DE GRUYTER
OPEN

Vol. 11, Issue 2/2015, 103-109 DOI: 10.1515/cee-2015-0013

IMPACT OF THE WELD GEOMETRY ON THE STRESS INTENSITY FACTOR OF THE WELDED T-JOINT EXPOSED TO THE TENSILE FORCE AND THE BENDING MOMENT

Jelena M. DJOKOVIĆ[1,*], Ružica R. NIKOLIĆ[2], Ján BUJŇÁK[3]

[1] Technical Faculty of Bor, Vojske Jugoslavije 12, 19210 Bor, Serbia.
[2] Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, 34000 Kragujevac, Serbia. Research Center, University of Žilina, Univerzitná 1, 01026 Žilina, Slovakia.
[3] Faculty of Civil Engineering, University of Žilina, Univerzitná 1, 01026 Žilina, Slovakia.
[*] corresponding author: jelenamdjokovic@gmail.com.

Abstract

In this paper it is analyzed the welded T-joint exposed to the axial tensile force and the bending moment, for determining the impact of the weld geometry on the fracture mechanics parameters. The stress intensity factor was calculated analytically, based on the concept of the linear elastic fracture mechanics (LEFM), by application of the *Mathematica*® programming routine. The presence of the weld was taken into account through the corresponding correction factors. The results show that increase of the size of the triangular welds leads to decrease of the stress intensity factor, while the SIF increases with increase of the welds' width. The ratio of the two welded plates' thicknesses shows that plate thicknesses do not exhibit significant influence on the stress intensity factor behavior.

Keywords:

Welding;
T-joint;
Filled weld;
Stress Intensity Factor (SIF);
LEFM concept.

1. Introduction

Elements of the modern steel structures are mainly joined by welding. Those elements are used for transferring the load from one to another. Thus, the resistance and the carrying capacity of the welded joints are of the utmost importance for integrity of the structure as a whole. There are different factors that are affecting the welded joint resistance: the quality of the weld's execution, cleanliness of the parts' surfaces prior to welding, temperature control of the environment before and during the welding, geometrical discontinuities (the weld's root, and radius, absence of overlap between the welded parts). Those factors directly influence resistance of the weld and its vicinity. Furthermore, they can cause a fatigue crack to develop in that area [1-3]. Influence of the weld's geometry on the fatigue life of the load-free welded joint was considered in paper [1], while in [2] an analysis was conducted of the fatigue crack growth in the welded structures subjected to bending. The local stress field is intensified by geometrical discontinuities, what decreases the carrying capacity of the welded joint and, as a result, safety and reliability of the welded structure are significantly compromised [4-5]. In paper [6] authors were investigating the possibility for unifying the various criteria, which are used for analysis of the welded joints' fatigue strength and which are based on the influence of geometry on the local stress field and on predicting the remaining working life based on the linear fracture mechanics concept. Influence of geometry of the main and attachment plates in the T and cruciform welded joints subjected to tension was analyzed in [7]. In paper [8] authors have determined the stress intensity factor of the welded tubes exposed to tension. A survey of determination of the stress intensity factor and fatigue crack growth in shells with a notch and in beams of the circular cross-section is presented in paper [9].

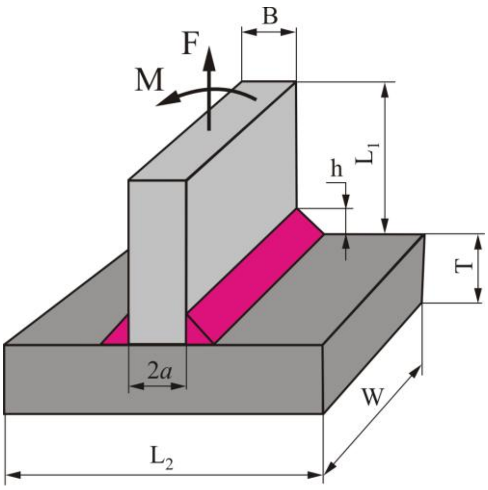
When the two parts are joined by the fillet weld, they are leaned against each other and welded in the corner of the joint, where the filler metal creates a weld. There, the face surface of the thinner part is not connected to the surface of the thicker part, Fig. 1. That geometrical discontinuity acts as a crack whose size is equal to thickness of the thinner material.

