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

Part I

Eugeniusz Ranatowski, Prof.
University of Technology and Life Science, Bydgoszcz

ABSTRACT

The process of welding has dynamic character and is related with the local change of the internal energy E of welded system and can be defined by general dependence between intensive φ_j and extensive ψ_j parameters. The knowledge of the run of thermo-dynamical process under welding indicates on the possibility of active modelling of weldability and the control of welding process: $\varphi_j = \partial E/\partial \psi_j$. Hence, these process can be enhanced by mathematical modelling and numerical analysis of weldability models of, i.e. welding processes of material behaviour in welding and the strength of welded structures. The main attention is focused on the assessment of susceptibility of materials under defined welding conditions using fracture mechanics parameters. The analysis is based on the normalised parameters such as: ∂/∂_c, K_{Ith}/K_{IC}, as a measure of the susceptibility of materials in welding process. The deformation process and fracture parameters calibrations are influenced by constraint; hence the importance of determining the deformation behaviour and fracture parameters as a function of constraint. Furthermore, there established analytically the condition of welding process in mismatched weld joints for strength equal to base metal. Finally, same analytical examples which present new capabilities of weldability estimates and mechanical properties of mismatched weld joints are presented.

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

INTRODUCTION

For some groups of welded joints, considerable local diversification of the material structure and, consequently, of the mechanical properties may occur in the weld or in the heat affected zone (HAZ). This can take place during welding of high strength steel and strain or age hardened steel, etc. Changes in the material structure are directly related to the mechanical properties.

The micro-structural models are in many cases sufficiently advanced to give accurate predictions for welds and HAZ. Till now the potential of quantitative weldability analysis and method in the design process is not so clear [1].

The problem of optimal design of welded structures is very complex and various attempts have been made to obtain effective methods which might be used in engineering, which requires appropriate dimensioning of materials and constructions. The application of the classical strength effort hypothesis is inconsiderable when defects, such as cracks, occur.

The discontinuities, such as cracks, show that the Huber – Mises equivalent of stress exceeds critical value at low load. The elasticity solutions of problems involving stress concentrations show that the stress becomes singular as the notch root radius tends to zero; the theoretical stress at the notch is singular. Various approximate methods of calculation are often used in designing, e.g. reducing internal forces, yet the best approach is based on fracture mechanics and its parameters and criterions. The application of fracture mechanics parameters to materials and constructions dimensioning is a great step towards effort process modelling compliant with the modelling rules [2], which justifies the aim of the present research – physical characteristics of weldability and the main parameters and criterions of fracture mechanics and its applicability to welded structure designing and dimensioning.

THE GLOBAL ESTIMATE OF THE WELDABILITY

Currently the welding as a technological process is concerned with special processes, the results of which cannot be checked in a complete degree by the subsequent control, test of production. Numerical weldability analysis is a new powerful research and development tool which is useful for metallurgists, technologist and design engineers. Weldability denotes the possibility to join parts by welding under defined conditions of design, materials and manufacture [1]. Weldability is conventionally ascertained and further developed by testing – empirical basis. This process can be enhanced and made more efficient by mathematical modelling and numerical analysis – theoretical basis. Strictly speaking, the numerical analysis of a weldability comprises thermodynamic, thermo-mechanical and micro-structural modelling of the welding process Ref. 3-4. The result of this operation is the different step of susceptibility of the material on welding process which physical measurement is the fracture resistance and decides on the utility of welded joints.

The mathematical modelling of property – determining processes presents a modern and powerful tool to improve engineering materials and their processing such as welding process. Outgoing from the fundamental mechanisms and their physical representation in the form of equation systems, the effect of influencing factors on weldability can be simulated by numerical models. The application of this method results in a considerable reduction of the total development time and costs of experimental investigation. The mathematical modelling allows an optimisation of the numerous influencing parameters with the aim to increase the process reliability and to improve the welding construction properties. It means that the modelling of welding processes requires taking into account the physical phenomena and their interactions [5]. The analysis of the welding process from above point of view, enables to execute the algorithm which is presented in Fig. 1.

