

The influence of the constraint effect on the mechanical properties and weldability of the mismatched weld joints

Part II

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ABSTRACT



Currently the welding as a technological process is concerned with special processes, the results of which cannot be checked in a complete degree by subsequent control, test of production what finally causes uncertainty of work of welded constructions. The process of welding is related to the local change of the internal energy of welded system and that leads to the local change of state of material expressing by change of microstructure and mechanical properties. This phenomena decide on the assessment of susceptibility of materials under defined welding condition and estimate of the weldability. It is compound relation and the mechanical behaviour of welded joints is sensitive to the close coupling between modules: heat transfer, microstructure evolution an mechanical fields. Welding process in physical meaning it is jointed with three laws govern mass and heat flow the laws of conservation of: mass, momentum and energy. The knowledge of the run of thermo-dynamical process under welding indicates on the possibility of active modelling and control of welding process with use intensive and extensive parameters. As the weld metal cools in the temperature range 2300 to 1800°K, the dissolved oxygen and deoxidising elements in liquid steel react to form complex oxide inclusions of 0.1 to 1 µm size range. In the temperature range 1800 to 1600°K, solidification of liquid to δ ferrite starts und envelops these oxide inclusions. After δ ferrite transforms to austenite in the temperature range 1100 to 500°K, the austenite transforms to different ferrite morphologies such as ferrite: allotriomorphic, Widmansiättena, and acicular. The macro-mechanical heterogeneity of welded structures is one of their primary features. The heterogeneous nature of the weld joints is characterised by macroscopic dissimilarity in mechanical properties. 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 result of this analysis is material susceptibility (SU). The fracture resistance of welded joints is mainly characterised by normalised parameters: $SU_1 = K_{th} / K_{IC}$ for cold cracking or in the exploitation condition by $SU_2 = \delta / \delta_C$ or J/J_C , $SU_1 \neq SU_2$. From above-mentioned equations result that does not exist one global parameter which defines the step of susceptibility SU of base materials has been also executed with use of SINTAP program.

Keywords: weld joint; weldability; weldability analysis; thermal cycle; heat source model; heat flow analysis; heat affected zone

EVALUATION OF THE STEP OF SUSCEPTABILITY OF WELDED JOINTS ON WELDING PROCESS

The final question is assessment of the step of susceptibility $S_{m/w}$ of welded joints on welding process. In accordance with PN-84/M-69005 the physical measure of this phenomena we can accept the fracture resistance of welded joints mainly characterised by fracture mechanics parameter.

Fracture mechanics design methodology is based on the realistic assumption that all materials contain initial defects that affect the load-carrying capacity of engineering structures. The defects are initiated in the material by manufacturing procedures or can be created during the service life, like fatigue,

environment-assisted or creep cracks. Usually, one dominant crack is assumed. Two pieces of information are needed to make a prediction of the failure behaviour in structural components containing defects such as cracks. They are the deformation behaviour of the structure and the fracture behaviour. The deformation behaviour gives the relationship between loading and displacement of the component or an analogous relationship such as stress and strain. It is usually done independently of the fracture behaviour but is done with the inclusion of the effect of the defect. The deformation behaviour usually combines a linear-elastic and an elastic-plastic contribution. The fracture parameters are also determined from the deformation behaviour of the structure and would include a combination of a linear elastic term, usually (SIF) – K , based and an (CTOD) – δ . The

deformation behaviour usually requires a knowledge of the tensile properties of the material in the structure.

A fracture safe design can be also influenced by the constraint effect especially in weld structures. The current work has concentrated on mostly looking at constraint effects on the fracture behaviour. The concern must also be given to the effect of constraint on deformation behaviour, especially in the nonlinear region of behaviour – for example at the crack tip. The nonlinear local deformation takes place in mismatched weld joints of the structures. The Engineering Treatment Model (ETM) applied to an analysis of mismatched weld joint uses calibration functions in which load is normalised by limit load and toughness.

In agreement with above statement the normalised parameter $\delta_R = \delta_w / \delta_B$ [δ_w, δ_B - the CTOD of crack in the weld metal (W) and base metal (B) respectively] can be used to assessment the step of susceptibility of the base material on welding process as:

$$\delta_R = \delta_{m/w} \geq 1 \quad (24)$$

The importance of “constraint” in the analysis of notched or cracked bodies has been recognised by many investigators. The constraint refers to the build-up of stress around a crack front due to the restraint against in-plane and out- of plane deformation. The analysis of failure in a structural component depends on two inputs, the deformation and fracture behaviours-both depend on constraint. The concern must be given to the effect of constraint on deformation behaviour especially in the non-linear region of behaviour. The manner and extend to which constraint affects the failure behaviour of the structure depends on the type of fracture and deformation that are occurring. The magnitude of the load in the region of non-linear deformation is strongly influenced by constraint. Thus, ignoring the effect of constraint on fracture toughness causes an overestimate of the failure load by nearly 60% [15].

