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STRUCTURAL INTEGRITY ASSESSMENT OF THICK WALL PRESSURE VESSEL BY FAILURE ASSESSMENT DIAGRAMME

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ABSTRACT
Structural integrity assessment, based only on farcture mechanics parameter, is not suitable for yielding and boundary conditions of plastic collapse. Approach to structural integrity assessment of pressure vessels using two-parameters method realized through the Failure assessment Diagramme is presented. This method take two possible boundary solutions: total plastic collapse and brittle fracture. Assessment is made having in mind the conservative approach in the analysis of critical defects on structural integrity before and after post weld heat treatment (PWHT).
Key words: structural integrity, fracture mechanics, failure assessment diagramme, residual stress

1. INTRODUCTION

Structural integrity assessment, based only on farcture mechanics parameters, is not suitable for yielding and boundary conditions of plastic collapse. For that reason, two-parameter approach are realized through the *Failure Analysis Diagram* (*FAD*)[4].

Failure assessment diagramme define boundary between two independent solutions, in one case, if the material is completely ductile, the structure fails due to plastic collapse at *Sr* = 1, while for fracture of a completely brittle material *Kr* = 1. In all other cases there is an interaction between plastic collapse and brittle fracture, so that *Kr* and *Sr* are less than 1, and the pairs of corresponding values make a boundary curve, that is defined by Eq. (2), Fig. 3.

The mechanism of plastic collapse is not covered by designed *CTOD* curve, so its analysis requires a more general, two-parameter approach, realized through the *Failure Analysis Diagramm* (*FAD*):

$$\frac{K_{eff}}{K_I} = \frac{\sigma_c}{\sigma}\left[\frac{8}{\pi^2}\ln\sec\frac{\pi}{2}\cdot\frac{\sigma}{\sigma_c}\right]^{\frac{1}{2}} \qquad \text{... (1)}$$

where: $K_I = \sigma\sqrt{\pi \cdot a}$ - stress intensity factor, MPa√mm; $\sigma = (\sigma_n + \sigma_{res})$, [MPa], net section stress and residual stress; $K_{eff} = K_{Ic}$, metal fracture toughness, K_{eff} was introduced instead of δ ($K_{eff}^2 = \delta \cdot \sigma_Y \cdot E$); σ_Y - yield stress replaced by plastic collapse stress σ_C as a more convenient yield criterion for actual structures; other parameters: a -crack lenght (depth) 15, 20 i 27 [mm], internal preassure, *p=35* [MPa], mean vessel radius, *R=447* [mm], vessel thickness, *t = 94* [mm].

Non dimensional plastic collapse parameter *Sr* is defined by formula:

$$S_r = \frac{\sigma_n}{\sigma_F}, \qquad \text{... (3)}$$

where: $\sigma_n = (1 + a/t) \cdot \sigma$, [MPa], primary stress caused by internal pressure ('boiler formula'), with stress concentration factor defined as section weakening coefficient; $1 + a/t$; σ_F, plastic collapse stress, $\sigma_F = (\sigma_{YS} + \sigma_{TS})/2$, σ_{YS}, yield stress, σ_{TS}, ultimate stress.

As a final step, non-dimensional variables $S_r = \sigma / \sigma_c$ and $K_r = K_I / K_{Ic}$ are defined, where it is supposed that K_{eff} equals to the fracture toughness of the material, so that Eq. (1) becomes:

$$K_r = S_r \left[\frac{8}{\pi^2} \ln \sec \frac{\pi}{2} \cdot S_r \right]^{-\frac{1}{2}} \qquad \text{...(2)}$$

Stresses necessary for determination of K_r and S_r are divided as on the design *CTOD* curve, into primary and secondary ones, and in determining S_r only the primary stresses are taken into account, as the secondary stresses do not affect structural collapse.

2. STRUCTURAL INTEGRITY ASSESSMENT

Analysis is based on assumption that ductile materials are not affected to britle fracture, but can fail due to plastic collapse if structure is overloaded.

Analysed example is a typical problem if regular control of *NDT* reveals 'unacceptable' defects (cracks) as was the case with welded supports on thick vessels for compressed air. Thick vessel had a few defects marked as 'unacceptable,' which were orientired in circumferential and longitudinal directions. The defects marked as 'critical' were analyzed using methods of fracture mechanics, by applying conservative approach[1]. Samples were taken from vessel in two directions(samples *CR* and *CL* acc. figure 1 and 2) and samples taken before(samples *CR-N* and *CL-N*) and after(samples *CR-O* and *CL-O*) post weld heat treatment (PWHT) with a view to analysis this effects on facture toughness K_{Ic} and critical crack size.