Analysis of influence of the fillet weld's geometry, plates' thicknesses and length of this geometrical discontinuity, is very significant for explaining the fillet welds behavior. That could help in obtaining the higher fracture resistance of welds.

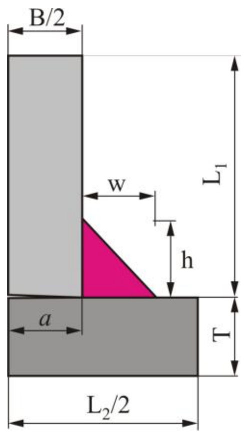
The impact of the weld's shape and geometry on the welded T-joints fracture resistance is considered in this paper, through determination of the stress intensity factor, what is done by application of the concept of the linear elastic fracture mechanics.

The considered problem of welding the two plates in the T-joint is presented in Fig. 1. The first plate's dimensions are length L_1, width W and thickness B and the second plate's dimensions are length L_2, width W and thickness T. The welded part is exposed to the tensile axial force F and the bending moment B. The weld's height is h and width w and it is of the triangular shape.

As can be noticed from Fig. 1, between the two parts there is an unwelded area of width 2a, which can be considered as a crack of the same length, 2a.



(a)



(b)

Fig. 1: Welded T-joint: (a) loads and (b) geometry.

2. Determination of the stress intensity factor

The stress intensity factor for welded joints is, in general case, calculated according to expression, [10]:

$$K_i = Y_i \cdot C_i \cdot \sigma_0 \sqrt{\pi a}\ , \tag{1}$$

where σ_0 represents the referent loading (axial tension, bending or torsion), Y_i is the dimensionless parameter, which depends on the weld's geometry and applied load, while C_i is the correction factor that takes into account the stress concentration due to presence of the weld.

Axial tension and bending, in general, require separate dimensionless parameters Y_t and Y_b, and correction factors, C_t and C_b, respectively, so, when they both act on the weld, equation (1) can be written as:

$$K_i = (Y_t \cdot C_t \cdot \sigma_t + Y_b \cdot C_b \cdot \sigma_b)\sqrt{\pi a}\ , \tag{2}$$

where σ_t and σ_b are the normal stresses due to tension and bending, respectively.

For problem presented in Fig. 1, axial tension and bending have dominant influence on Mode I stress intensity factor, while their influence on Mode II SIF is negligible [6] and it is not considered in this paper.

The Mode I stress intensity factor, for the considered case of the welded T-joint, shown in Fig. 1, based on equation (2), can be written as:

$$K_I = \left[Y_F C_F \sigma_F + Y_M C_M \sigma_M\right]\sqrt{\pi a}\,, \tag{3}$$

where the dimensionless parameter for axial tensile force is:

$$Y_F = \sqrt{\sec\left(\frac{\pi}{2}\frac{a}{a+w}\right)}\,, \tag{4}$$

and the corresponding correction factor is:

$$C_F = \left[1 + \left(\frac{B}{1.8B + 11.2w + 0.84T + 1.68h}\right)^{0.65}\right] \cdot \left[1 + 0.64\frac{(a/B)^2}{2h/B} - 0.12\frac{(a/B)^4}{(2h/B)^2}\right], \tag{5}$$

while the dimensionless parameter for bending moment is:

$$Y_M = \frac{\alpha}{2}\sqrt{\frac{1-\alpha}{1-\alpha^3}} \cdot \left[1 + \frac{1}{2}\alpha + \frac{3}{8}\alpha^2 - \frac{11}{16}\alpha^3 + 0.464\alpha^4\right], \tag{6}$$

where:

$$\alpha = \frac{a}{a+w}\,, \tag{7}$$

and the corresponding correction factor is:

$$C_M = \left[1 + 1.9\sqrt{\tanh\left(\frac{2T}{B+2w}\right) \cdot \tanh\left(\frac{2w}{B}\right)^{0.25}}\right] \cdot \left[1 + 0.64\frac{(a/B)^2}{2h/B} - 0.12\frac{(a/B)^4}{(2h/B)^2}\right]. \tag{8}$$

3. Working life of the welded joint

Welded structures very frequently fracture due to fatigue of the weld. One of the most influential factors that cause the fatigue fracture is the geometry of the weld. A fatigue crack in the welded joint usually is initiated from some of the imperfections in the weld, which are actually the inherent parts of the weld.

