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COMPARISON OF NUMERICALLY AND EXPERIMENTALLY DETERMINED SCF FOR NOZZLE IN CYLINDRICAL PRESSURE VESSEL

Josip Kacmarcik
Mechanical Engineering Faculty Zenica
Fakultetska 1, Zenica
Bosnia and Herzegovina

Nedeljko Vukojevic
Mechanical Engineering Faculty Zenica
Fakultetska 1, Zenica
Bosnia and Herzegovina

Fuad Hadzikadunic
Mechanical Engineering Faculty Zenica
Fakultetska 1, Zenica
Bosnia and Herzegovina

ABSTRACT
In this paper the stress concentration factor for the case of set-on nozzle in a cylindrical vessel under internal pressure is researched. Two different nozzle geometries are investigated using numerical and experimental methods, FEM analysis performed in ABAQUS and strain gauges measurements. Based on numerical and experimental results, stress concentration factors defined by maximum principal and maximum von Mises equivalent stresses are calculated and compared. The comparison shows good agreement between the stress concentrations factors determined with the two different methods.
Keywords: nozzle, cylindrical pressure vessel, stress concentration, FEM, strain gauges

1. INTRODUCTION

Nozzles represent one of the most common causes for stress concentration in pressure vessels and stress concentration factors can be very useful in pressure vessel design. FEM analysis is very efficient method for determination of stress concentration factors, however reliability of FEM analysis should always be assessed. In this paper comparison of the geometric (theoretical) SCF's determined with FEM and strain gauges measurements is done to assess the reliability of FEM results. The case of set-on nozzle (flush nozzle) in a cylindrical vessel under internal pressure is investigated for two different nozzle geometries.

2. PROBLEM DESCRIPTION

Set-on nozzle is welded to the outside of the vessel with the weld that penetrates through the nozzle wall so the height of the weld is equal to the thickness of the nozzle wall. The characteristic dimensions of the nozzle and the vessel are: R – the external radius of a vessel, r- the external radius of a nozzle, T – the thickness of a vessel wall, t – the thickness of a nozzle wall, Figure 1. The following variables (geometric ratios) are used to describe geometry of the nozzle and the vessel:

$$x_1 = r / R;\ x_2 = R / T;\ x_3 = T / t \quad (1)$$

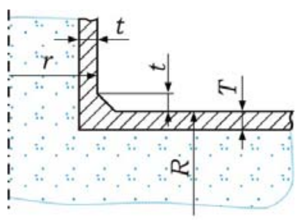


Figure 1. Cross section of set-on nozzle in cylindrical vessel.

The vessel is loaded with the internal pressure *p*, Figure 2, acting also on the inner surface of the nozzle inducing the axial force in the nozzle given by:

$F = p \cdot A = p \cdot (r-t)^2 \cdot \pi$, ...(2)

and tension stress:

$\sigma_1 = F / A_1$ ....(3)

Length of the nozzle and distance from the nozzle to other discontinuities on the vessel are considered infinite, that is large enough to not influence stress concentration.

Stress concentration factor is defined as the ratio of the maximum principal stress σ_P or the maximum von Mises stress σ_{VM} to the reference (nominal) stress σ_n , so two SCFs are defined:

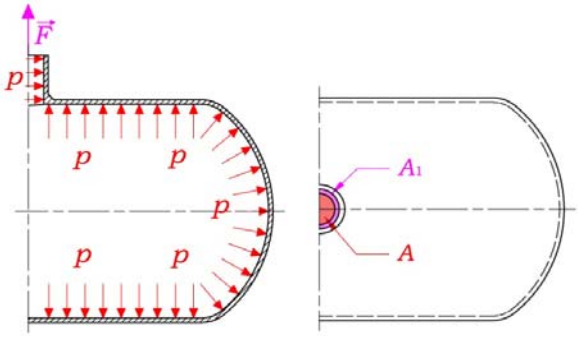


Figure 2. Nozzle and vessel load.

$$K_{VM} = \frac{\sigma_{VM}}{\sigma_n},\ K_P = \frac{\sigma_P}{\sigma_n} \quad (4)$$

Nominal stress used for this problem is the hoop membrane stress for cylindrical pressure vessel:

$$\sigma_n = \frac{p \cdot (R-T)}{T} \quad (5)$$

3. EXPERIMENTAL SET-UP

A LPG tank with the external diameter 315 mm and wall thickness 3 mm is used for preparing the experimental model. Two plugged pipes are welded on the vessel to produce two set-on nozzles, designated C1 and C2, Figure 3. The dimensions of the vessel and the nozzles with the geometric variables (x_1, x_2, x_3) are shown in Table 1. The pipes are left with enough length so that length does not influence the stress distribution. There is also enough distance between the pipes to not influence the stress distribution[1]. In the axial direction of the vessel, beside both pipes two strain gauge rosettes are installed, one smaller delta rosette (HBM 1-RY41-3/120) and one rectangular rosette (HBM RY11-10/120), so there are four measuring points, designated T1, T2, T3 and T4, Figure 3 and Figure 4. One control biaxial strain gauge (T0) is also installed on the vessel on enough distance from the pipes to avoid influence from the pipes on the stress distribution.