Having in mind the conservative approach in the analysis of critical defects, it has been assumed that defect spreads over the external length of the cylindrical part of vessel. In that case, the problem is observed in the section transversal to longitudinal and circumferential directions of vessel, where the influence of the curve is negligible. The crack length exists no more in the analysis and the dimension so far defined as width becomes the length (15, 20 and 27 mm). Thus the problem is reduced to a tensile plate, the dimensions of which are significantly larger than the crack length, where non-symmetry caused by the location of crack is neglected.

The idea of such a conservative approach is to prove in the simplest way that structural integrity is not threatened.

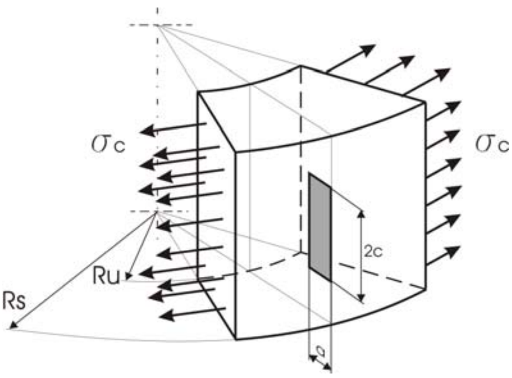

Figure 1. Longitudinal crack and circumferential stress in net section (CR-samples)

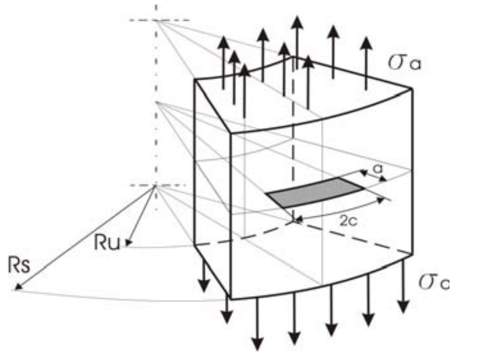

Figure 2. Circumferential crack and axial stress in net section(CL-samples)

Table 1. Non dimensional parameters Kr i Sr for longitudinal crack

Specimen	Crack size	Circumfernc. stress	Residual sterss in circk. direction	$\sigma_c+\sigma_{r-c}$	Stress intensity factor	Fracture toughness	Non dimensional parameter	Stress intensity factor	Primary stress	Yield stress	Ultimate stress	Plastic collapse stress	Non dimensional parameter
	a **mm**	σ_c MPa	σ_{res-c} MPa	σ MPa	K_I MPa√m	K_{Ic} MPa√m	$\mathbf{K_r}$	1+a/t	σ_n MPa	R_{eH} MPa	R_m MPa	σ_F MPa	$\mathbf{S_r}$
CR-N	**15**	166,4	293,8	460,2	99,8	87,6	**1,14**	1,16	193,0	328,7	592,7	460,7	**0,42**
CR-N	**20**	166,4	293,8	460,2	115,3	87,6	**1,32**	1,21	201,8	328,7	592,7	460,7	**0,44**
CR-N	**27**	166,4	293,8	460,2	134,0	87,6	**1,53**	1,29	214,2	328,7	592,7	460,7	**0,47**
CR-O	**15**	166,4	130,6	297,0	64,4	101,6	**0,63**	1,16	193,0	328,7	592,7	460,7	**0,42**
CR-O	**20**	166,4	130,6	297,0	74,4	101,6	**0,73**	1,21	201,8	328,7	592,7	460,7	**0,44**
CR-O	**27**	166,4	130,6	297,0	86,5	101,6	**0,85**	1,29	214,2	328,7	592,7	460,7	**0,47**

For logitudinal and circumferential cracks are taken with same assumption in the conservative approach, and amount of parameters K_r i S_r are presented in table 1 and 2.

Representative total stress is induced by internal pressure (‘boiler formula’)

$\sigma_c = \dfrac{p \cdot R}{t}$ i $\sigma_a = \dfrac{p \cdot R}{2 \cdot t}$ and cross-sectional residual stress[1,2].

The influence of the vicinity of the dish cover is taken to be negligible, that behalf safety of structural integrity assessment.