When the stress intensity factor K_I, becomes greater than the experimentally determined material characteristics – fracture toughness K_{Ic}, the unstable crack growth would occur. The relationship between the crack length increase Δa and increase of the number of load cycles, ΔN, is the crack growth equation. Paris and Erdogan [11] have established that the change of the stress intensity factor can describe the subcritical crack growth in the fatigue load conditions in the same way as the stress intensity factor describes the critical or the fast fracture. The crack propagation speed is a linear function of the stress intensity factor in the logarithmic diagram, i.e.:

$$\frac{da}{dN} = C(\Delta K)^m\,, \tag{9}$$

where: a – is the crack length, which is changing from the initial value to the critical one, which leads to fracture; N – is number of the load cycles, C and m are the material constants and $\Delta K = K_{max} - K_{min}$ – is the change of the stress intensity factor (i.e., the difference between the stress intensity factor at maximum and minimum load).

The residual working life is obtained by integration of equation (9):

$$N = \int_{a_i}^{a_{cr}} \frac{da}{C(\Delta K)^m}\,, \tag{10}$$

where: a_i – is the initial crack length, while a_{cr} is the critical crack length.

The period of the crack initiation is generally much smaller that the fatigue crack growth period. This is why it is considered that the whole working life of the welded joint is equal to the latter period, while the former period is neglected as the small variable of the higher order. The duration of the fatigue crack growth depends on the load as well as on the weld's geometry. The working life of the welded joint is increasing with the decrease of the applied cycling loading. Subsequently, that increase causes increase of the total working life of the welded joint.

4. Conclusions

The variation of the normalized Mode I stress intensity factor in terms of the normalized crack length is shown in Fig. 2, for the case when the weld is in the form of the isosceles triangle and for the two dimensions of the weld *h* = *w* = 5 mm and *h* = *w* = 10 mm.

The normalized Mode I stress intensity factor variation, in terms of the normalized crack length, is shown in Fig. 3 for the case of non-isosceles triangular shape of the weld, for the two dimensions of the weld *h* = 5 mm, *w* = 10 mm and *h* = 10 mm, *w* = 5 mm.

Both variations of the Mode I SIF were obtained according to expression (3) and application of the symbolic programming package *Mathematica*®. The normalization factor for the Mode I stress intensity factor is $1[\mathrm{MPa}]\cdot\sqrt{\pi\cdot 0.01[\mathrm{m}]}$. Thicknesses of the two plates were *B* = *T* = 10 mm. The two materials' characteristics, used in this analysis, were the Young's elasticity modulus *E* = 210 GPa and the Poisson's ratio *v* = 0.3.

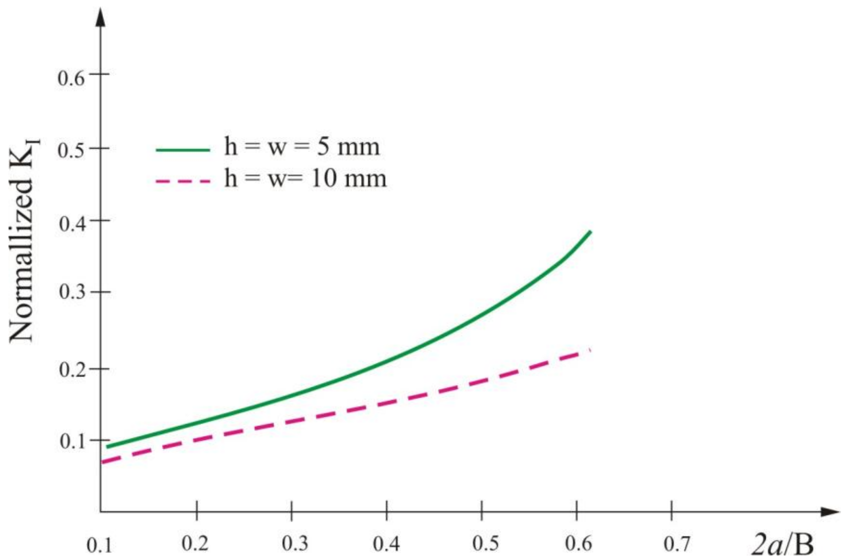


Fig. 2: Normalized Mode I stress intensity factor in terms of the normalized crack length for the case of the weld in the form of isosceles triangle and equal plate thicknesses (*B* /*T* = 1).

