Proceedings of the 7th International Conference on Mechanics and Materials in Design
Albufeira/Portugal 11-15 June 2017. Editors J.F. Silva Gomes and S.A. Meguid.
Publ. INEGI/FEUP (2017)

PAPER REF: 6601

# ESTIMATION OF FAILURE RESISTANCE OF PRESSURE VESSELS WITH INTERNAL CRACKS

**Bogdan Szybiński(*), Paweł Romanowicz**
Institute of Machine Design, Fac. of Mechanical Engineering, Cracow Univ. of Technology, Cracow, Poland
(*)*Email:* boszyb@mech.pk.edu.pl

## ABSTRACT

In the paper the analysis of vessels with internal cracks, with the flat endplates with circular non-circular stress relief grooves is performed. The analysis is made for different cracks sizes and locations. Special attention is paid for cracks located in the vicinities of the weld joining the endplate and the vessel tube, and in the groove area (stress concentration). The study is made both for ductile and brittle materials.

***Keywords:*** fracture mechanics, pressure vessels, stress concentration, FEM analysis.

## INTRODUCTION

The failure resistance analysis of the pressure vessels with flat endplates with circular and non-circular stress relieve grooves, and with internal cracks are studied in the paper. The study concentrates on influence of such parameters as: the geometry of the groove in flat endplate, the crack length and its orientation, type of the material used on fracture resistance to failure.

Flat endplates are used both in circular vessels and in boilers with non-circular cross section (*Standard, EN 12952-3*, *Standard, EN 13445-3*). The set of conditions, stated in codes, providing the choice of the stress relief groove parameters - minimum thickness $e_h$ in the groove area and the radius of the groove $r_{ik}$ is given in the form of inequalities, which results in certain admissible ranges for $r_{ik}$ and $e_h$. These can be illustrated in $r_{ik}$ and $e_h$ coordinates by the polygonal area. The optimal choice of the groove parameters and experimental confirmation of numerical results was described in earlier papers (Szybiński, Romanowicz, 2012 and Szybiński, Wróblewski 2012).

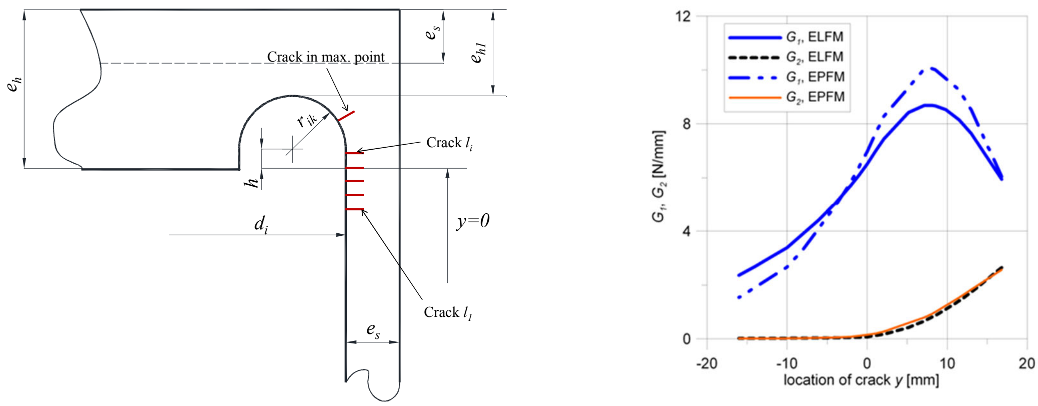
The obtained results show the risk of possible premature failure of boilers with cracks. Particularly strong influence of the material properties, brittle or ductile, on the failure resistance is observed.

## RESULTS AND CONCLUSIONS

The numerical analyses were performed for two different failure mechanisms - brittle and ductile fracture. Determination of the critical length of the crack was made using the strain energy release rate *G*. Such parameter was calculated using the Virtual Crack Closure Technique (*ANSYS*, 2009, Surjya 2015). The critical values of strain energy release rate for the investigated materials are given in the Table 1. It can be observed that the brittle material (S235JR steel) have much smaller energy absorption than ductile material (namely 16Mo3steel). Moreover, the welding process changes the micro-structure of the material. In the heat affected zone (HAZ) grain size and hardness are generally increased but the fracture toughness significantly goes down (Dzioba, 2016). Such changes depend on the different parameters of the welding process and chemical compositions of the welded materials. Because of this the appearance of the crack in the surroundings of the weld joints can be essential for the failure endurance of the considered vessel. It should be also noted that the presence of cracks is not taken into account in standard boilers calculations, which generally assume the uniform and free from faults structure.

Table 1 - Critical strain energy release rate for investigated materials after laser welding

| Material | S235JR | 16Mo3 (base material) | 16Mo3 (weld material) | 16Mo3 (HAZ, recrystallized) | 16Mo3 (HAZ, fine grained) |
|---|---|---|---|---|---|
| $G_{IC}$[N/mm] | 3.1 | 423 | 173 | 341 | 231 |




(a) (b)

Fig. 1 - (a) Stress relief groove, size and locations of cracks, (b) strain energy release rates $G$ for different location of cracks, crack length 4.216 mm, optimal groove (16Mo3 steel)

The numerical calculations were made for different location of cracks for optimal (Fig. 1) and non-optimal geometry of the circular and non-circular stress relief groove. Here, the center of the weld joint is located on $y$ = 0 position. Fig. 1b presents the $G$ values calculated for the optimal configuration of the stress relief groove when ductile material is used for boiler fabrication, for different crack positions. Here the crack length was assumed to be equal to 21% of the pipe thickness. The maximal failure mode I occurs in the stress relieve groove area, close to the point, in which the maximal equivalent stress occurs.

## REFERENCES

[1]-ANSYS, ver.12.1, Swanson Analysis Systems, 2009.

[2]-Europ. Standard, EN 12952-3:2001. Water-tube boilers…. Design and calculation of pressure parts.

[3]-Europ. Standard, EN 13445-3, Unfired pressure vessels - Part 3: Design, CEN, 2002.

[4]-Dzioba I, Zowczak W., Kasińska J., Pała T., Testing of the low carbon Cr-Mo steel parts for mechanical properties of the laser welded joints (in Polish), Mechanik nr 1/2016.

[5]-Surjya K. M., Fracture Mechanics, Fundamentals and Applications, Cambridge University Press 2015.

[6]-Szybiński B. *et al.*, Numerical and experimental analysis of stress and strains in flat ends of high-pressure vessels, Key Engin. Mat., 490, pp. 226-236, 2012.

[7]-Szybiński B., Wróblewski A., Parametric optimization of stress relief groove shape in flat ends of boilers, Journal of Strain Analysis for Engineering Design, 47(1), p. 55-63, 2012.