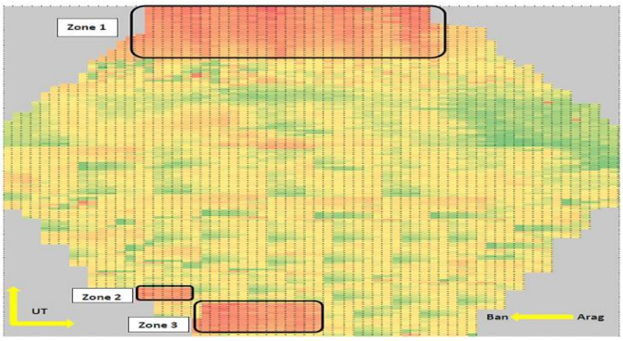

Figure-3. Ultrasonic thickness measurement results.

A minimum thickness of 16.05 mm, a maximum thickness of 17.8 mm, and an average thickness of 17.22 mm are recorded throughout the dent extension. The healthy zone thickness 17.74 mm. From the anomaly grid the thickness profile shown in Figure-4 is extracted.

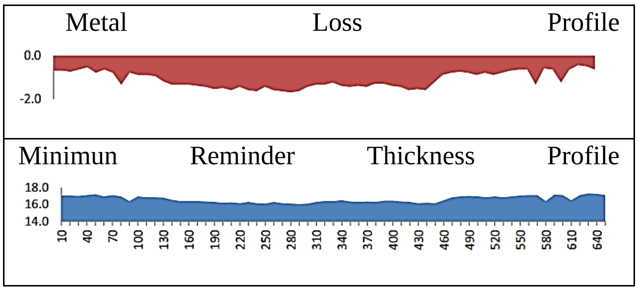

Figure-4. Thickness profile measured by ultrasound in buckling

2.3 Characterization of the Material

For the purpose of determining the mechanical properties of the material, 4 samples located in accordance with the API 5L standard were extracted: 2013 for voltage, 10 tension test pieces located in the dent, and 3 more samples to establish chemical properties, microstructural and hardness of the pipeline material.

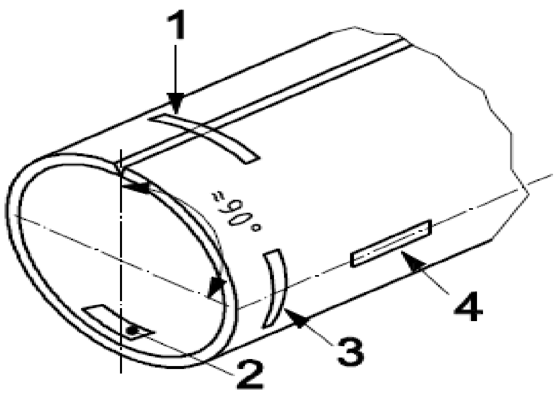

Figure-5. Location of voltage test pieces according to API 5L: 2013.

2.4 Stress Test

The results obtained from the stress test, performed on different samples taken from the pipe section, do not reveal a significant change in the mechanical properties of the dented section relative to the undamaged area. The results are shown in Table-2.

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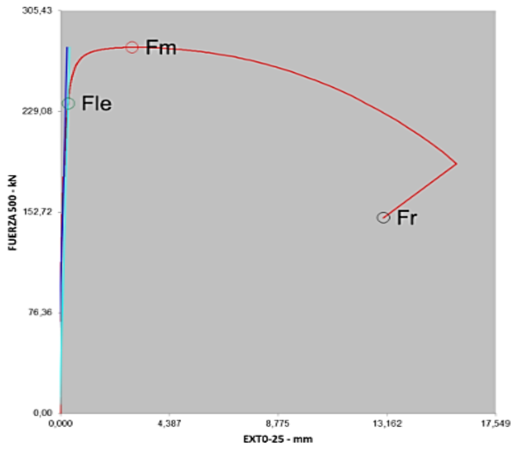
Table-2. Stress test results.

