ANALYTICAL ASSESSMENT OF THE CONSTRAINT EFFECT OF UNDERMATCHED WELD JOINTS

E. Ranatowski

The paper deals with some aspects of the theory of constraint factor K_W and its application to an assessment of the fracture resistance of undermatched weld joints. Conclusions from the theoretical analysis form some basis for the application of parameter K_W to an assessment of the fracture parameters. For example, there an assessment of the ratio of driving forces δ_R was made.

INTRODUCTION

Weld joints are often highly inhomogeneous. For some groups of welded joints, considerable local variations of the material structure and consequently, of the mechanical properties may occur in the weld or in the heat affected zone (HAZ). Changes in the material structure are directly related to the fundamental mechanical properties in that area, e.g., Re and R. We will focus our attention on a simplified theoretical model in which the weld metal or part of the HAZ is imitated by a soft layer (W) the yield strength of which $R_e{}^W$ is smaller than that of the base material, $R_e{}^B$. Moreover, the model was based on the assumption that the materials used are of ideal plasticity.

Mechanical Department, Technical University
ul. Ks. Kordeckiego 20, 85-225 Bydgoszcz, Poland

CHARACTERIZATION OF THE CONSTRAINT FACTOR K_W

Determination of change in the state of stress occuring in that area is of primary importance for a correct interpretation and estimation of mechanical properties. The main difficulty in the adequate estimation of the state of stress is that the material of an undermatched weld joint undergoes heterogeneous deformations which result in non-uniform stress pattern. It is possible for discontinuities of stresses to arise, but that should not disturb the equilibrium state.

After setting the assumption a stress analysis was made for the cases of perpendicular and non-perpendicular orientation of the reduced - hardness zone relative to the loading direction according to reference (1). The stress analysis was made in agreement with principles of the mechanics of solids and the components of the state of stress in undermached weld joints under static tension are determined by the equilibrium equations and the equation of the plasticity condition which fulfilling the boundary condition on the interface of the reduced hardness zone.

First of all, the results establish the constraint factor K_W:

$$K_w = \frac{2}{\sqrt{3}}\left(\frac{1}{4(1-q)}\left[\frac{\pi}{2} + 2(1-2q)\sqrt{q(1-q)} - \arcsin(2q-1)\right] + (1-q)\frac{1}{4\chi}\right) \quad (1)$$

$$0 \leq q < 1 \quad (2)$$

$$\chi = h / l \quad (3)$$

The constraint factor K_W describes the actual relative strength of undermatched weld joints as a result of the change in the state of stress.

Figure 1 presents the dependence of the constraint factor K_W on the parameters χ and q. Furthermore the constraint factor K_W as a function of χ has been presented on the figure 2 and some values of K_W are given in table 1.

The theoretical values of K_W indicate that the mechanical properties of the soft layer can be considerably improved due to the change in stresses of that area. Finally, the relative thickness χ of the layer (W), which has no negative effect on the whole strength of the undermatched weld joints,

TABLE 1 Values of the constraint factor K_W according to equation (1)

χ	0,025	0,975	0,025	0,975
q	0,025	0,025	0,975	0,975
K_W	12,18	1,21	0,52	0,25

can be calculated from the following equation according to reference (1):

$$\chi = \frac{1-q}{2\sqrt{3}(1-q)K_S\gamma^B - [\frac{\pi}{2} + 2(1-2q)\sqrt{q(1-q)} - \arcsin(2q-1)]} \qquad (4)$$

$$K_S = \frac{R_e^B}{R_e^W} > 1 \qquad (5)$$

$$\gamma^B = \frac{R^B}{R_e^B} \geq 1 \qquad (6)$$

INFLUENCE OF K_W ON THE FRACTURE RESISTANCE

The above analysis forms a basis for the application of K_W to the assessment of the fracture parameters. According to the previously determined equations by Schwalbe (2) for assessing the ratio of the driving forces in the weld metal and base metal and after taking the constraint factor K_W, we will be able to determine the parameter $\delta_R = \delta_W / \delta_B$ as follows:

