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FATIGUE STRENGTH ASSESSMENT OF WELDED JOINTS BY USING NOTCH STRESS APPROACH

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ABSTRACT
The fatigue strength assessment of welded joints by using the known parent material fatigue strength is considered in this paper. The stress concentration factor was determined performing FEA of single-sided transverse attachment joints for mean value of weld toe radius which was calculated by using several measurements of the weld toe radius along the weld length. The fatigue strength of welded joints was determined by taking into account the stress concentration factor, the hardness in HAZ, residual stress and misalignment. The results obtained by these calculations are compared with experimental results.
Keywords: welded joint, fatigue strength, weld toe radius, stress concentration factor

1. INTRODUCTION
Fatigue strength of welded joint depends, among other factors, on its geometry i.e. on the weld profile and particularly magnitude of the weld toe radius that depend on the welding process and technology of the welded joint production as well as the skill of the operator. Statistical distribution of fatigue strength can be attributed to the statistical distribution of the geometric parameters. The fatigue strength assessment of welded joints by using the known parent material fatigue strength is considered in this paper. This assessment could be performed by using notch stress aproach if there is no significant crack-like deffect at the weld toe. The hardness in heat affected zone, residual stresses and misalignment are also included in these calculations.

2. WELDED JOINT
Specimens were fabricated from low-carbon structural steel S355JO conformed to JUS EN 10025 2003 Standard specification. Mechanical properties of the steel are given in Table 1.

Table 1. Mechanical properties of steel

Yield strength, MPa	Tensile strength, MPa	Elongation, %
389.7	534.2	30

The chemical composition, shown in Table 2, conformed with the requirements of the S355JO Standard specification.

Table 2. Chemical composition of steel

Element	C	Mn	Si	P	S	Cu	Cr	Mo	Ti	Al	Sn
Content, %	0.15	1.46	0.24	0.015	0.012	0.03	0.03	0.02	0.013	0.04	0.002

The main plate and the transverse stiffener were welded by the MAG process. After welding, the specimens were saw cut from the assembly and then milled to finished sizes shown in Fig. 1. The rolling direction of the main plate corresponded to the longitudinal axis of the specimens and to the direction of loading.

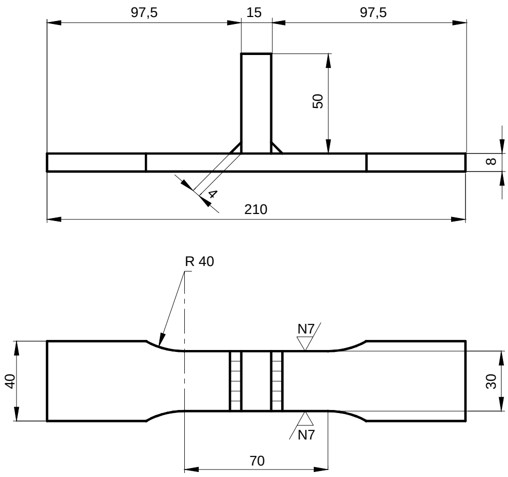

Figure 1. Test specimen

3. ANALYSIS OF THE WELDED JOINT

A very impotrant factor influencing fatigue strength, is the geometry of the weld toe. The weld profiles were measured at several locations along the weld length. Data were stored in the computer and the magnitudes of weld toe radii were determined by using computer graphics. One of these weld profiles is shown in Fig. 2. Statistical distribution of weld toe radii is shown in Fig.3.

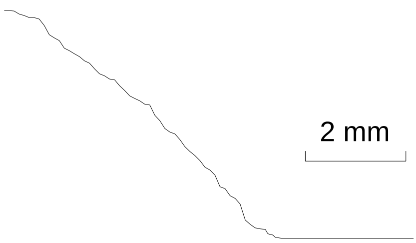

Figure.2. Fillet weld profile

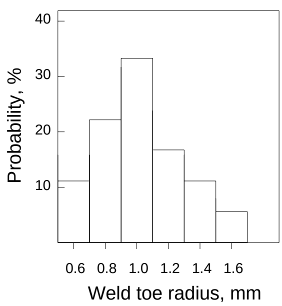

Figure.3. Distribution of fillet weld toe radii

Calculated mean value of the determined weld toe radii is r = 1 mm. The stress distribution for this value of weld toe radius was obtained using the finite element method. Because of the symmetry (Fig.1) it is sufficient to analyse only one half of the joint (Fig.4). Stress concentration factor determined by FEA is K_T = 1.7.

4. FATIGUE STRENGTH OF WELDED JOINT

Fatigue test results obtained from smooth specimens are given in Fig. 5. The S-N curve determined by the regression analysis [1] is given in the same figure (curve 1). The equation of S-N curve for smooth specimens is:

$$log\, N = 24.7208 - 7.3957\, log\, \Delta\sigma_{ss} \quad (1)$$

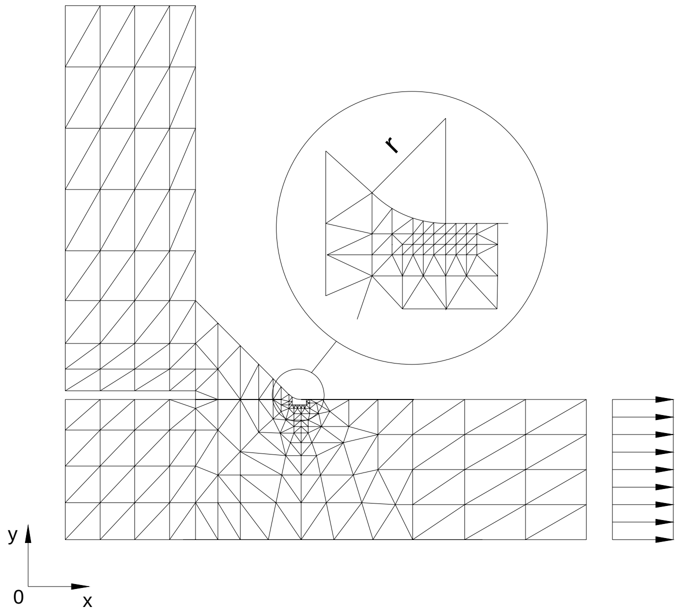

Figure 4. Finite element mesh for one half of the non-load carrying, fillet-welded transverse stiffener