The first step of our calculation (module I) effects heat flow character in welding process and determines the nature of the weld thermal cycle and hence, in transformable alloys the metallurgical process and the microstructure of weld metal and heat affected zones (HAZ) (module II) and change of the mechanical specificity (module III). Besides, in agreement with Fig. 1 the estimate of the weldability consists with two stages:

- recurring projection process of the structure feature of weld metal and HAZ in comparison with base metal-submodules 1, 2, 3, 4,
- estimating of the result of this process through analysis of the feature of mechanical properties-submodules 5, 6, 7, 8.

According to former configuration we can ascertain that Ref.6-7:

- solute distribution during weld pool solidification is an important phenomenon resulting in segregation that can significantly affect the weldability, microstructure and properties,
- solidification in weld metal region is complicated by several factors:
  - dynamic nature of the welding process,
  - unknown weld pool shape,
  - epitaxial growth,
  - variations in temperature gradient and the weld metal cooling rate may vary from 10^2 to 10^3 °C s^{-1} for the conventional welding process to 10^5 to 10^7 °C s^{-1} for high – energy beam processes,
- weld solidification controls the size and shape of grains, segregation and defects such as porosity and hot cracks,

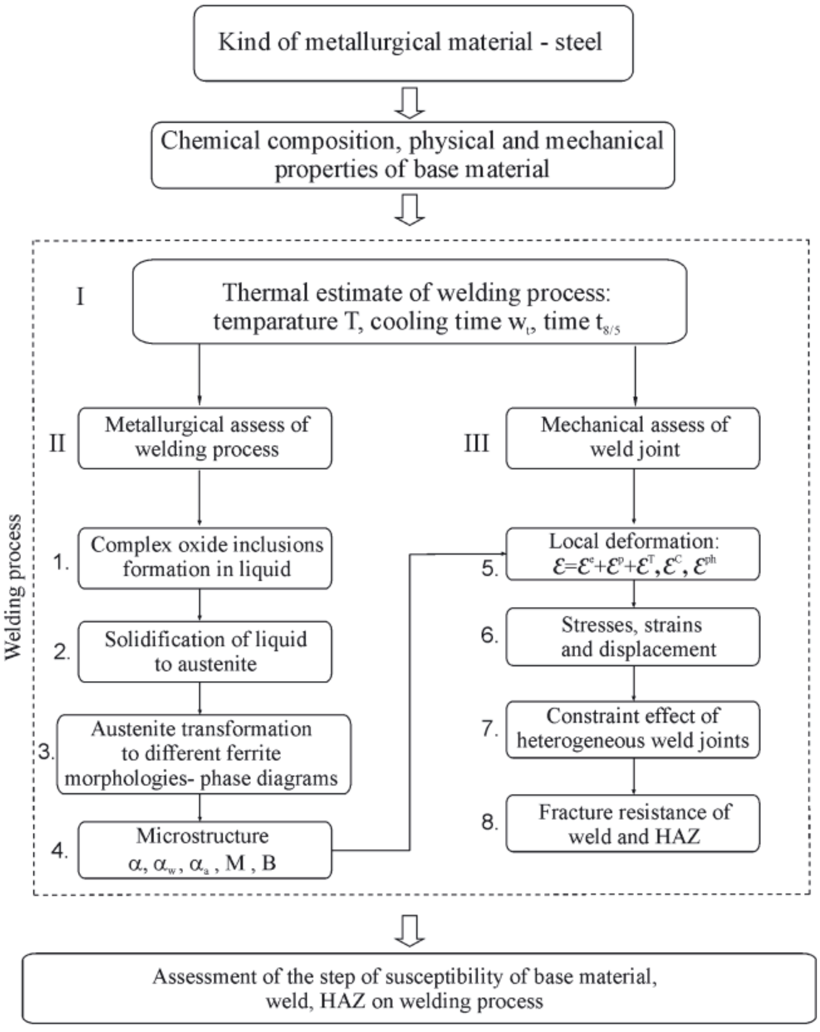

Fig. 1. *Flow chart of the model to assess numerical weldability*

- a lot of attention has been given to modelling the microstructure in weld metal areas and in addition to the phase transformations in solid state during weld thermal cycles,
- the austenite grain size is assumed to be inversely proportional to the nucleation rate is function of $\Delta G^{\delta\to\gamma}$ (G- Gibbs energy).
- the transformation of austenite to various ferrite morphologies in low-alloy ferritic steel weld metal is very sensitive to prior austenite grain size and there is a need for models to predict the austenite grain size as a function of weld metal compositions and welding process variables.