Testing TR1			
			
	Breaking Estrain	Mpa	623,415
	Elastic limit tension	Mpa	528,106
	Module	Mpa	76275,9987
	Maximum strength	Mpa	277,669
	Yield strength tensile	**Tensile strength**	
	528,106 Mpa 76595,29 Psi	623,415 Mpa 90418,70 Psi	
	API5L Grado X70		
	70300 Psi	82700 Psi	

Samples	Yield strength tensile API 5L X70 MPa - (psi)		Yield strength tensile MPa - (psi)	Tensile strength API 5L X70 MPa - (psi)		Tensile strength Mpa - (psi)
	Min	**Max**		**Min**	**Max**	
Tr1	485 (66427.3)	635 (92099)	528,106 -76595,3	570 (82671)	760 (110229)	623,415 -90418,7
Tr2			535,872 -77721,7			636,656 -92339,1
Tr3			593,146 -86028,6			686,334 -99544,3
Tr4			577,815 -83805			620,711 -90026,5
T1			558,813 -81048,9			653,502 -94782,5
T2			549,678 -79724,1			670,053 -97183
T3			574,091 -83264,9			644,915 -93537
T4			567,335 -82285			622,452 -90279
T5			543,525 -78831,6			631,257 -91556,1
T6			539,522 -78251,1			633,662 -91904,9
T7			607,505 -88111,2			685,918 -99484
T8			603,058 -87466,2			671,62 -97410,2
T9			580,32 -84168,3			658,895 -95564,6
T10			612,359 -88815,2			676,323 -98092,4
Average			83196,75			94979,37

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2.5 3D Assembles

The buckling was characterized using Scan 3D.

Table-3. Results scan 3D buckling area.

3D Scan Rating	Results
Thickness	17.72 mm
Dent length	3662.982 mm
Dent Width	1219 mm
%Rmin/%Rnom	26.36%
%Rmax/%Rnom	105.43%
Maximum diameter	1261.157 mm
Minimum Diameter	323 mm
Depth	482.784 mm

2.6 Mesh with Topology CETRIA3

A finite element software is used to continue the modelling process, thus continuing with the process of surface discretization, generating a uniform 2D mesh, of type CETRIA3 using a 20 mm element size, with a total number of elements in the mesh of 62336 and a total number of nodes in the mesh of 31338.

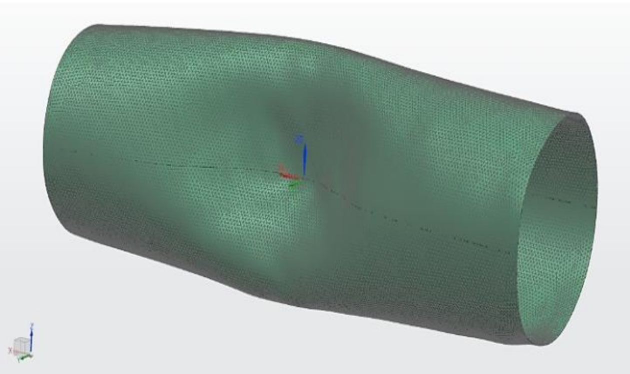

Figure-6. 2D mesh area, CETRIA3.

MESH INFORMATION	
Name	2d_mesh (1)
Mesh type	2D
Export the mesh to the Solver	true
Number of elements in the mesh	62336
Number of nodes in the mesh	31338
Tri3 Thin Shell elements	62336
==== Thickness	
Font thickness	Physical properties table
INFORMATION ABOUT MESH COLLECTOR	
Name	ThinShell (1)
Type	Thin Shell
INFORMATION ABOUT THE MESH FORMULA	
Element type	CTRIA3
==== Mesh parameters	
Meshing method	Subdivision
Item size	20 mm
Maximum growth coefficient	1.3
==== Model cleaning options	
CAD curvature abstraction	FALSE
Small figure tolerance	10
(% of element size)	FALSE
Delete hole	FALSE
Merge the edges	FALSE

Figure-7. Mesh information report.