Table 2. Non dimensional parameters Kr i Sr for circumferential crack

Specimen	Crack size	Longitudinasl stress	Residual sterss in long.direction	$\sigma_a+\sigma_{r-a}$	Stress intensity factor	Fracture toughness	Non dimensional parameter	Stress intensity factor	Primary stress	Yield stress	Ultimate stress	Plastic collapse stress	Non dimensional parameter
	a **mm**	σ_a MPa	σ_{res-a} MPa	σ MPa	K_I MPa√m	K_{Ic} MPa√m	$\mathbf{K_r}$	1+a/t	σ_n MPa	R_{eH} MPa	R_m MPa	σ_F MPa	$\mathbf{S_r}$
CL-N	**15**	83,2	260,6	343,8	74,6	73,4	**1,02**	1,16	96,5	292,6	586,2	439,4	**0,22**
CL-N	**20**	83,2	260,6	343,8	86,2	73,4	**1,17**	1,21	100,9	292,6	586,2	439,4	**0,23**
CL-N	**27**	83,2	260,6	343,8	100,1	73,4	**1,36**	1,29	107,1	292,6	586,2	439,4	**0,24**
CL-O	**15**	83,2	106,5	189,7	41,2	93,4	**0,44**	1,16	96,5	292,6	586,2	439,4	**0,22**
CL-O	**20**	83,2	106,5	189,7	47,5	93,4	**0,51**	1,21	100,9	292,6	586,2	439,4	**0,23**
CL-O	**27**	83,2	106,5	189,7	55,2	93,4	**0,59**	1,29	107,1	292,6	586,2	439,4	**0,24**

3. CONCLUSION

Parameters K_r and S_r are less than 1, and the pairs of corresponding values make a boundary curve. Based on values obtained for K_I/K_{Ic} and $S_r=\sigma_n/\sigma_F$ the points (*PWHT* samples *CR-O* and *CL-O*), are plotted in the failure analysis diagram (*FAD*), and all located in the safe part of the diagram, fig. 3. According to figure 3, all samples marked with *CR-N* and *CL-N* (specimens before heat treatment) are located in the unsafe part of diagram, Fig 3.

Having in mind the conservatism of this analysis in all its aspects, it may be concluded that the *PWHT* vessels are safe not only from brittle fracture, but from the plastic collapse, too. Results of this analysis show significancy and necessity of post weld heat treatments on welded supports by thick wall pressure vessels and their infuence on structural integrity, consequently all heat treated samples are located in safe part of diagram (*FAD*).

It is essential to note that the *FAD* enables simple analysis of the integrity that may reliably establish whether a component is fracture-safe or not, on condition that the geometry and loading are presented in a conservative way.

On the other hand, if the integrity cannot be proved, this does not mean that the component is useless, but that additional, more complex analysis are necessary.

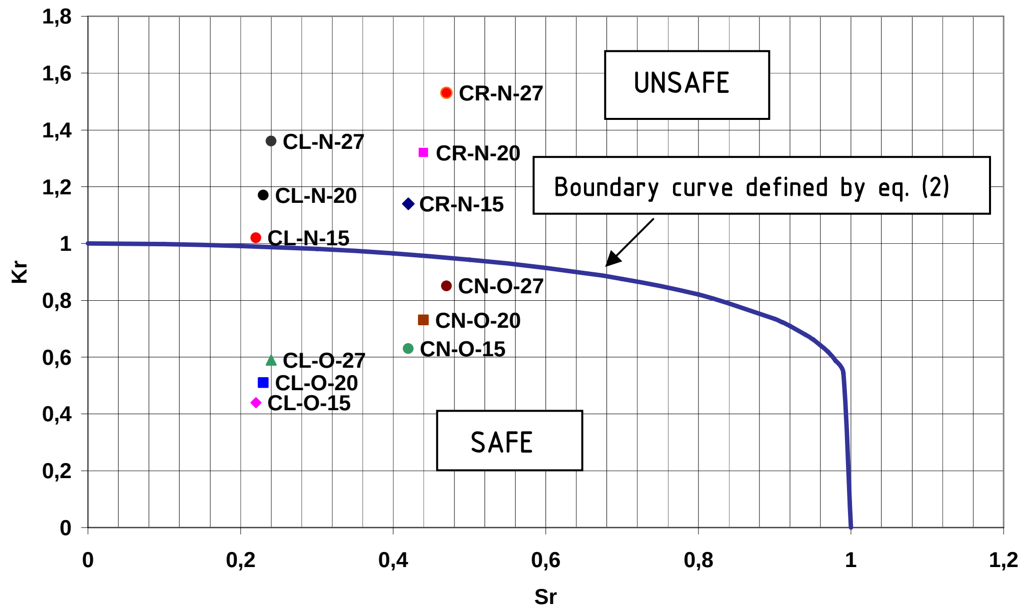

Figure 3. Failure Assessment Diagramme -FAD

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