The mechanical analysis of the welded joints is more complex than the heat flow analysis because of the geometry changes and because of the complex stress – strain relationship. Models of the mechanical properties of base metal, HAZ and weld metal, are needed as input data for thermal analysis. The welding process has dynamic character and in general, mechanical behaviour of metals under thermal cycle can be described by module III and submodules 5 ÷ 8, Fig. 1 Ref. 8-10. In this conceptual modelling, the constitutive relation: stress-strain link is the most important in the welding mechanics. One of the fundamental assumption is that the total strain can be divided into components which are produced by different physical processes – submodule 5 [11].

The coupling between thermal and mechanical fields enable to assess the thermo-mechanical diffusion equation [3]:

$$\rho c\dot{T} + \partial q_i / \partial x_j = \dot{Q}_{int} - \frac{E\alpha T}{1-2\nu}\cdot\dot{\varepsilon}^{e}_{ii} + \xi S_{ij}\dot{d}_{ij} \qquad (1)$$

where:

q_i – heat flux per unit area
Q_{int} – internal heat generation
S_{ij} – deviatoric stress tensor
d_{ij} – viscoplastic strain rate tensor
ξ – parameter characterising inelastic energy dissipation $S_{ij}\dot{d}_{ij}$ ($\xi < 1$).

Therefore, it is possible to divide the thermo-mechanical analysis of the welding process into two main parts – the analysis of the thermal field and the subsequent analysis of the mechanical fields for estimate residual stresses and residual deformation submodule 6.

The submodules 7 and 8 characterises the influence of constraint effect of heterogeneous welded joints on the mechanical properties. The effect of strength mis-match in steel weldments has received much attention.

The assessment of the step susceptibility of the base material on welding process is finally lean upon the fracture toughness parameter K_{mat} in terms of stress intensity factor K or his normalised value or others fracture parameters such as δ-CTOD, J.

THE VALUATION OF CONSTRAINT EFFECT IN MISMATCHED WELDED JOINTS

The theory of constrained materials in classical mechanics of deformable media is characterised by a restriction on the class of possible motions. One of the simplest mechanical constraints, namely the condition of incompressibility, has played a central role in the formulation and utilisation of constitutive equations for linear and non-linear elastic solids as well as the development of constitutive theories of other media including plasticity.

In order to solve this problem for mismatched welded joints which constitutes the aim of the present work, the simplified model is created with thin layer W (soft or hard – representing the weld metal or part of HAZ) which is taken into account and show in Fig. 2.

One of the primary features of welded structures is the macro-mechanical heterogeneity. The heterogeneous nature of the weld joints is characterised by macroscopic dissimilarity in mechanical properties. This mismatch causes constraints in macroscopic scale and local stress concentrations which are enhanced by geometric and physical parameters of the mismatched weld joints and state of loading – under tension or bending loading. The determination of local change in the stress occurring at the interface of zones (B) and (W) is then of primary importance for correct interpretation and estimation of new mechanical properties.

The components of the stress state in mismatched weld joints under static tension are determined by the equilibrium equations and the equation of the plasticity condition which fulfils the boundary condition of the interfaces of zones B and W. The stress analysis in this area has been performed in [12].

A very useful form of the stress state we can obtain by changing the parameters $\gamma \to q$:

- undermatched case:

$$\gamma = k_1 / k \; ; \; |\gamma| \le 1 \; ; \; k = R_e^{W(un)}/\sqrt{3} \; ; \; -k \le k_1 \le k \; ; \; R_e^{W(un)} \le R_e^{B}$$

- overmatched case:

$$\gamma = k_1 / k \; ; \; |\gamma| \le 1 \; ; \; k = R_e^{W(ov)}/\sqrt{3} \; ; \; -k \le k_1 \le k \; ; \; R_e^{W(ov)} \le R_e^{B}$$