The above example shows that constraint effects on fracture toughness could be important in determining the maximum load at failure for structural components. The effect of the constraint on the deformation is considerable, especially when the fracture process occurs on the non-linear part of loading.

For example while considering the above - mentioned problem when the crack is located in the middle part of the layer parallel to the interfaces and in homogeneous material.

The change of the size $r_p^{un/ov}$ of the plastic zones at the crack tip for the layer (R_e^W) normalised by r_p for a homogeneous material (R_e^H) unconstrained at $R_e^W = R_e^H$ and at the same of plate thickness can be assessed as [12]:

$$\frac{r_p^{un}}{r_p} = \frac{1}{(K_W^{un})^2} \quad \text{or} \quad \frac{r_p^{ov}}{r_p} = \frac{1}{(K_W^{ov})^2} \quad (25)$$

Fig. 6 presents the characteristics of the normalised size of the plastic zone at the crack tip for the under- and overmatched cases.

It should be noted that in the layer (W) favourable conditions for passing from plane stress to plane strain occur when the value of $K_W^{un/ov}$ is increased. One of the most important procedures is the recently introduced Engineering Treatment Model (ETM), which permits usage of the CTOD as functions of the applied load or strain for work hardened materials [16].

In accordance with the equations determined by Schwalbe [16] for assessing the ratio of the driving forces in mismatching model and after taking the constraint factor $K_W^{un/ov}$, it will be able to determine the normalised parameter $\delta_R = \delta_w / \delta_B$ [δ_w, δ_B - the CTOD of crack in the weld metal (W) and base metal (B) respectively] as follows [13]:

- undermatching case at matching ratio $K_S = R_e^B / R_e^{W(un)} > 1$:

$$\sigma_1 < R_e^{W(un)} < R_e^B \quad \delta_R = K_S \frac{1 + \frac{K_S^2}{2} \left(\frac{\sigma_1}{R_e^B} \right)^2}{1 + \frac{1}{2} \left(\frac{\sigma_1}{R_e^B} \right)^2} \quad (26)$$

lower limit:

$$\frac{\sigma_1}{R_e^B} \rightarrow 0 \quad \delta_R = K_S \quad (27)$$

upper limit:

$$\frac{\sigma_1}{R_e^B} = \frac{1}{K_S} \quad \delta_R = \frac{3}{2} \frac{K_S^3}{2K_S^3 + 1} \quad (28)$$