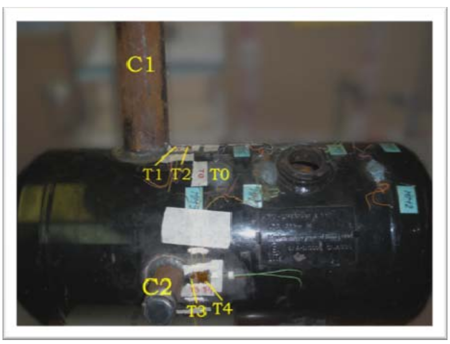


Figure 3. Experimental model with the installed strain gauges

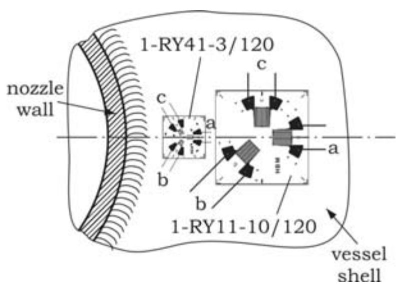


Figure 4. Strain gauges installation.

Table 1. Vessel and nozzle dimensions.

Nozzle	r [mm]	R [mm]	T [mm]	t [mm]	x_1	x_2	x_3
C1	38,05	157,5	3	4,3	0,2416	52,5	0,6977
C2	21,2	157,5	3	3,2	0,1346	52,5	0,9375

[1] The conditions from EN 13445-3

Multifluid pump ENERPAC MP 700 is used for producing pressure and the test pressure was 20 bars. For the measurement and data acquisition multichannel instrument HBM UPM-40A is used. Experimental set-up is shown on the figure 5. For every direction on the strain gauge rosettes strains are measured and expressions from the theory of elasticity are implemented to obtain stresses (principal and von Mises) in the measuring points.

Figure 5. Experimental set-up.

4. FEM ANALYSIS

Finite element analysis is applied to the nozzle geometries from the strain gauges experiment; i.e two FEM models (C1, C2) are made. Numerical simulation is done in ABAQUS software. Investigated problem is modelled as 3D problems due to shape of nozzle-vessel connection. Only 1/8 of the vessel and 1/4 of the nozzle is modelled because it is possible to defined three symmetry planes, figure 6. FEM models are made based on the conditions stated in the problem description.

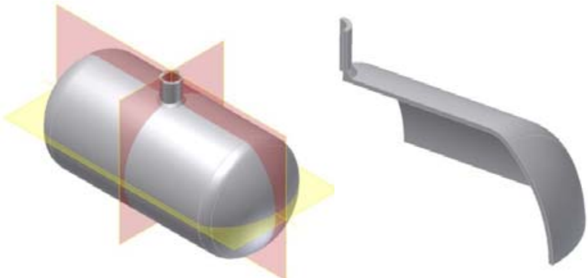
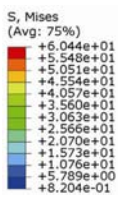
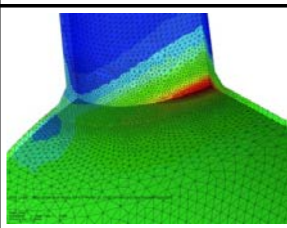
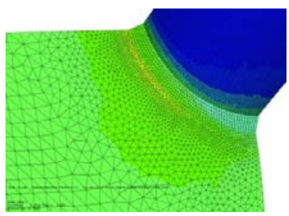
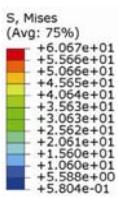
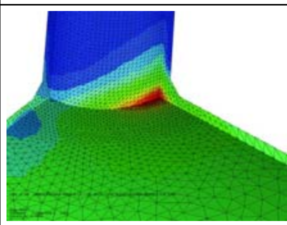
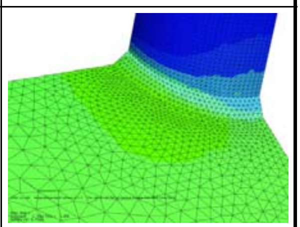


Figure 6. Symmetry planes and modeled part.