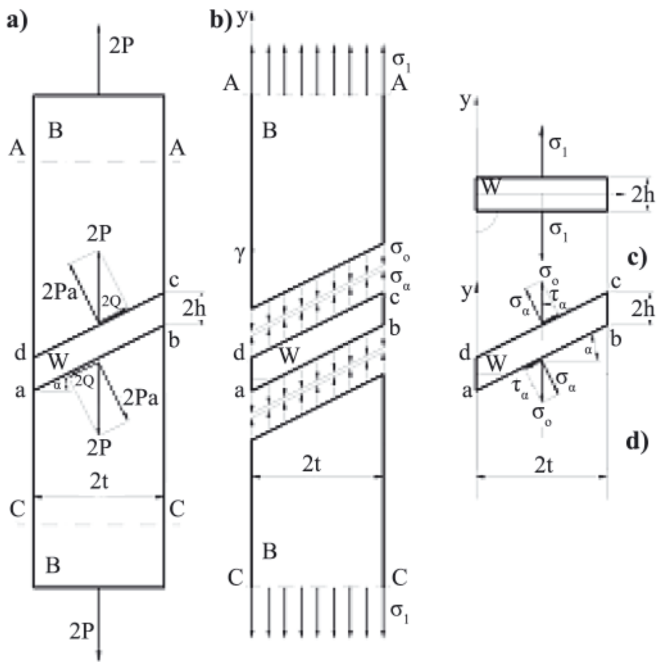

Fig. 2. Characteristic of the model of the mismatched weld joints: ***a)*** *geometrical configuration - layer W is inclined to external load;* ***b)*** *distribution of external stresses σ_1 and σ_α;* ***c)*** *external stress at interface for perpendicular layer;* ***d)*** *external stress at interface for inclined layer*

The parameter γ represents the internal normalised tangential stress at interfaces and parameter q ($0 \le q \le 1$) represents the external normalised tangential stress caused by force 2Q. While using of the relation between γ and q as:

$$\gamma + 1 = 2q \to \gamma = 2q - 1 \qquad (2)$$

and after insert the value of q:

$$q = (\sigma_1/k)\sin 2\alpha \qquad (3)$$

to equation (2) can be transformed the components of stress in the form very useful in engineering practice as follows [13]:
- undermatching case:

$$\sigma^{un}_{xx(n)} = \frac{\sigma^{un}_{xx}}{k} = \Bigg[\frac{1}{2 - 2\cdot\left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)} \cdot$$
$$\cdot\left[\frac{\pi}{2} - \left[2\cdot\left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)-1\right]\cdot\sqrt{1-\left[2\cdot\left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)-1\right]^2} + \right.$$
$$\left. -\arcsin\left[2\cdot\left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)-1\right]\right] + \left(1-\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)\cdot\frac{\xi}{\kappa} + \tag{4}$$
$$-2\cdot\sqrt{1-\left[\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right| + \left(1-\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)\cdot\frac{\eta}{\kappa}\right]^2}\,\Bigg]$$

$$\sigma^{un}_{yy(n)} = \frac{\sigma^{un}_{yy}}{k} = \frac{1}{2 - 2\cdot\left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)} \cdot$$
$$\cdot\left[\frac{\pi}{2} - \left[2\cdot\left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)-1\right]\cdot\sqrt{1-\left[2\cdot\left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)-1\right]^2} + \right. \tag{5}$$
$$\left. -\arcsin\left[2\cdot\left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)-1\right]\right] + \left(1-\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)\cdot\frac{\xi}{\kappa}$$

$$\sigma^{un}_{xy(n)} = \frac{\sigma^{un}_{xy}}{k} = \frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right| + \left(1-\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W}\cdot\left|\sin(2\cdot\alpha)\right|\right)\cdot\frac{\eta}{\kappa} \tag{6}$$

where:

$k = R_e^W/\sqrt{3}$; $R_e^W \le R_e^B$; $\kappa = 2h/2t$

$\eta = 2y/2t$; $\xi = 2x/2t$; $\kappa \ge \eta$

R_e^W – yield point of layer

R_e^B – yield point of base material.