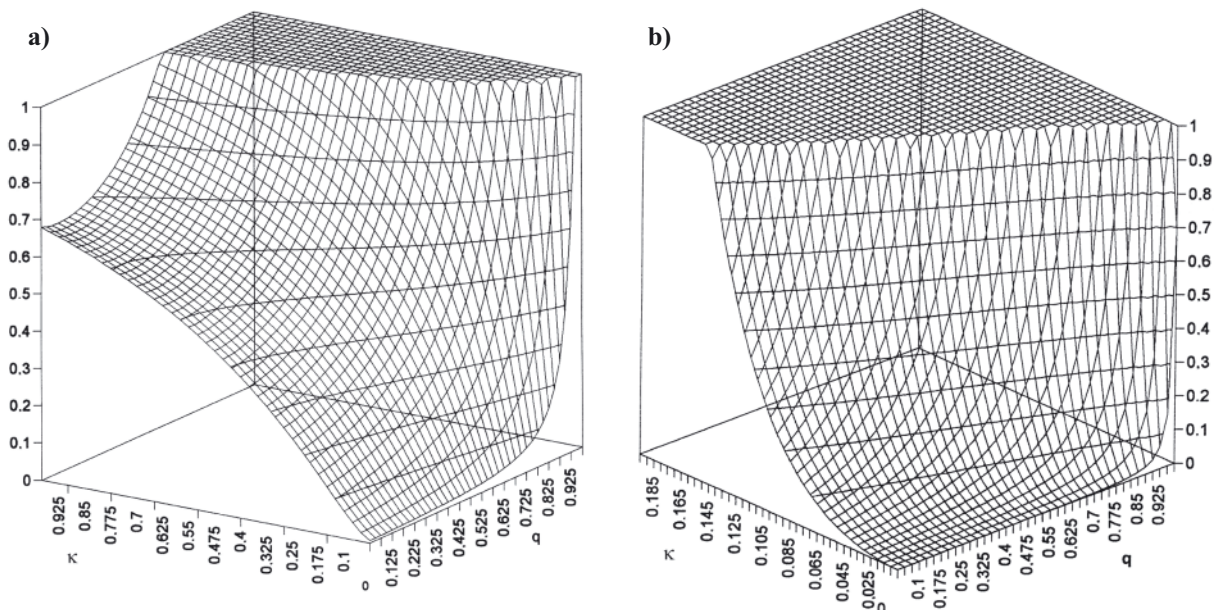


Fig. 6. Normalised size of: a) r_p^{un}/r_p b) r_p^{ov}/r_p respectively for undermatched and overmatched models of weld joints

$$R_e^B > \sigma_1 \geq R_e^{W(un)} \quad \delta_R = \left(\frac{K_W^{un}}{K_S} \right)^{\left(1 - \frac{1}{n_W}\right)} \quad (29)$$

$$\sigma_1 \geq R_e^B \geq R_e^{W(un)} \quad \delta_R = \left(\frac{K_W^{un}}{K_S} \right)^{\left(\frac{1}{n_W} - \frac{1}{n_B}\right)} \left(\frac{1}{K_S} \right)^{\left(1 - \frac{1}{n_W}\right)} \quad (30)$$

- overmatching case at matching ratio $K_S = R_e^B / R_e^{W(un)} < 1$:

$$\sigma_1 < R_e^B < R_e^{W(ov)} \quad \delta_R = K_S \frac{1 + \frac{K_S^2}{2} \left(\frac{\sigma_1}{R_e^B} \right)^2}{1 + \frac{1}{2} \left(\frac{\sigma_1}{R_e^B} \right)^2} \quad (31)$$

lower limit:

$$\frac{\sigma_1}{R_e^B} \rightarrow 0 \quad \delta_R = K_S \quad (32)$$

upper limit:

$$\frac{\sigma_1}{R_e^B} = 1 \quad \delta_R = \frac{2}{3} K_S \left(1 + \frac{K_S^2}{2} \right) \quad (33)$$

$$R_e^{W(ov)} > \sigma_1 \geq R_e^B \quad \delta_R = \left(\frac{K_W^{ov}}{K_S} \right)^{\left(1 - \frac{1}{n_B}\right)} \quad (34)$$

$$\sigma_1 \geq R_e^{W(ov)} \geq R_e^B \quad \delta_R = \left(\frac{K_W^{ov}}{K_S} \right)^{\left(\frac{1}{n_W} - \frac{1}{n_B}\right)} \left(\frac{1}{K_S} \right)^{\left(1 - \frac{1}{n_W}\right)} \quad (35)$$

The results of this study of mismatched weld joints reveals the high dependence of the fracture parameter δ_R according to the equations (26) ÷ (35) on parameters such as $K_W^{un/ov}$, K_S and n_W , n_B . These are new and modified equations in which it was introduced that the quantitative assessment of the constraint effect on the fracture toughness of the mismatched weld joints is used.

For example in Figures 7 and 8 the characteristics of the driving forces ratio δ_R has presented as a function of relative thickness κ of zone W in according to equations (30), (35) for a ferritic steel whose properties are:

- undermatching case:
 $R_e^W = 434$ MPa; $R_e^B = 605$ MPa
 $n_W = 0.25$; $n_B = 0.20$
- overmatching case:
 $R_e^W = 605$ MPa; $R_e^B = 434$ MPa
 $n_W = 0.20$; $n_B = 0.25$

Furthermore, the parameter δ_R has been presented in Figures 9, 10 as a function of κ at $q = 0$ and $K_S = 1.05 \div 1.30$ for undermatching case and as a function of K_S at $q = 0$ and $\kappa = 0.1$; 0.9 ; 4 ; 10 .

The results of this study of mismatched weld joint reveals high dependence of the fracture parameter δ_R according to

equations (30) ÷ (35) on the constraint factors K_W^{un} , K_W^{ov} and matching ratio K_S and strain hardening exponents n_W , n_B .