Regions (B) and (W) fully plastic

$$\delta_R = (\frac{1}{K_S})^{(1-(1/n_w))} (\frac{K_w}{K_S})^{(\frac{1}{n_w} - \frac{1}{n_B})} \qquad (7)$$

Figure 3 presents the characteristics of the parameter δ_R as a function of χ at $q=0{,}1 \div 0{,}9$ according to equation (7) for a high strength steel whose properties are:

$$R_e^W = 813{,}5 \quad (MPa) \qquad and \qquad R_e^B = 1046{,}5 \quad (MPa).$$

Furthermore the parameter δ_R has been presented in figure 4 as a function of χ at $q=0$ and $K_S = 1{,}05 \div 1{,}30$ according to equation (7).

CONCLUSIONS

An analytical assessment of the fracture resistance of an undermatched weld joints reveals high dependance of the fracture parameter δ_R according to equation (7) on the parameters: $K_W = f(\chi, q)$ and K_S . The constraint factor $K_W = f(\chi, q)$ increases when the parameters χ and q decrease. The actual value of K_W depends also on the mechanical properties of undermatched weld joints such as: γ^B, K_S. The thus determined parameter δ_R gives the basic information about how to choose the critical parameter CTOD in undermatched weld joints for having strength equal to base material.

SYMBOLS USED

γ^B = parameter of the mechanical properties of the base material
δ_R = ratio of the driving forces
χ = relative thickness of the soft layer
h = half of the thickness of the soft layer (m)
K_S = matching ratio
K_W = constraint factor
l = half of the width of soft layer (m)
n_B = strain hardening exponent of the base material
n_W = strain hardening exponent of the weld or part of HAZ
R_e^W = yield point of the weld or part of HAZ (MPa)
R_e^B = yield point of the base material (MPa)
R^B = tensile strength of the base material (MPa)

REFERENCES

(1) Ranatowski E. "Analysis of the mechanical properties of undermatched weld joints" Proceedings of the International Symposium on Mis-Matching of Welds, Mechanical Engineering Publications, London, U.K., 1994

(2) Schwalbe K.H. "Effect of weld metal mis - match on toughness requirments; Some simple analytical considerations using the Engineering Treatment Model (ETM)" International Journal of Fracture, 56, 1992, pp. 257-277.

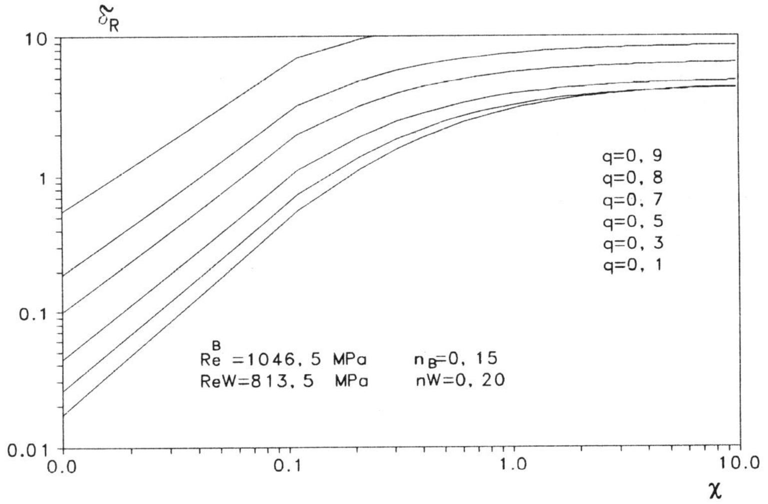

Figure 3 Diagram of δ_R as a function of χ at $q = 0{,}1 \div 0{,}9$ and $K_S = 1.3$