2.7 Properties of Material

Finally, to establish boundary conditions, material properties (such as stress to creep, stress to the voltage module of young, poisson, among others) restrictions and mechanical operating conditions (operating pressure variations) are defined as follows:

Material characteristics are considered according to API 5L X 70 according to the tensile test defining the elastic zone with a maximum creep resistance of 573 Mpa (83196 PSI) and the plastic zone with a maximum tensile strength of 654 Mpa (94979 PSI).

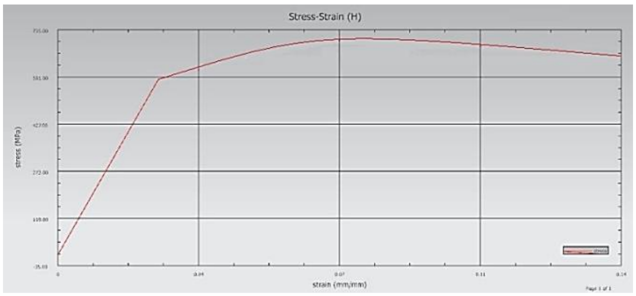

Figure-8. Configuration of mechanical properties (Characteristic effort deformation curve).

The thickness of the mesh is determined according to the future thickness loss (5 years) according to the monitored corrosion rate.

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$$t_c = t_{nom} - LOSS - FCA \quad (1)$$

$$t_c = 17.74 - 1.69 - 1 \quad (2)$$

$$t_c = 15.05 \quad (3)$$

2.8 Restrictions of the Model

With regard to the restriction of the model, it is considered that the modelled section is the continuity of a much longer duct, therefore, different types of degrees of freedom are considered so as not to affect the stresses that can be produced by the continuity of the tube. For this reason, in the circumferential edge of the ends three types of restrictions are established, setting the degrees six degrees of freedom (translational and rotational) to allow the expansion or contraction that the tube can generate due to the pressures or loads that affect it axially and radially.

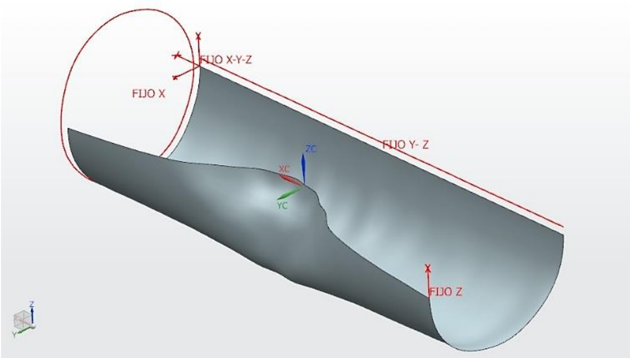

Figure-9. Representation of model restrictions.

2.9 Loads Applied

The operational conditions were determined taking into account the design code ASME B 31.8 so we calculated the PD (Design Pressure) as shown in equation (4)

$$P_D = \frac{2t\,SMYS}{D} Df \quad (4)$$

$$P_D = 1646\ PSI\ \ (11.3\ Mpa)$$

Table-4. Operating pressure working ranges.

Operation Range		
MaxOP	**1180.54 (Psi)**	**7.94 (Mpa)**
MinOP	272.68(Psi)	2.98 (Mpa)
Pd	1600.00 (Psi)	11.3 (Mpa)

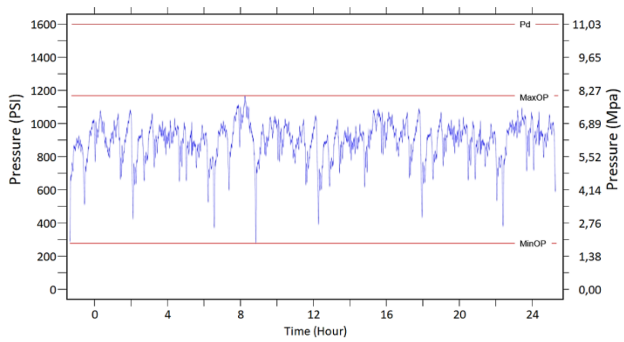

Figure-10. Pressure spectrum for one day of operation.