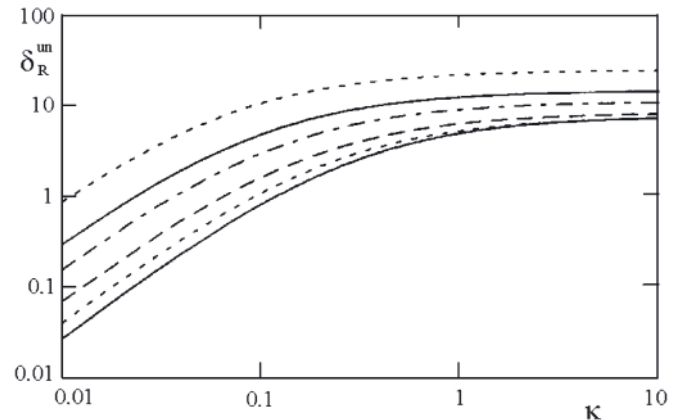


Fig. 7. Diagram of δ_R^{un} as a function of κ at $q = 0.1 \div 0.9$ and $K_S = 1.39$

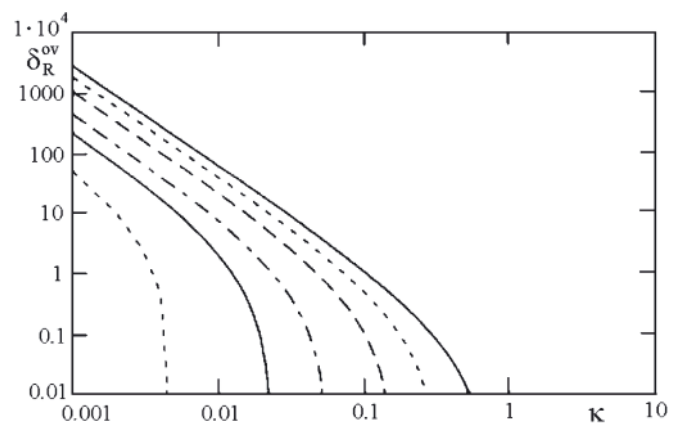


Fig. 8. Diagram of δ_R^{ov} as a function of κ at $q = 0.1 \div 0.9$ and $K_S = 0.72$

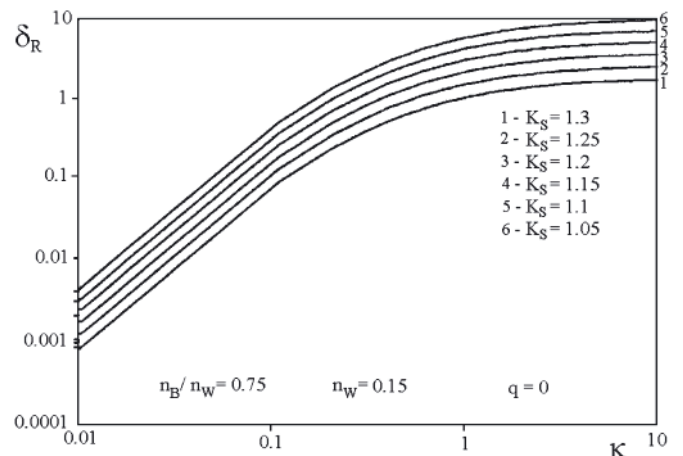


Fig. 9. Diagram of δ_R^{un} as a function of κ at $K_S = 1.05 \div 1.30$

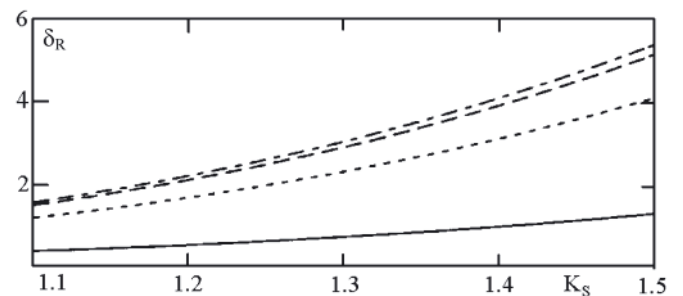


Fig. 10. Diagram of δ_R^{un} as a function of K_S at $q = 0$, $\kappa = 0.1$; 0.9 ; 4 ; 10

SYNTETIC CONCLUSIONS

- The objective in Computational Welding Mechanics is to extend the capability to analyze the evolution of temperature, stress and strain in welded structures together with the evolution of microstructure. In narrowest sense computational weld mechanics is concerned with the analysis of temperatures, displacements, strains and stresses in welded structures.
- Having based on the thermo-mechanical couple in welding process the algorithm can be defined for the weldability estimating with the modules I ÷ III and submodules 1 ÷ 8 for the numerical assessment of this one. The basic characteristic of strains, stress constraint effect and normalised fracture mechanics parameters as measurement of the susceptibility are calculated. Finally, an analytical assessment of the step of susceptibility of base material, weld, HAZ on welding process is described.

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