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An Effect of Residual Stresses and Internal Defects on Fatigue Crack Initiation of Laser Welded Sheets

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Abstract: The paper summarizes the results of fatigue tests and residual stresses evaluation. The tests at laser welded joints on sheets with 4 mm thickness made from high-strength S700MC steel have been provided. An effect of pores in weld metal on fatigue crack initiation has been investigated and compared with known and many times experimentally approved Murakami's theory that described an effect of internal defects on fatigue properties. The residual stresses redistribution in weld joint has been used as an explanation of significant differences between our experimental results and theory.

Keywords: Fatigue; Residual Stress; Laser Welding; Pores.

1 Introduction

Experimental fatigue testing of materials is very often a standard procedure of a process of construction design. Using simulation methods the properties of real constructions under fatigue loading are usually predicted from material data. This approach has been approved many times by experiences from real world. In case of welded joints it is only expected that static mechanical properties are at least as good as basic material so also fatigue behavior is presumed as similar. Analysis of residual stresses in welded joints in cooperation with experimental fatigue testing had shown that the presumption of weld-joints fatigue properties from basic material could be problematic. Murakami and Endo theory [1] has been used to evaluate the effect of defects in weld metal. An area of real defects in material at fracture surface has been compared to calculated critical area - $area_{\max}$- from Eq. 1 and 2:

$$\sigma_w = \frac{1,56(HV+120)}{\left(\sqrt{area_{\max}}\right)^{1/6}} \times \left(\frac{1-R}{2}\right)^{\alpha} \tag{1}$$

$$\alpha = 0,226 + HV \times 10^{-4} \tag{2}$$

This $area_{\max}$ represents minimal size of defect where fatigue crack initiation should be expected (all founded defects in this work were internal so equation for defects on the edge area is not mentioned).

2 Experimental

In this work the fatigue properties of laser welded joints prepared by high-power diode laser (HPDL) has been investigated. Power of the HPDL was set to 3.5 kW; the welding speed was 0.75 mm/min. The steel sheets with 4 mm thickness made of S700MC have been used as experimental material. Standard static mechanical and metallographic analyses have been performed before fatigue testing. In general, all mechanical properties required by welding standard ČSN EN ISO 15614-1 are suitable so based on standards weld joints could be used in service – see Tab. 1 and Fig. 1. However, the welding process defects – pores in weld metal – have been

Tab. 1: Basic mechanical properties of weld joints.

Parameter	Required	Measured
Tensile strength	R_m = 750 – 950 MPa	750 MPa
$KV^{-40°C}$ in HAZ	$KV^{-40°C}$ = min 40 J	100 J
$KV^{-40°C}$ in weld metal	$KV^{-40°C}$ = min 40 J	65 J

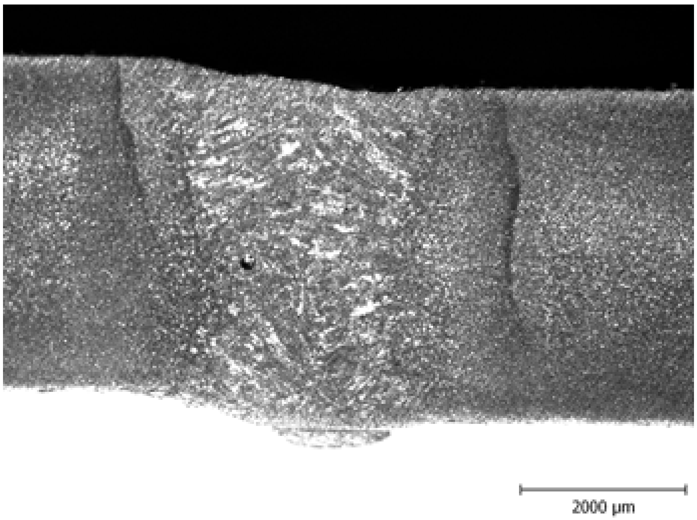

Fig. 1: Macrostructure of laser welded joint.

found. According to common theories [1,2] the negative effect of pores presence on fatigue crack initiation has been expected.

The surfaces of welded sheets have not been grinded during manufacturing of specimens so original geometrical discontinuities of weld joints have been preserved. Because of low sheets thickness and to prevent unwanted buckling the fatigue tests have been performed by cyclic tensile loading only (repeated one-direction loading). After fractographic analysis using SEM Murakami and Endo theory [2] has been used for evaluation of effect of pores. The XRD measurements were performed on PROTO iXRD COMBO diffractometer in ω-goniometer or iso-inclination mode with Cr$K\alpha$ radiation. The line $\{211\}$ of α-Fe phase was measured with the iterplanar lattice spacings computed from maxima of Pearson VII functions fitted to Cr$K\alpha_1$ profiles after Cr$K\alpha_2$ stripping carried out by Rachinger method. The stresses were computed presuming biaxial state of residual stresses (RS) using Winholtz-Cohen method and X-ray elastic constants 1/2 s_2 = 5.76 TPa^{-1}, -s_1 = 1.25 TPa^{-1}.