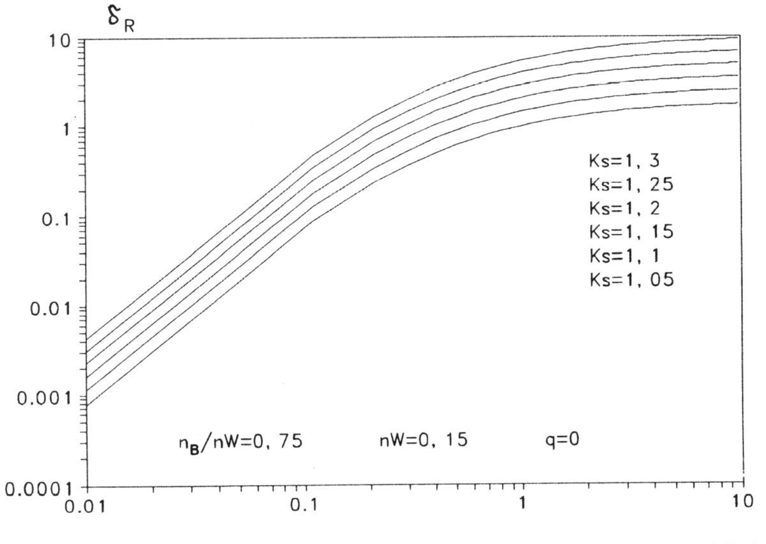

Figure 4 Diagram of δ_R as a function of χ at $q=0$ and $K_S=1{,}05 \div 1{,}30$

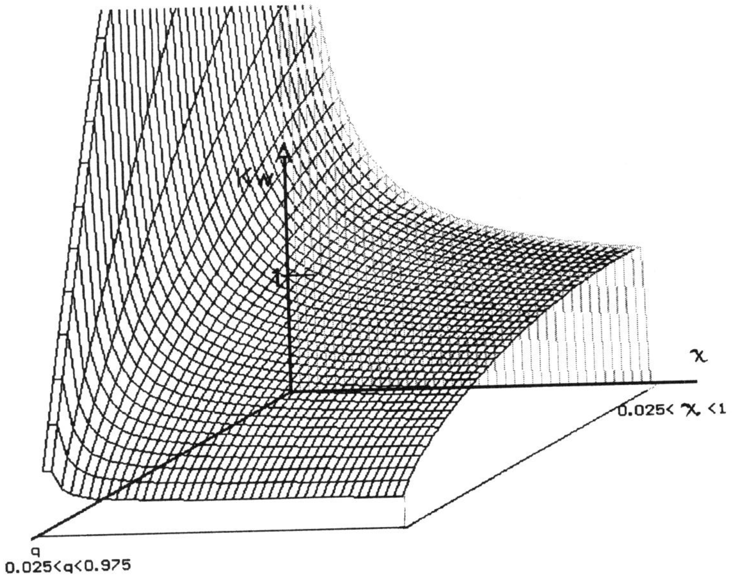

Figure 1 Characteristic of the constraint factor $K_W = f(\chi, q)$

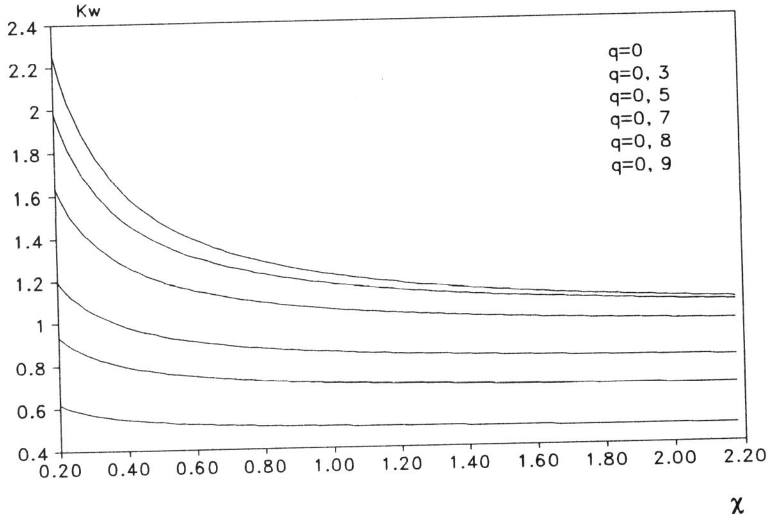

Figure 2 Diagram of $K_W = f(\chi)$ for $0 \leq q \leq 0,9$