3D solid tetragonal elements are implemented for mesh generation. In order to get more accurate results the mesh in the region of stress concentration was finer than in the rest of domain. From the FEM analysis results maximum von Mises and maximum principal stress on the outside of the vessel-nozzle connection are acquired. Although, based on the FEM analysis, internal stresses are greater than external, external are used for the comparison because the strain gauges are installed on the external side. FEM analysis results, shoving von Mises stress distribution and mesh, for both models, is shown in Table 2.

Table 2. FEM analysis results (von Mises stresses)

Model	Scale	Internal view	External view
C1.			
C2.			

4. COMPARISON OF SCFs DETERMINED VIA FEM ANALYSIS AND STRAIN GAUGE MEASUREMENTS

Values of the stresses (principal and von Mises) obtained via FEM analysis and strain gauge measurements are used to calculate stress concentration factors according to (4). Because it is not possible to install strain gauge rosette on the point where maximal stress concentration is expected, i.e. edge of the weld between vessel and nozzle (also concluded based on the FEM analysis), calculated stress concentration factors in measuring points are used to extrapolate maximal stress concentrations factors. This extrapolation for nozzles C1 and C2, and measuring points T1, T2, T3 and T4 is shown in Figure 7. The extrapolated values are used for comparison with the SCF's obtained from the FEM analysis results. This comparison is shown in table 3.

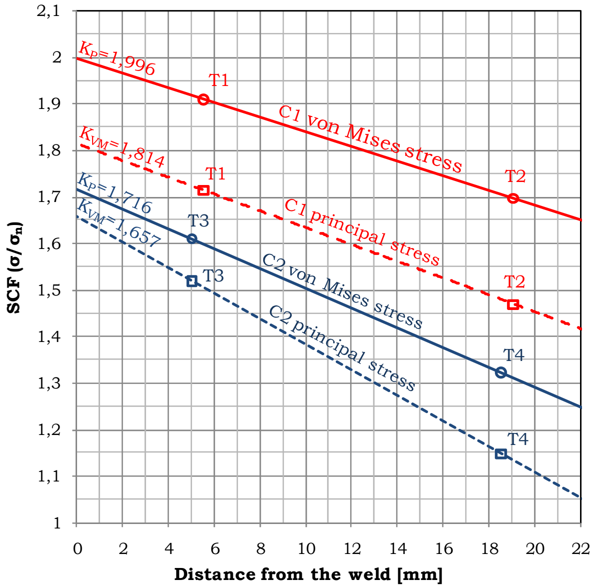


Figure 7. Extrapolation of SCF's bases on the strain gauges measurements results

Table 3. Comparison of SCFs determine via FEM analysis and strain gauge measurements.

SCF	Nozzle	SG	FEM	Deviation
K_P	C1	2,00	2,14	**7,2%**
	C2	1,72	1,6	**-6,8%**
K_{VM}	C1	1,81	1,88	**3,6%**
	C2	1,66	1,4	**-15,5%**

4. CONCLUSIONS

The comparison shows good agreement between the stress concentrations factors determined with the two different methods. The maximal deviation of 15,5 % is acceptable for engineering application of stress concentration factors. FEM analysis procedure implemented in this paper is reliable enough for determination of stress concentration factors in pressure vessel design. This research also shows advantage of FEM analysis in possibility to determine stresses on the vessel internal side that can be greater than external stresses, which would be very difficult to do using strain gauges.

5. REFERENCES

[1] Kacmarcik J., Eksperimentalno i numeričko određivanje faktora koncentracije napona za otvore sa ojačanjem u posudama pod pritiskom, Master thesis, Masinski fakultet, Univerzitet u Zenici, 2010

[2] EN 13445-1:2002, Unfired pressure vessels – Part 3: Design

[3] Spence J., Tooth A. S., Pressure Vessel Design: Concepts and Principles, Taylor & Francis Routledge, 1994

[4] Pilkey Walter D, Pilkey Deborah D.: Peterson's Stress Concentration Factors, Third Edition, John Wiley & Sons, Inc., 2008

[5] Warren C. Young, Richard G. Budynas: Roark's Formulas for Stress and Strain, Seventh Edition, McGraw-Hill, 2002

[6] Abaqus Analysis User's Manual, Version6.7, Dessault Systemes, 2007