3 Results

The fatigue test results (Fig. 2) were characteristic by quite a higher scatter. Fractographic analysis showed that fatigue crack initiated from the surface in weld metal in all cases. Also many pores have been found on fracture surface (Fig. 3). According to Murakami and Endo theory [1] at least one pore large enough to cause initiation of fatigue crack at this defect has been found in almost all specimens (only 1 exception) using SEM analysis of fracture surfaces. In the end there has been found 28 pores at 12 specimens with larger size than critical dimension calculated by used theory. The comparison of real area of defects and calculated critical area from [1] is shown at Fig. 4. Only pores with area bigger than 10000 μm^2 are included. Green lines in this represents pores with area smaller than critical – area ratio $<$ 100 %, blue lines than represents pores where fatigue crack initiation should be expected (area ratio $>$ 100 %). To explain this disagreement with theory the results of residual stresses analysis have been used.

The results of XRD analysis shows that RS in surface area (and also area of fatigue crack initiation) are from -50 up to +150 MPa (Fig. 5). The redistribution of RS in laser weld joints has been already investigated and published in our previous paper [3]. It is expected that redistribution of RS in S700MC is very similar. Using this presumption compressive RS in the center of weld joint are expected. The differences in redistribution of

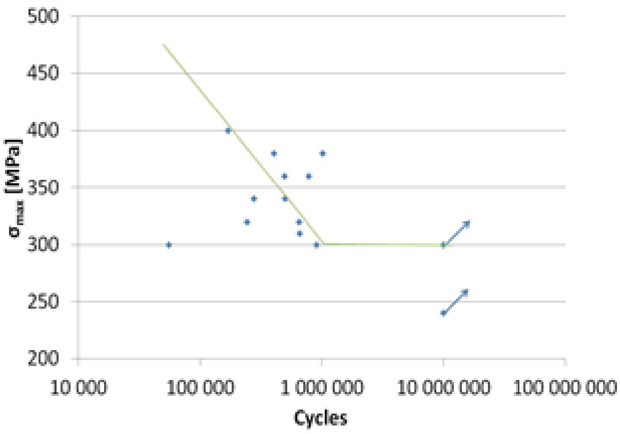

Fig. 2: The results of fatigue tests with schematic Wöhler curve.

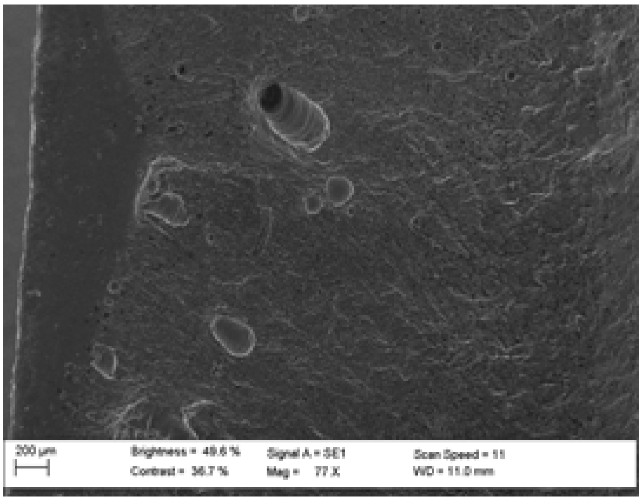

Fig. 3: Pores close to initiation area of fatigue crack.

