E. Ranatowski

University of Technology and Life Science, Department of Mechanical Engineering,
Sylwestra Kaliskiego 7, 85-796 Bydgoszcz, Poland

RELATION STRUCTURE – FRACTURE RESISTANCE IN PROCESS OF ESTIMATE THE WELDABILITY OF LOW ALLOY STEELS

PART II

ABSTRACT

Numerical weldability analysis is a new powerful research and development tool which is useful for metallurgistics technologist and design engineers. Saying strictly the numerical analysis of weldability comprises thermodynamic, thermomechanical and microstructural modelling of the welding process. The fracture resistance of welded joints is mainly characterised by normalised parameters: $SU_1 = K_{Ith} / K_{IC}$ for cold cracking or in the exploitation condition by $SU_2 = \delta / \delta_C$ or J/J_C , $SU_1 \neq SU_2$. Conclusions from the theoretical analysis form a basis to an assessment measure of the stress state parameter S_p as a physical measure of the deformation and effort of the mismatched weld joints. There also was made characteristic of the effect on the inclination of the layer (W) on the form of fracture. Finally, some aspects of estimation of the K_C and K_{IC} values for the layer (W) with the SINTAP programme overview are presented.

Key words: *stress state parameter S_p , undermatched and overmatched welds, SINTAP programme*

ASSESSMENT OF THE STRESS STATE IN ASPECT OF THE STRESS PARAMETER S_p

We can introduce to the further consideration the stress state parameter S_p as follows:

$$S_p = \frac{\sigma}{\sigma_H}$$

(21)

where:

- σ - mean stress,
- σ_H - equivalent of stress according to Huber-Mises.

and:

$$\sigma = \frac{\sigma_x + \sigma_y}{2} \quad (22)$$

$$\sigma_H = \frac{\sqrt{2}}{2} \sqrt{2(\sigma_x - \sigma_y)^2 + 2\sigma_x\sigma_y + 6\tau_{xy}^2} \quad (23)$$

Experimental tests show that the value of the mean stress σ has no influence on the plastic yielding of metals. The value of σ_H plays an important role in the theory of plastic deformation. In this situation between σ and σ_H , is a physical measure of the influence of the stress state at interface on the deformation and effort of the mismatched weld joints.

After inserting $\sigma_x, \sigma_y, \tau_{xy}$ in accordance with Eqns. (8), (9), (10) and (18) to (21) we obtain the stress state parameter S_p as follows:

- undermatched weld joint

$$S_p = \frac{\left[\frac{1}{1-\gamma} \left(\frac{\pi}{2} - \gamma \sqrt{1-\gamma^2} - a \sin(\gamma) \right) + \frac{1-\gamma}{2} \frac{\xi}{\kappa} \right] - 2 \sqrt{1 - \left(\frac{1+\gamma}{2} + \frac{1-\gamma}{2} \frac{\eta}{\kappa} \right)^2}}{2 \cdot \frac{\sqrt{2}}{2} \left\{ \left[2 \cdot \left(\sqrt{\frac{1+\gamma}{2} + \frac{1-\gamma}{2} \frac{\eta}{\kappa}} \right)^2 \right]^2 + \left[\frac{1}{1-\gamma} \left(\frac{\pi}{2} - \gamma \sqrt{1-\gamma^2} - a \sin(\gamma) \right) + \frac{1-\gamma}{2} \frac{\xi}{\kappa} \right] - \right.}$$

$$\frac{\left[\frac{1}{1-\gamma} \left(\frac{\pi}{2} - \gamma \sqrt{1-\gamma^2} - a \sin(\gamma) \right) + \right.}{-2 \cdot \sqrt{1 - \left(\frac{1+\gamma}{2} + \frac{1-\gamma}{2} \frac{\eta}{\kappa} \right)^2} + \left[\frac{1}{1-\gamma} \left(\frac{\pi}{2} - \gamma \sqrt{1-\gamma^2} - a \sin(\gamma) \right) + \frac{1-\gamma}{2} \frac{\xi}{\kappa} \right] +}$$

$$\left. \frac{\left. + \frac{1-\gamma}{2} \frac{\xi}{\kappa} \right]}{+ 6 \cdot \left(\frac{1+\gamma}{2} + \frac{1-\gamma}{2} \frac{\eta}{\kappa} \right)^2} \right\}^{\frac{1}{2}} \quad (24)$$