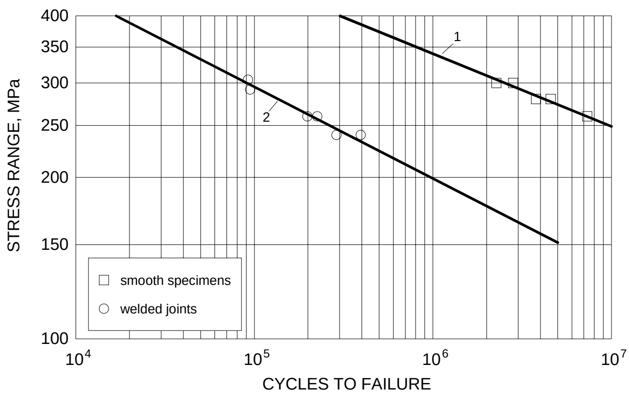

Figure 5. Experimental results and S-N curves for: 1-smooth specimens; 2- welded joints

The fatigue strength at 2×10^6 cycles of the smooth specimens (mill-finished material) obtained from eq.1, is $\Delta\sigma_{ss}$ = 309 MPa. Fatigue strength of welded joints could be estimated using the equation:

$$\Delta\sigma_{wj(calc)} = \frac{\Delta\sigma_{ss}}{k_{res} \cdot k_m \cdot \gamma \cdot K_f} \tag{2}$$

where: K_f is fatigue notch factor (effective stress concentration factor), γ is surface roughness reduction factor, k_m is stress magnification factor (due to misalignment), k_{res} is residual stress factor. Fatigue notch factor is determined by using Neuber's method [2]:

$$K_f = 1 + \frac{K_T - 1}{1 + \sqrt{\frac{A}{r}}} = 1.55 \tag{3}$$

where A is material constant. The material characteristic values of the parent material are used, modified in accordance with the hardness in the area of crack initiation i.e. HAZ at weld toe. Base material tensile strength and hardness are 534.2 MPa and 200 HV, respectively. Mean value of the hardness along HAZ width is 300 HV and assuming the proportional increse in tensile strength, the corresponding tensile strength in HAZ is obtained to be R_m = 800 MPa and corresponding material constant $\sqrt{A} = 0.27$ [2]. The smooth specimens were milled to finished sizes and corresponding surface roughness reduction factor γ_s = 0.80; for the welded joints γ_{wj} = 0.95 (local surface of the main plate were ground before the welding), and the total surface roughness reduction factor is γ = 0.84 [2].

Factor k_m taking account of the effect of angular misalignment is calculated using formula [3-5]:

$$k_m = 1 + \frac{\lambda}{4}\alpha\frac{L_1}{t}\frac{\tanh\frac{\beta}{2}}{\frac{\beta}{2}} \tag{4}$$

where is α =2° angular distortion (inserted in eq.4 in radians), t = main plate thickness, L_1 = distance between load points, λ = constant dependent on boundary conditions (λ=3 for fixed ends); at the end is correction term taking account of straightening of joint under tensile load [5], where

$\beta = \frac{L_1}{t}\sqrt{\frac{3\sigma_{max}}{E}}$, $\sigma_{max} = \frac{\Delta\sigma}{1-R}$ at 2×10^6 cycles, E = Young's modulus.

Factor k_{res} takes the effect of tensile residual stresses into account and could be assumed 1.12 or 2×1.12 (factor 1.12 corresponds to a downgrading by one detail category) [6]. In this paper was assumed 1.12 because of small main plate thickness, since with decrease of this thickness, the effect of residual stresses also decreases. Factor k_m and fatigue strength of welded joints were determined in three steps.

$$\Delta\sigma_{wj(calc)} = \frac{\Delta\sigma_{ss}}{k_{res}\cdot k_m\cdot\gamma\cdot K_f} = \frac{309}{1.12\cdot1.3456\cdot0.84\cdot1.55} = 157.48\,\text{MPa}$$

Fatigue test results obtained from welded joints are given in Fig. 5. The S-N curve determined by the regression analysis [1] is given in the same figure (curve 2). The equation of S-N curve for welded joints, determined by the regression analysis of the experimental results, is:

$$\log N = 19.4643 - 5.8563\log\Delta\sigma_{wj(exp)} \tag{5}$$

The fatigue strength at 2×10^6 cycles of the welded joints obtained from eq.(5) is $\Delta\sigma_{wj(exp)} = 177\,\text{MPa}$. The calculated results show excelent agreement with experimental results: $\Delta\sigma_{wj(calc)}/\Delta\sigma_{wj(exp)}$=0.89.

5. CONCLUSIONS

The fatigue strength assessment of welded joints by using the known parent material fatigue strength is considered in this paper. This assessment could be performed by using notch stress aproach if there is no significant crack-like deffect at the weld toe. Previously should be determined weld toe radius (mean value), stres concentration factor, hardness in heat affected zone, fatigue notch factor, residual stress factor and stress magnification factor (due to misalignment). The calculated results show excelent agreement with experimental results.

6. REFERENCES

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