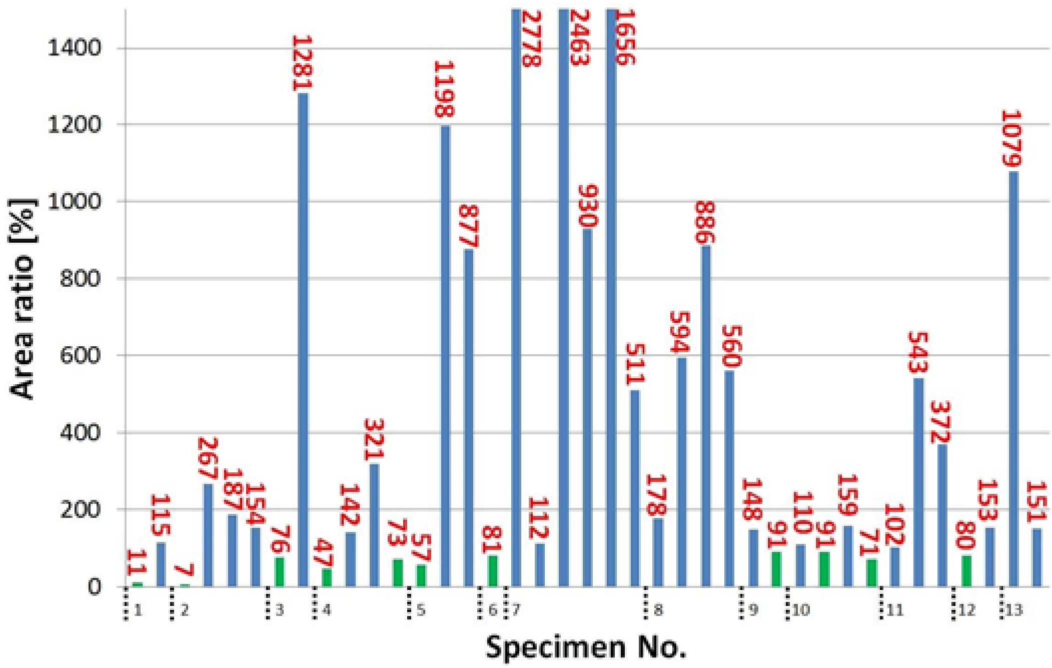

Fig. 4: Comparison of pores area – measured vs. Murakami and Endo theory.

RS in weld joint leads to different loading stresses during fatigue testing in base metal, surface area of weld metal and in the center of weld metal and also in HAZ.

Using summation of loading forces from fatigue machine and RS a very uneven redistribution of loading stresses has been occurred. At the level of fatigue limit – that means 300 MPa from fatigue machine – real loading stresses in the center of weld metal up to 100 MPa. On the other hand in surface area – where all fatigue cracks initiated – the real loading stresses are up to 450 MPa.

The significant disagreement of results with Murakami and Endo theory can be explained by differences of RS in each part of laser welded sheets. The notch effect of surface roughness of weld joint has been also discussed. Our calculation results showed very low significance of this effect.

4 Conclusion

Fatigue properties of laser welded joints made of S700MC steel has been tested. Fatigue limit $\sigma_c = 300$ MPa has been achieved.

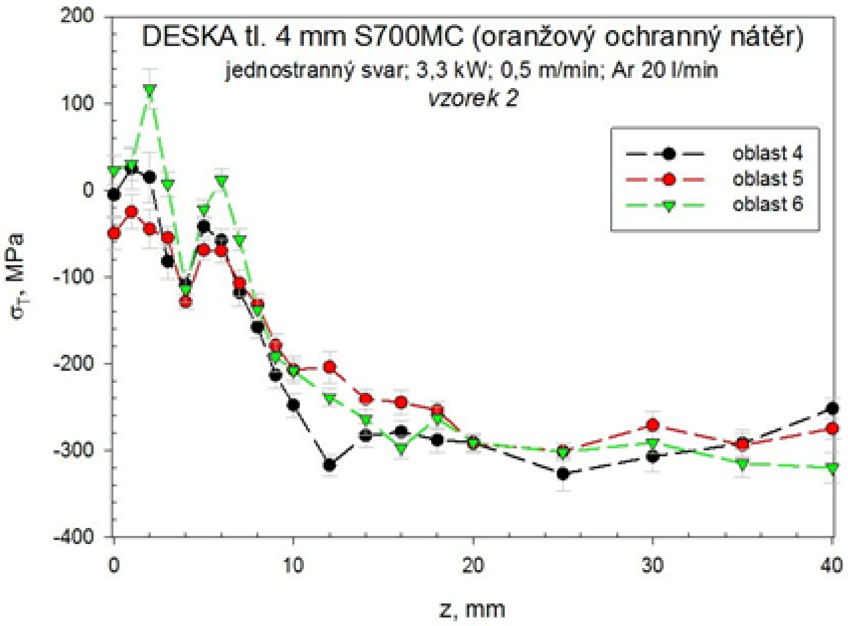

Fig. 5: Surface residual stresses in transversal direction of laser welded sheets made of S700MC steel.

Murakami and Endo theory has been used for evaluation of effects of pores in weld metal on fatigue crack initiation. According to this theory 28 pores have been found where fatigue crack initiation should be expected.

The disagreement with the theory has been explained by interpretation of RS analysis results. An effect of RS redistribution in weld metal caused initiation of fatigue crack from the edge area even where large internal defects have been occurred.

Acknowledgement

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