The normalized Mode I stress intensity factor variations, in terms of the normalized crack length, are shown in Figs. 4 and 5, for the same parameters as in Figs. 2 and 3, respectively, but for the case when the two plates have different thicknesses. The thickness of the first plate is *B* = 10 mm and of the second plate *T* = 20 mm. The materials' parameters are also the same as for Figs. 2 and 3.

From Fig. 2 one can notice that increase of the weld dimensions leads to decrease of the stress intensity factor. From Fig. 3 follows that the stress intensity factor increases with increase of the welds width *w*. Both conclusions are valid for the case when the two plates have the same thicknesses

(B/T = 1). From Figs. 4 and 5 one can notice that the same trends and conclusions are valid even in the case when the two plates do not have the equal thicknesses (B/T < 1).

Comparisons of Figs 2 and 4 and 3 and 5, respectively, show that the ratio of thicknesses of plates that are being welded has no significant influence on the stress intensity factor behavior.

Variation of the fatigue crack length in terms of number of the load cycles, based on equation (9), is presented in Fig. 6. The weld was the isosceles triangle and variation of the fatigue crack length is presented for the two dimensions $h = w = 5$ mm and $h = w = 10$ mm. Thicknesses of the two plates were equal and amounted to $B = T = 10$ mm. Material constants, necessary for calculating the working life, were $m = 2.75$, $C = 1.5\times10^{-11}$ and $\Delta K = 2.9$ MPam$^{-1/2}$.

Based on Fig. 6 one can conclude that the variations of the weld size have only a small effect on the fatigue life of the welded joint.

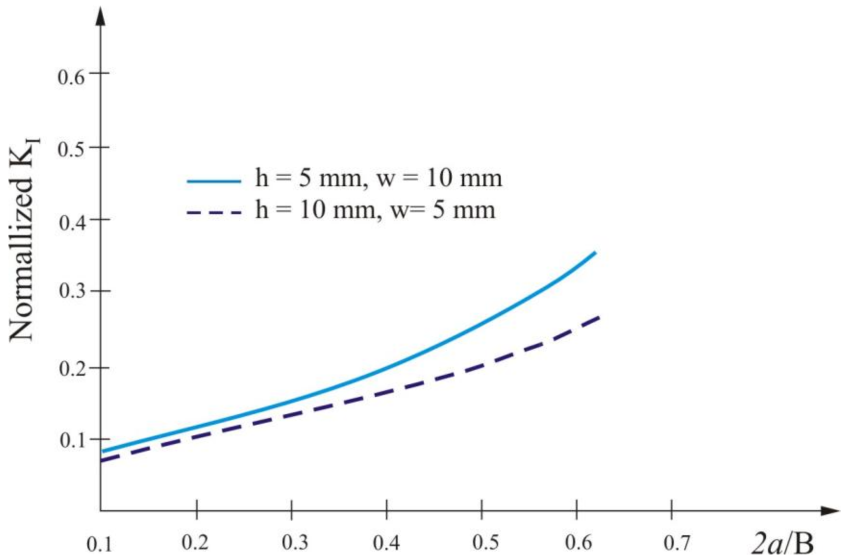


Fig. 3: Normalized Mode I stress intensity factor in terms of the normalized crack length for the case of the weld in the form of the non-isosceles triangle and equal plate thicknesses (B/T = 1).