The σ_1 can assess the following values for undermatching case:

a. B - elastic, W – elastic:

$$\sigma_1 < R_e^W < R_e^B \tag{7}$$

b. B – elastic, W – plastic:

$$R_e^W \le \sigma_1 < R_e^B \tag{8}$$

c. B and W – plastic:

$$\sigma_1 \ge R_e^B \ge R_e^W \tag{9}$$

- overmatched weld joints:

$$\sigma_{xx(n)}^{ov} = \frac{\sigma_{xx}^{ov}}{k} = \left[\frac{1}{2 - 2 \cdot \left(\frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right)} \cdot \right.$$
$$\cdot \left[-\frac{\pi}{2} + \left[2 \cdot \left(\frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right) - 1 \right] \cdot \sqrt{1 - \left[2 \cdot \left(\frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right) - 1 \right]^2} + \right.$$
$$\left. + \arcsin \left[2 \cdot \left(\frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right) - 1 \right] \right] + \left(1 - \frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right) \cdot \frac{\xi}{\kappa} + \tag{10}$$
$$\left. + 2 \cdot \sqrt{1 - \left[\frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| + \left(1 - \frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right) \cdot \frac{\eta}{\kappa} \right]^2} \right]$$

$$\sigma_{yy(n)}^{ov} = \frac{\sigma_{yy}^{ov}}{k} = \frac{1}{2 - 2 \cdot \left(\frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right)} \cdot$$
$$\cdot \left[-\frac{\pi}{2} + \left[2 \cdot \left(\frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right) - 1 \right] \cdot \sqrt{1 - \left[2 \cdot \left(\frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right) - 1 \right]^2} + \right. \tag{11}$$
$$\left. + \arcsin \left[2 \cdot \left(\frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right) - 1 \right] \right] + \left(1 - \frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right) \cdot \frac{\xi}{\kappa}$$

$$\sigma_{xy(n)}^{ov} = \frac{\sigma_{xy}^{ov}}{k} = \frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| + \left(1 - \frac{\sqrt{3} \cdot \sigma_1}{2 \cdot R_e^W} \cdot |\sin(2 \cdot \alpha)| \right) \cdot \frac{\eta}{\kappa} \tag{12}$$

where:

$k = R_e^W / \sqrt{3}$; $R_e^W > R_e^B$; $\kappa = 2h/2t$

For overmatching case the σ_1 can assess the following values:

a. B – elastic, W – elastic:

$$\sigma_1 < R_e^B < R_e^W \tag{13}$$

b. B – plastic, W –elastic:

$$R_e^B \le \sigma_1 < R_e^W \tag{14}$$

c. B and W – plastic:

$$\sigma_1 \ge R_e^W \ge R_e^B \tag{15}$$

The conversion of stress state makes a change to mechanical properties of the different part of the mismatched welded joints. As an effective measure of constraint effect we can introduce the stress state parameter S_p as follows:

- undermatching case:

$$S_p^{un} = \sigma_m^{un} / \sigma_H^{un} \tag{16}$$

- overmatching case:

$$S_p^{ov} = \sigma_m^{ov} / \sigma_H^{ov} \tag{17}$$

where:

$\sigma_m^{un\,/\,ov}$ – mean stress

$\sigma_H^{un\,/\,ov}$ – equivalent of stress according to Huber-Mises.

Some examples of an assessment of $S_p^{un\,/\,ov}$ are presented in Fig. 3.
These examples reveal the different tendencies of change of $S_p^{un\,/\,ov}$ with α increase and periodic character.

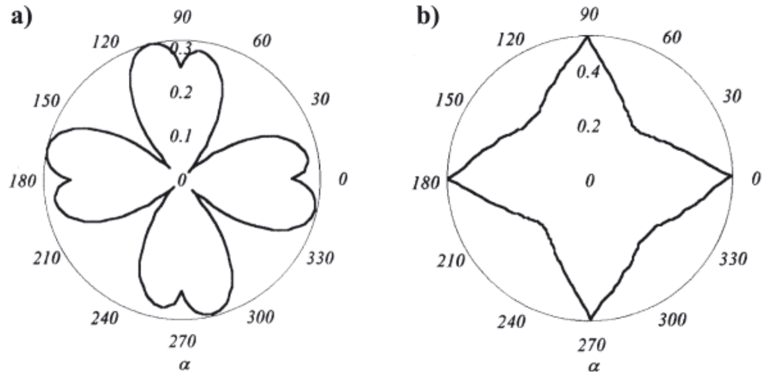

***Fig. 3.** Characteristic of : **a)** S_p^{un} (σ_1 = 500 MPa, R_e^W = 434 MPa) and **b)** S_p^{ov} (σ_1 = 500 MPa, R_e^W = 605 MPa) at α = 0 ÷ 360° in polar coordinates and geometric feature κ = 0.75 , η = 0.1 , ξ = 0.1*