The pressure spectrum is determined based on information from the pipeline's operating history, with the most significant events set in a day of operation. Cycle counting is determined according to the "Rain flow" method as set out in API 579-1/ASME FFS-1 2007 Fitness-For-Service, ANNEX B3 HISTOGRAM DEVELOPMENT AND CYCLE ANALYSIS FOR FATIGUE ANALYSIS / B3.4 Cycle Counting Using the Rain Flow Method. (Astm No. E19).

The Von Mises calculation for alternating forces ($\Delta S_{p,k}$) is applied using the model:

$$\Delta\sigma_{ij,k} = {}^{m}\sigma_{ij,k} - {}^{n}\sigma_{ij,k} \quad (5)$$

$$\Delta S_{P,k} = \frac{1}{\sqrt{2}}\left[\begin{array}{l}\left(\Delta\sigma_{11,k} - \Delta\sigma_{22,k}\right)^2 + \left(\Delta\sigma_{11,k} - \Delta\sigma_{33,k}\right)^2 + \\ \left(\Delta\sigma_{22,k} - \Delta\sigma_{33,k}\right)^2 + 6\left(\Delta\sigma_{12,k}^2 + \Delta\sigma_{13,k}^2 + \Delta\sigma_{23,k}^2\right)\end{array}\right]^{0.5} \quad (6)$$

And Twice Yield method, since a step from load cycle to cycle is applied,

$$\Delta\varepsilon_{peq,k} = \frac{\sqrt{2}}{3}\left[\begin{array}{l}\left(\Delta p_{11,k} - \Delta p_{22,k}\right)^2 + \left(\Delta p_{22,k} - \Delta p_{33,k}\right)^2 + \\ \left(\Delta p_{33,k} - \Delta p_{11,k}\right)^2 + 1.5\left(\Delta p_{12,k}^2 + \Delta p_{23,k}^2 + \Delta p_{31,k}^2\right)\end{array}\right]^{0.5} \quad (7)$$

the maximum calculated equivalent plastic deformation range, ($\Delta\varepsilon_{eff,k}$), and the equivalent voltage range of von Mises ($\Delta S_{p,k}$)

$$\Delta\varepsilon_{eff,k} = \frac{\Delta S_{P,k}}{E_{ya,k}} + \Delta\varepsilon_{peq,k} \quad (8)$$

are typical output variables in a nonlinear analysis by finite element analysis, and thus obtain the results of Von Mises stress in the elasto-plastic circumstance.

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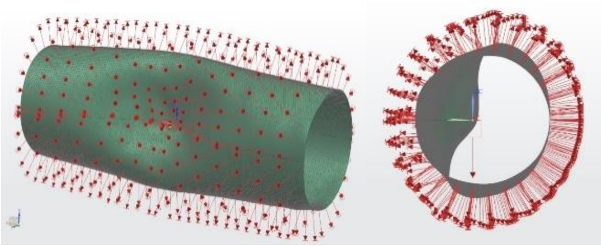

Figure-11. Distribution of normal load to nodal elements.

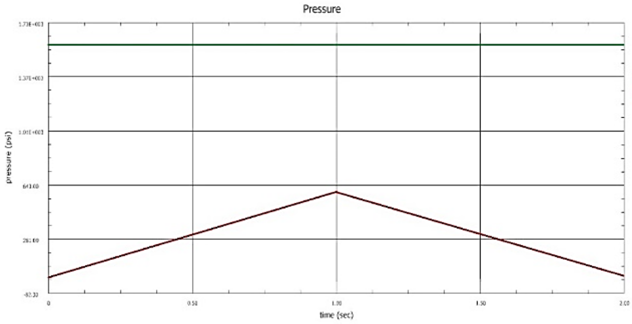

Figure-12. Load distribution in 2 sec time interval.

3. RESULTS AND DISCUSSIONS

For the non-linear type of analysis, a time-interval analysis is taken into account, thus the conditions of the cyclic pressure applied in a time interval (t=2 s) are established as shown in Figure-13 simulating the condition of this time in a band of 50 iterations. Table-5 shows 10 simulation results showing the stress distribution of von Mises, equivalent deformation for a pressure cycle (0 to 500 psi) In time space (0 to 2 sec) (see Figures 13 and 14). The stress values are located at 356 Mpa to 697 Mpa in variation to the load, the results show a variation from elastic to plastic deformation when the pressure range exceeds 200 psi, thus continuously breaking up the material.

