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Investigation on the effect of geometric and structural notch on the fatigue notch factor in steel welded joints

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ABSTRACT

The paper presents an analysis of complex fatigue notch in welded joints, defined through the effect of both geometric notch and structural notch. The undertaken analysis involved fatigue tests conducted using S355N steel test pieces without a notch and with geometric, structural and complex notch. The test results were used to compare fatigue lives of notchless elements with fatigue lives of elements with each notch type.

As an effect of numerous analysis fatigue notch factor was proposed, defined as a power function of number of load cycles and formulated for butt joints under different loadings. The results were compared with results obtained according to the Xiao-Yamada concept of theoretical notch factor.

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1. Introduction

Welded joints are widely used in various industries, including construction, offshore, automotive, and oil&gas, often providing joint of elements essential in terms of providing safety of operation [1–3]. Several methods have been proposed to examine the fatigue phenomena in welded joints: for example, the high stress volume approach [4], the Strain Energy Density (SED) approach [5–7], the critical plane-based criterion [8–10]. The welded joints are particularly susceptible to fatigue destruction, whereas fatigue processes are among the most often causes of failure [11–13], often resulting in high costs or even fatalities [14]. The reason of such a susceptibility is their geometry and changeable structure of the material. The geometric profile configuration of weld and the heterogeneity of material structure in the proximity of welding zone both result from the welding process. As a consequence, such structural element become point of stress concentration [15,16], often playing essential role in safety of the entire structure.

In the following, as stress concentrator we define any type of geometric profile configuration or/and heterogeneity of material structure, occurring in the cross-section of the tested element and giving arise to a stress concentration. Such stress concentrators may be divided into three groups: geometric, structural and complex stress concentrators. In case of a geometric stress concentrator (named geometric notch, in the following), the stress concentration is produced by the configuration of geometric profile of the structural element. The values of stresses at the notch root can be many times higher than nominal values. In case of a structural stress concentrator (named structural notch, in the following), the stress concentration is produced by heterogeneities in material structure [17,18]. In case of a complex stress concentrator (named complex notch, in the following), the stress concentration is produced by both the configuration of geometric profile and the heterogeneities in material structure. An example of complex notch are welded joints.

The paper is aimed at the formulation of fatigue notch factor function for complex notch defined through the effects of geometric and structural notch, independent between each other. The paper analyses each type of the above notches. Based on the experimental studies, effects of complex notch on fatigue life, under cyclic tension-compression and oscillatory bending, are described. For this purpose a fatigue notch factor function applicable in a wide range of cycles is proposed, defined as a function of geometric and structural notch factors.

2. Welded joint as a complex notch

In the literature effect of complex notch on stress field is usually described by using the theoretical notch factor K_t [19–21]. Such a factor describes the stress concentration at weld toe in terms of nominal value (Fig. 1), taking into account the stress gradient in the vicinity of welding.

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Nomenclature

$A_{5\ min}$	minimal elongation after tensile test of specimen with gage section length equal to 5× gage diameter (%)
A, m	material constants of the S-N curve (–)
c	notch depth (mm)
C, b	material constants in the Basquin equation (MPa), (–) (respectively)
E	Young's modulus (GPa)
K_f	fatigue notch factor (–)
$K_f^{(i)}$	fatigue complex notch factor under load i, where $i = tn$ – tension-compression, bn - bending
$K_{f\ (w,s)}^{(i)}$	experimental fatigue complex notch factor under load i (–)
$K_{f\text{-}s}^{(i)}$, $K_{f\text{-}w}^{(i)}$	fatigue structural/geometric notch factor (respectively), under load i (–)
K_t	theoretical notch factor (stress concentration) (–)
$K_{t\text{-}s}$	theoretical structural notch factor (–)
$K_{t\text{-}w}$	theoretical geometric notch factor (–)
$K_{t\text{-}w\ (U,\ V)}$	theoretical geometric notch factor of the test pieces with geometric U and V notch (–)
N	number of cycles (–)
$R_{0.2}$	yield strength at 0.2% plastic strain (MPa)
R_m	ultimate tensile strength (MPa)
t	weld plate thickness (mm)
Z_{min}	minimal reduction in area after tensile test (%)
α, β	exponents in the $K_f^{(i)}(N)$ function (–)
ν	Poisson's ratio (–)
θ	weld face angle (deg)
ρ	notch root radius (mm)
σ_a	stress amplitude (MPa)
$\sigma_a^{(i)}(N)$	stress amplitude in the S-N curve of parent material under load i, corresponding to a given number of cycles N (MPa)
$\sigma_{a\ (w,s)}^{(i)}(N)$	nominal stress amplitude in the S-N curve of welded test pieces under load i (with geometric/structural notch - respectively), corresponding to a given number of cycles N (MPa)
σ_{max}	stress at the notch root (MPa)
σ_n	nominal stress (MPa)