- overmatched weld joint

$$S_p = \frac{- \left[\frac{-1}{1-\gamma} \left(\frac{\pi}{2} - \gamma \sqrt{1-\gamma^2} - a \sin(\gamma) \right) + \frac{1-\gamma}{2} \frac{\xi}{\kappa} \right] + 2 \sqrt{1 - \left(\frac{1+\gamma}{2} + \frac{1-\gamma}{2} \frac{\eta}{\kappa} \right)^2}}{2 \cdot \frac{\sqrt{2}}{2} \left\{ 8 \left[\left[\frac{-1}{1-\gamma} \left(\frac{\pi}{2} - \gamma \sqrt{1-\gamma^2} - a \sin(\gamma) \right) \right] + \frac{1-\gamma}{2} \frac{\xi}{\kappa} \right] + \left(\sqrt{\frac{1+\gamma}{2} + \frac{1-\gamma}{2} \frac{\eta}{\kappa}} \right)^2 \right\}^2 -}$$

$$\frac{\left[\frac{-1}{1-\gamma} \left(\frac{\pi}{2} - \gamma \sqrt{1-\gamma^2} - a \sin(\gamma) \right) + \right.}{-2 \cdot \left[\left[\frac{-1}{1-\gamma} \left(\frac{\pi}{2} - \gamma \sqrt{1-\gamma^2} - a \sin(\gamma) \right) \right] + \frac{1-\gamma}{2} \frac{\xi}{\kappa} \right] + 6 \cdot \left(\frac{1+\gamma}{2} + \frac{1-\gamma}{2} \frac{\eta}{\kappa} \right)^2} \right\}^{\frac{1}{2}} \cdot}$$

$$\frac{\left. + \frac{1-\gamma}{2} \frac{\xi}{\kappa} \right]}{\left[\left[\frac{-1}{1-\gamma} \left(\frac{\pi}{2} - \gamma \sqrt{1-\gamma^2} - a \sin(\gamma) \right) \right] + \frac{1-\gamma}{2} \frac{\xi}{\kappa} \right] + 6 \cdot \left(\frac{1+\gamma}{2} + \frac{1-\gamma}{2} \frac{\eta}{\kappa} \right)^2} \right\}^{\frac{1}{2}} \quad (25)$$

Figs. 7 and 8 presents some examples of an assessment of the equivalent of stress in agreement to (23) and stress state parameters S_p in accordance to (24) and (25).

Fig. 7a, b presents the equivalent of stress $\sigma_{H(rel)}$ increases for under- and overmatched weld joint. The first example reveals that at $\sigma_{H(rel)}$ increases at: $\kappa = 0,3; 0,5; 0,75; 0,99$ and $\eta = 0,2; \xi = 0,9$ at $-1 < \gamma < 1$. The second example reveals that the equivalent of stress monotonic increases up to attain the maximum and then decreases at $\kappa = 0,3; 0,5; 0,75; 0,99$ and $\eta = 0,2; \xi = 0,9$ at $-1 < \gamma < 1$. It indicated about difference state of deformation at interface of the under- and overmatched weld joint.

Fig. 7. Characteristic of $\sigma_{H(rel)}$ for: a. undermatching case, b. overmatching case at: $\kappa = 0,3; 0,5; 0,75; 0,99$ and $\eta = 0,2; \xi = 0,9$ at $-1 < \gamma < 1$

Fig. 8a, b presents the characteristic of S_p for under- and overmatched weld joint. These examples reveal the difference tendency – upward tendency for undermatched and downward tendency for overmatched weld joints at same geometric characteristic as above.

It testify that at interface of the undermatched weld joints is “hard” state of stress which causes increase of the mechanical properties such as yield point etc., but decrease the fracture resistance [2].

In the overmatched weld joints is conversely situation – at the interface of overmatched weld joints is “soft” state of stress which causes decrease of the mechanical properties such as yield but increase the fracture resistance.

Fig. 8. Characteristic of S_p for: a. undermatching case, b. overmatching case at:

$$\kappa = 0.3; 0.5; 0.75; 0.99 \text{ and } \eta = 0.2; \xi = 0.9 \text{ at } -1 < \gamma < 1$$

THE SINTAP PROGRAMME OVERVIEW

The structural integrity assessment procedures SINTAP are the techniques used to assess the fitness – for – purpose of critical components and welded structures. The SINTAP project covered both modelling and experimental work. Beside this programme resulted in the compilation of a large amount of data and the use of these data to provide a number of novel solutions to practical fracture avoidance problems. The underlying principles of the SINTAP method are [3]:

- a hierarchical structure based on the quality;
- decreasing conservatism with increasing data quality;
- detailed guidance on determination of characteristic input values such as fracture toughness;
- the choice of representation of results in terms of a failure assessment diagram (FAD) or crack driving force (CDF);
- specific methods incorporating the effect of weld strength mismatch;
- guidance on dealing with situations of low constraint and, for components containing fluids, leak before break analysis;
- compendia of solutions for stress intensity factors (SIFs), limit load solutions and weld residual stress profiles.