Table-5. Results of temporary steps.

Frame	Time (s)	Pressure (PSI)	Deformation: displacement (mm)				Stress (Mpa) Von Mises
			X	Y	Z	Magnitude	
1	0.2	100	1.41	5.50	1.50	6.4	356.10
2	0.4	200	2.80	1.20	3.60	11.92	573.19
3	0.6	300	4.68	1.90	4.77	19.09	578.87
4	0.8	400	1.1e1	3.46e1	9.29	37.24	595.34
5	1.0	500	6.2e1	1.8e2	5.43e1	2.04e2	697.70
6	1.2	400	6.06e1	1.81e2	5.29e1	1.91e2	581.17
7	1.4	300	5.92e1	1.71e2	5.14e1	1.92e2	581.45
8	1.6	200	5.7e1	1.70e2	5.0e1	1.86e2	581.61
9	1.8	100	5.63e1	1.64e2	4.85e1	1.8e2	558.67
10	2.0	0	5.49e1	1.58e2	4.7e1	1.74e2	691.10

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Figures 13 and 14 show the distribution of stresses along the defect, where its concentration of stresses and plastic collapse are housed in the most abrupt geometry changes located on the shoulders of the dent.

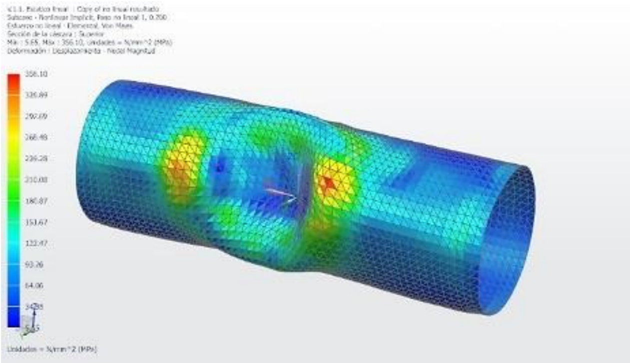

Figure-13. Non-linear step 1, 0.2 sec. - deformation.

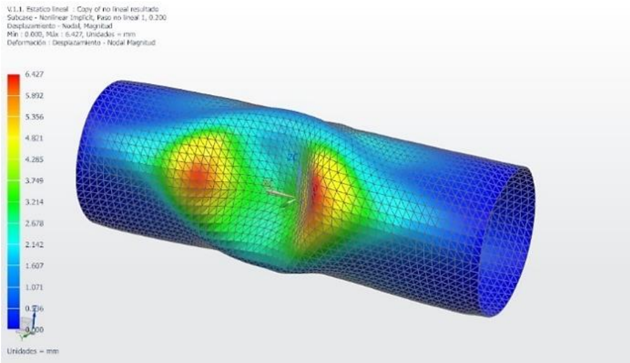

Figure-14. Nonlinear step 1, 0.2 sec. Stress distribution.

CONCLUSIONS

The mechanical conditions of the pipe with dent failure to be highlighted derived from the research are: a percentage of dent = 45.23%, a wall thickness of 17.74 mm. the results of the stress test did not reveal significant changes in the mechanical properties of the dented section relative to the undamaged area (SMYS: 83196 psi, Su: 94979 psi).

With regard to the boundary conditions established by the CAD model, it can be affirmed that the precision of the CAD survey together with the digital processing can generate a homogeneous mesh triangulation, the analytical quality is at 97%.

When analyzing and solving by means of finite elements the behavior of the pipe with dent failure in a non-linear static regime can be concluded under the proposed hypotheses and limitations in the input data, the dented region has no residual life. For the pressure ranges analyzed, the wall of the dented tube flows completely through the pressurized process. On the basis of the above, it is considered that the pipeline cannot continue to operate under the pressure spectrum similar to that analyzed as the risk of plastic collapse is high.

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