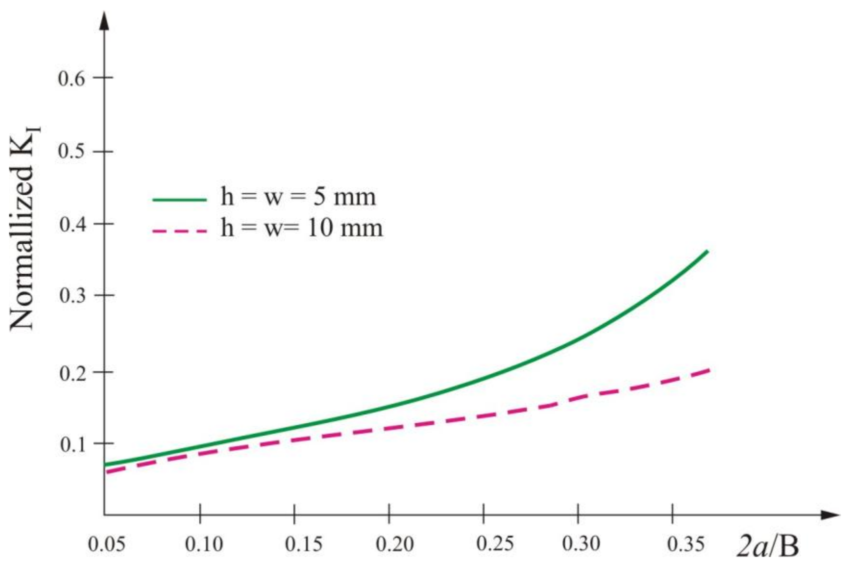


Fig. 4: Normalized Mode I stress intensity factor in terms of the normalized crack length for the case of the weld in the form of isosceles triangle and different plate thicknesses (B/T < 1).

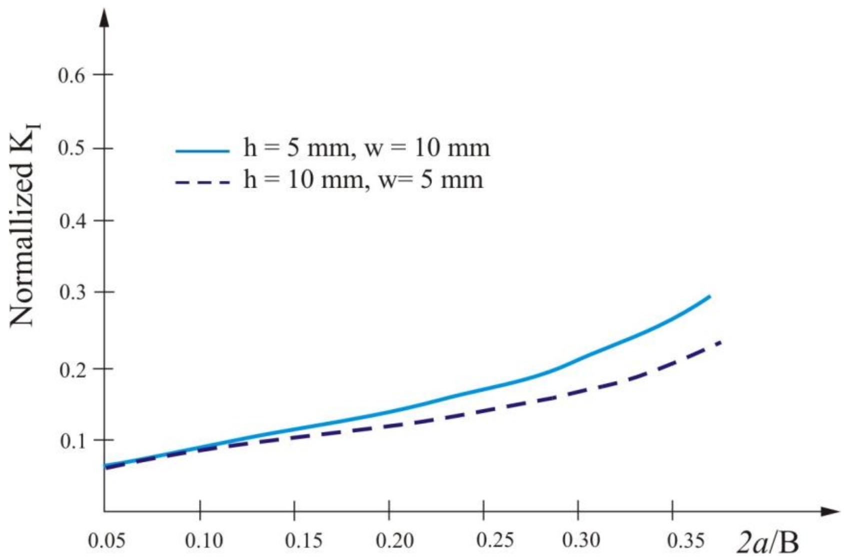


Fig. 5: Normalized Mode I stress intensity factor in terms of the normalized crack length for the case of the weld in the form of non-isosceles triangle and different plate thicknesses (*B* /*T* < 1).