Furthermore, the change analysis of stress state in mismatched models of welded joints enables estimation of constraint factors $K_W^{un\,/\,ov}$ as follows [13]:

$$\begin{aligned} K_W^{un} = \frac{2}{\sqrt{3}} \cdot \Bigg[& \frac{1}{4 \cdot \left(1 - \frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha)\right)} \cdot \\ & \cdot \left[\frac{\pi}{2} + 2 \cdot \left[1 - 2 \cdot \left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha) \right) \right] \right] \cdot \\ & \cdot \sqrt{\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha) \cdot \left(1 - \frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha) \right)} + \\ & - \arcsin\left[2 \cdot \left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha) \right) - 1 \right] \Bigg] + \left(1 - \frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha) \right) \cdot \frac{1}{4\cdot\kappa} \Bigg] \end{aligned} \tag{18}$$

$$\begin{aligned} K_W^{ov} = \frac{2}{\sqrt{3}} \cdot \Bigg[& \frac{1}{4 \cdot \left(1 - \frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha)\right)} \cdot \\ & \cdot \left[-\frac{\pi}{2} - 2 \cdot \left[1 - 2 \cdot \left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha) \right) \right] \right] \cdot \\ & \cdot \sqrt{\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha) \cdot \left(1 - \frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha) \right)} + \\ & - \arcsin\left[2 \cdot \left(\frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha) \right) - 1 \right] \Bigg] + \left(1 - \frac{\sqrt{3}\cdot\sigma_1}{2\cdot R_e^W} \cdot \sin(2\cdot\alpha) \right) \cdot \frac{1}{4\cdot\kappa} \Bigg] \end{aligned} \tag{19}$$

The great value of $K_W^{un/ov}$ appears at small values of κ and when α = 0° or α = 90° at values of $\sigma_1 = R_e^B$ for undermatched case or $\sigma_1 = R_e^W$ for overmatching case – Fig. 4.

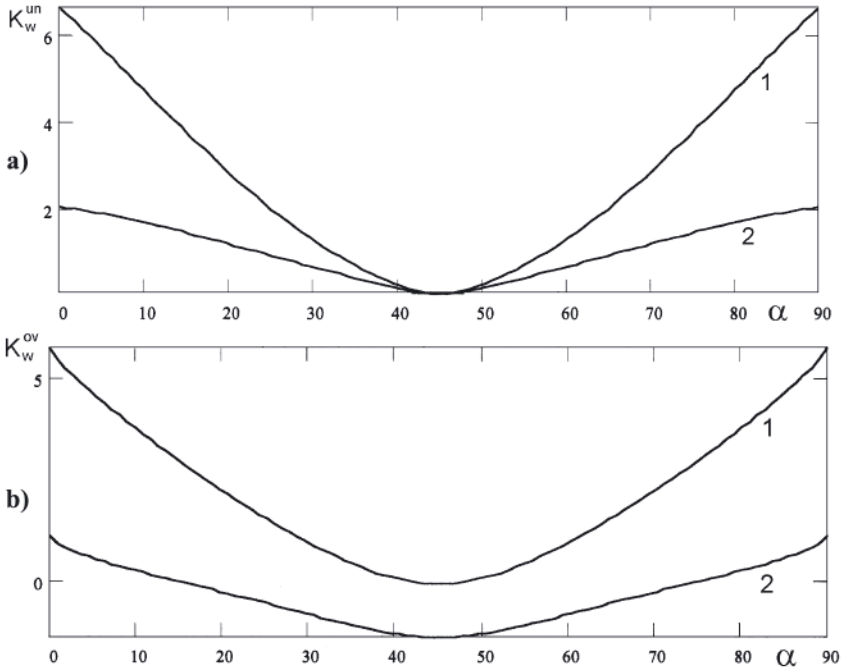

Fig. 4. Characteristic of K_W^{un} and K_W^{ov} for: a) undermatching: R_e^W = 434 MPA, σ_1 = 500 MPA, α = 0 – 90°, κ_1 = 0.05; κ_2 = 0.25, curves: 1 for κ_1; 2 for κ_2; b) overmatching: R_e^W = 605 MPA, σ_1 = 500 MPA, α = 0 – 90°, κ_1 = 0.05; κ_2 = 0.25, curves: 1 for κ_1; 2 for κ_2