The two principal methods for analysis which are used in SINTAP procedures are the FAD and the CDF. Just, defect assessment methods for strength mismatched structures have been developed by incorporating the strength mismatch effect into the methods for homogeneous structure. Such mismatch specific methods include the ARAMIS method [4] based on the EPRI approach: the modified R6 method [5] and the Engineering Treatment Model for mismatch (ETM-MM) [6]. The FAD route follows in SINTAP the philosophy of R6 and the CDF route follows the philosophy of the ETM-MM method. There are seven levels of analysis in the SINTAP procedure are made – Tab.3 [3].

Table 3. Selection of analysis level [3]

No	Level	Data needed	When to use
1	2	3	4
0	Default level Default	Yield or proof strength.	When no other tensile data available.
1.	Standard levels Basic	Yield or proof strength: ultimate tensile strength.	For quickest result. Mismatch in properties less than 10%.
2.	Mismatch	Yield or proof strength: ultimate tensile strength. Mismatch limit loads.	Allows for mismatch in yield strengths of weld and base material. Use when mismatch is greater than 10% of yield or proof strength.
3.	SS (stress – strain defined)	Full stress strain curves.	More accurate and less conservative than Levels 1 and 2. Weld mismatch option included
4.	Advanced levels Constraint allowance	Estimates of fracture toughness for crack tip constraint conditions relevant to those of cracked structure.	Allows for loss of constraint in thin sections or predominantly tensile loadings.
5.	J – Integral analysis	Needs numerical cracked body analysis.	Best accurate
6.	Special case: leak before break analysis	Yield or proof strength – as No 1.	Piping and pressure vessel components.

In accordance with Tab.3 the SINTAP procedure allows a structural assessment analysis to be performed provided that the following are known: loading conditions, the corresponding applied K_I or δ and J values, materials toughness. In the CDF method, calculations are made of an applied parameter, such as the J – integral or crack opening displacement COD - δ which characterises the state of stress and strain ahead of the tip of a crack in a component. In a Level I assessment, J is estimated as [7, 8, 9]:

$$J = J_e [f(L_r)]^{-2} \quad (26)$$

where: J_e is the elastic value of the J integral which can be deduced from K_I as:

$$J_e = K_I^2 / E' \quad (27)$$

The function $f(L_r)$ in Eqn. (26) is defined in terms of the load ratio, as:

$$L_r = F / F_y \quad (28)$$

and $f(L_r)$ is equal:

$$f(L_r) = (1 + 0,5 L_r^2)^{-1/2} [0,3 + 0,7 \exp(-0,6 L_r^6)] \quad (29)$$

For $L_r > 1$, Eqn (29) can be refined for materials described by power – law plasticity.

From the physics point of view F_y is the plastic collapse load defined for a rigid plastic material with yield stress σ_y equal to that of the component of interest. The value of F_y is proportional to σ_y and also depends on the component geometry and the defect size, a .

In the FAD method, two parameters are calculated, the load ratio, L_r , already defined by Eqn. (26)÷(29) and the ratio K_r defined by [7, 8, 9]:

$$K_r = K_I / K_{mat} \quad (30)$$

or

$$K_r = (J_e / J)^{1/2} \quad (31)$$

Eqn. (31) provides the consistency between FAD and CDF expressions. These two parameters have been calculated, fracture is avoided if the point (L_r, K_r) is within a region defined on failure assessment diagram as depicted in [6]. The failure avoidance region is given by the failure assessment curve:

$$K_r = f(L_r) \quad (32)$$

and a cut – off:

$$L_r = L_r^{max} \quad (33)$$

The Eqns (30) ÷ (33) proves that the condition $K_r \leq f(L_r)$ is equivalent to $J \leq J_{mat}$ so that the CDF and FAD procedures are fully compatible. The level of analysis is characterised mainly by the detail of the materials tensile data used.

CONCLUSIONS

The following features of mismatched welded joints were established:

- characteristic of stress state at interface of the under- and overmatched weld joints by determined the fundamental equations on assessment the components of stress $\sigma_x, \sigma_y, \tau_{xy}$ under static tension with some analytical examples,
- stress state parameter S_p as a function of mean stress σ and equivalent of stress σ_H which is a physical measure of the effort of the mismatched weld joints.

The above settlement and conclusions form some basis to an assessment of the fracture parameters with the constraint effect of the mismatched weld joints.

The current situation concerning existing procedures and their pending development was assessed and two principal methods for analysis which are used in these procedures are the FAD and the CDF. The objective of the SINTAP procedure application is the engineering design. Beside, welding process can have a detrimental effect on structural integrity and are an important consideration in the defect assessment of welded

structures. This problem is link up with estimate of the weldability of materials and weldments such as offshore drilling, ships etc.

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