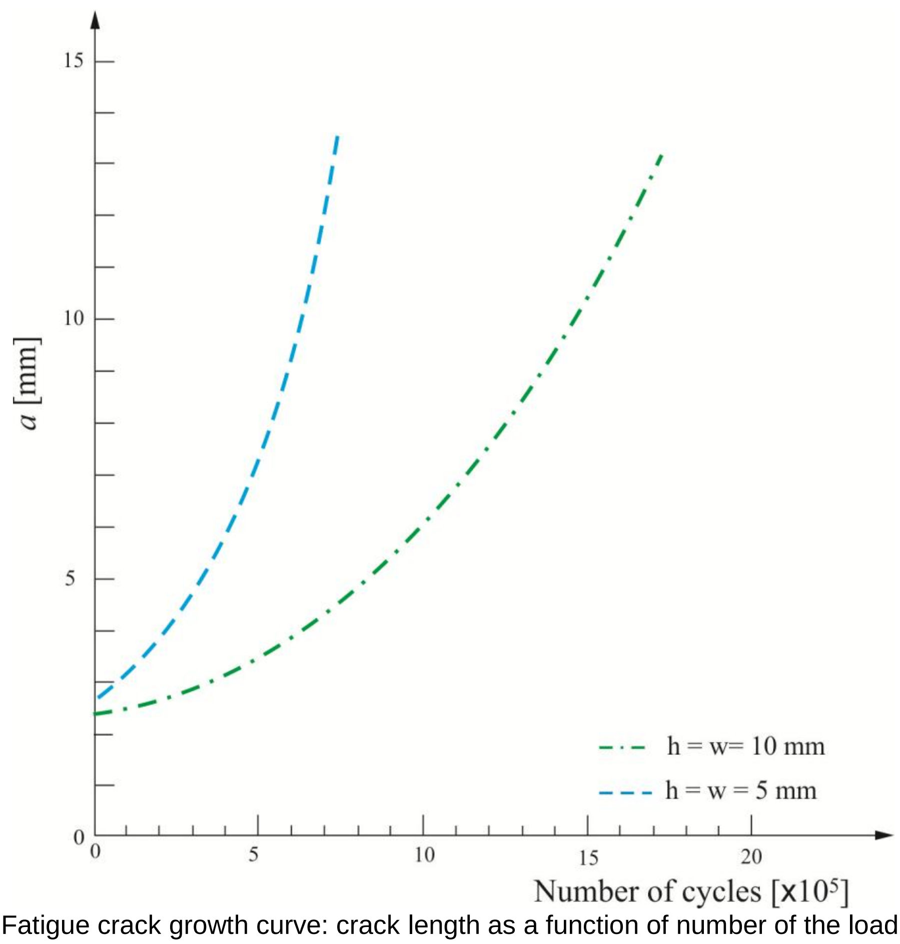


Fig. 6: Fatigue crack growth curve: crack length as a function of number of the load cycles.

Acknowledgement

This research was partially supported by the Ministry of Education, Science and Technological Development of Republic of Serbia through Grants ON174001, ON174004 and TR32036 and by European regional development fund and Slovak state budget by the project "Research Center of the University of Žilina" - ITMS 26220220183.

References

[1] LEE, C. H. – CHANG, K. H. – JANG, G. C. – LEE, C. Y.: (2009), Effect of weld geometry on the fatigue life of non-load-carrying fillet welded cruciform joints, Engineering Failure Analysis, Vol. 16, pp. 849-855.

[2] BAIK, B. – YAMADA, K. – ISHIKAWA, T.: (2011), Fatigue crack propagation analysis for welded joint subjected to bending, International Journal of Fatigue, Vol. 33, pp. 746-758.

[3] CHATTOPADHYAY, A., G. – GLINKA, M. - El-ZEIN, J. Qian – FORMAS, R.: (2011), Stress analysis and fatigue of welded structures, Welding in the World, Vol. 55 (7-8), pp. 2-21.

[4] DJOKOVIĆ, J. M. – VULOVIĆ, S. D. – NIKOLIĆ, R. R. – BUJŇÁK, J.: "Mode I Stress intensity factor of thin-walled beams", Proceedings of 20. Conference "Statics of buildings", Edited by Ján Kysel, 12.-13. March 2015, Pieštany, Slovakia, pp. 113-119, ISBN 978-80-89655-07-6, EAN 8788089655076.

[5] DJOKOVIĆ, J. M. - NIKOLIĆ, R. R. – BUJŇÁK, J. – SEDMÁK, A.: Influence of the weld geometry on the working life of the cylindrical welded joint, Structural Integrity and life, No. 1, 2015. ISSN 1451-3749. (In press).

[6] ATZORI, B. - LAZZARIN, P. - TOVO, R.: (1999), From the local stress approach to fracture mechanics: a comprehensive evaluation of the fatigue strength of welded joints, Fatigue and Fracture of Engineering Materials and Structures, 22, 369-382.

[7] MOTARJEMI, A. K. - KOKABI, A. H. - ZIAIE, A. A. - MANTEGHI, S. - BURDEKIN, F. M.: (2000), Comparison of the stress intensity factor of T and cruciform welded joints with different main and attachment plate thickness, Engineering Fracture Mechechanics, 65, 55-66.

[8] SHEN, W. - CHOO, Y. S.: (2012), Stress intensity factor for a tubular T-joint with grouted chord, Engineering Structures, Vol. **35**, pp. 37-47.

[9] CARPINTERI, A., - RONCHEI, C. - VANTADORI, S.: (2013), Stress intensity factors and fatigue growth of surface cracks in notched shells and round bars: two decades of research work, Fatigue and Fracture of Engineering Materials and Structures, 36, 1164-1177.

[10] HOBBACHER, A.: (1993), Stress intensity factors of welded joints, Engineering Fracture Mechanics, Vol. 46, pp. 173-182.

[11] PARIS, P. – ERDOGAN, F.: (1963), A Critical Analysis of Crack Propagation Laws, Journal of Basic Engineering, Vol. D85, pp. 528-534.