We can also transform the constraint factors $K_W^{un/ov}$ as follows [14]:

$$K_W^{un} = \frac{2}{\sqrt{3}}\left(\frac{1}{4(1-q)}\left[\frac{\pi}{2} + 2(1-2q)\sqrt{q(1-q)} - \arcsin(2q-1)\right] + (1-q)\frac{1}{4\kappa}\right) \tag{20}$$

$$K_W^{ov} = \frac{2}{\sqrt{3}}\left(\frac{1}{4(1-q)}\left[-\frac{\pi}{2} - 2(1-2q)\sqrt{q(1-q)} + \arcsin(2q-1)\right] + (1-q)\frac{1}{4\kappa}\right) \tag{21}$$

where:
$0 \le q < 1$
$\kappa = 2h/2t$

Fig. 5. shows the dependence of the constraint factors $K_W^{un/ov}$ on the parameters κ and q.

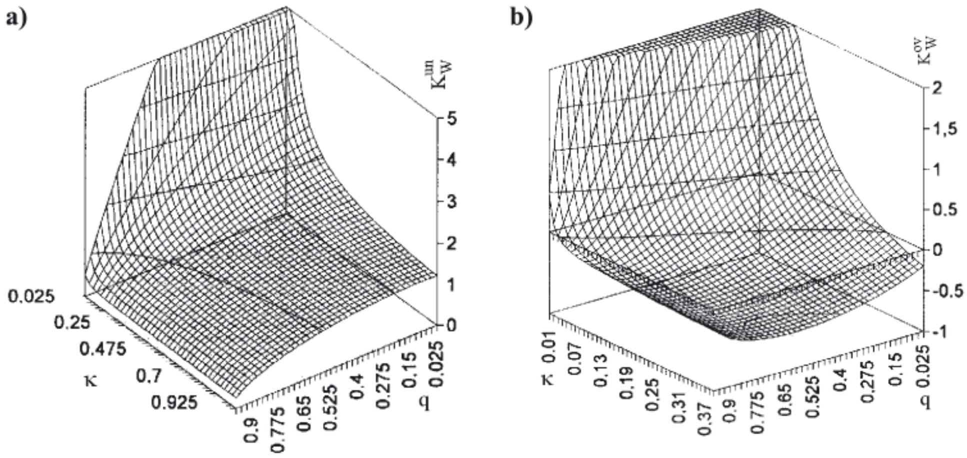

Fig. 5. Diagrams of K_W^{un}, K_W^{ov} for: a) undermatched; b) overmatched models of weld joints

The above data indicate that the constraint factors K_W^{un}, K_W^{ov} increases at small values of κ and q but it attains the different values for under- and overmatched cases. Under the assumption that the materials of zones B and W are perfectly ductile the new values of the yield point is given by:

- undermatching case ($R_e^W < R_e^B$):

$$R_e^{W(un)} = K_W^{un} \cdot R_e^W \tag{22}$$

- overmatching case ($R_e^W > R_e^B$):

$$R_e^{W(ov)} = K_W^{ov} \cdot R_e^W \tag{23}$$

The values of $K_W^{un/ov}$ indicate that the constraint effect considerably influences the mechanical properties of the mismatched weld joints.

CONCLUSION

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.

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CONTACT WITH THE AUTHOR

Prof. Ranatowski Eugeniusz
Faculty of Mechanical Engineerig,
University of Technology and Life Science,
Prof. S. Kaliskiego 7
85-763 Bydgoszcz, POLAND
e-mail: ranatow@utp.edu.pl

The end of Part I – to be continued in POLISH MARITIME RESEARCH, No 2/2012