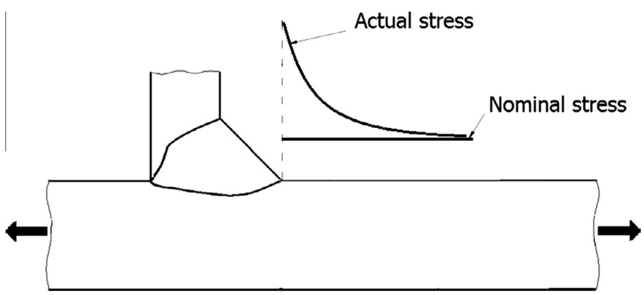

Fig. 1. Stress concentration in a fillet welded joint.

For welded joints a typical assumption is that the K_t factor depends on weld notch root radius, ρ, and on the weld toe blend angle θ (Fig. 2).

As can be seen, such an approach does not involve the effect of material heterogeneities on stress and strain tensor [22]. The issue of notch factor exists also in the fatigue life determination procedures, where the term of fatigue notch factor K_f is known. Such a factor describes differences between S-N curves corresponding to parent material and to the considered welded element (Fig. 3). These differences result from the differences in stress fields; therefore the approach to K_t determination indirectly define also the approach to determination of fatigue notch factor, K_f. The above approach to K_t determination also defines fatigue notch factor K_f,

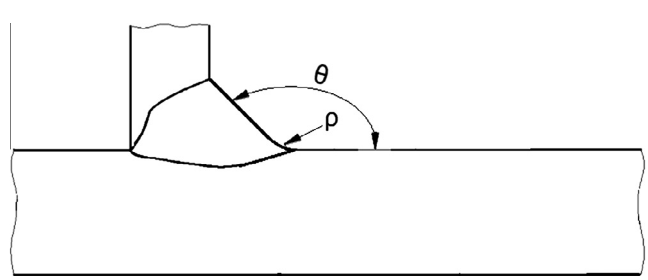

Fig. 2. Characteristic geometrical properties of a fillet welded joint, where ρ is the toe radius and θ is the weld toe blend angle.

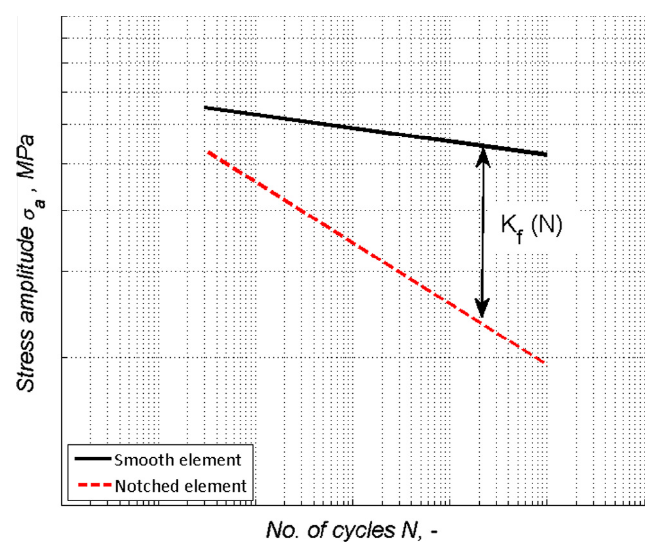

Fig. 3. Definition of fatigue notch factor K_f.

claiming no influence of material structure on fatigue life whereas the procedure should also take the structural notch into account.

In 2004, Xiao and Yamada in their paper [23] devoted to determination of structural stresses in cruciform joints proposed the following definition of theoretical notch factor K_t that considers the effect of both geometric profile configuration (geometric effect) and heterogeneities in material structure (structural effect):

$$K_t = K_{t-w} \cdot K_{t-s} \tag{1}$$

where

$K_{t\text{-}w}$ is the factor depending on geometric profile configuration (geometric notch factor), -;

$K_{t\text{-}s}$ is the factor depending on heterogeneities in material structure (structural notch factor), -.

In their proposal, the total stress distribution along the crack path direction is considered to be the sum of the geometric stress

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