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# RESISTIVITY DURING CYCLE LOADING OF FINE GRAIN HEAT AFFECTED ZONE (HAZ) OF 17CrNiMo7 STEEL PREPARED INTO LABORATORY FURNACE

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Structural components which are loaded in cyclic load mostly fail due to fatigue. The fatigue strength of metals as well as weld joint regions in metals depends on mechanical properties especially hardness, the size of defect and the size of grains. Resistivity of the fine grain HAZ prepared against fatigue crack initiation will be explained in this article. Samples of material with martensitic fine grain microstructure were prepared by laboratory furnace by proper thermal treatment. Mechanical properties of fine grain heat affected zone and its microstructure were investigated. Special attention was given to behavior of fine grain during the cycle loading under stress concentration. Stress concentration was similar to the one in real welds. The S-N curve and the fatigue limit were determined. The Paris curve and the threshold for crack propagating were also determined.

*Key words:* 17CrNiMo7 steel, fine grain HAZ, microstructure, mechanical properties, fatigue limit

## INTRUDUCTION

The phenomenon of crack initiation from small defects in metals caused by cyclic stress at level lower than the fatigue limit, in connection with the initial fatigue crack propagation to the size when it becomes a non-propagation crack is now well understood [1,2,3]. Design of high strength steels for very high cycle fatigue regime [4,5]. The heat input needed for welding, increases material temperature in the vicinity of the weld metal. As result of heat input residual stresses will be present and some transformation in microstructure will occur at high heated area of base material, this caused heat affected zone (HAZ) of the weld joint see Figure 1.

The martensitic microstructure is usually hard and brittle with low impact toughness, and it is not always convenient for welded joints. As result of hardness appearance of cracks under load condition of structures is high. Initiated cracks at CG HAZ propagate fast in beginning and when they reach the grain border they stop [6]. In order to explain the behavior of fine grain microstructure on cyclic load, laboratory furnace was used to prepare specimens with as welded condition and cooling speed is reduced of heated material. This process result on less hard and less brittle microstructure and result in fine grain microstructure, which were be used for investigation. It is known the post weld heat treatment improve the microstructure [7], but some types of material do not allow post weld heat treatment like micro-alloyed steels.

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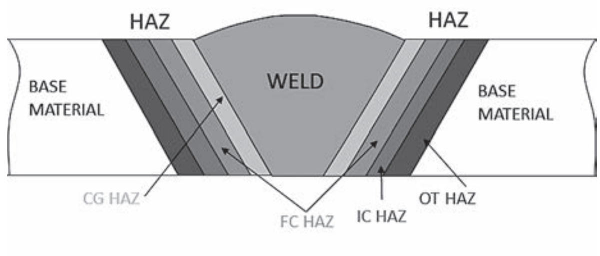



**Figure 1** Welded joint; Base material, HAZ (heat affected zone), Weld material

This is the reason why in some cases martensitic microstructure stays in the HAZ. Taking this into account, stress concentration can appear in welds due to weld toe's shape where inconvenient fine grain microstructure exists. This region could cause problems especially when welded joint is loaded by cycle loading, where residual stresses are present. These stresses play important role in the crack initiation and initial propagation at fine grain microstructure (FG HAZ) and this has influence in reduction on total fatigue life of weld joint.

## MATERIAL

The steel 17CrNiMo7 was used to prepare samples of FG HAZ microstructure. Chemical composition and mechanical properties of the steel are shown in Tables 1 and 2.

Table 1 **Chemical composition of the steel / wt%**

| C | Si | Mn | P | S |
|---|---|---|---|---|
| 0,18 | 0,22 | 0,43 | 0,012 | 0,028 |
| Cr | Ni | Cu | Mo | Al |
| 1,56 | 1,48 | 0,15 | 0,28 | 0,023 |

Table 2 **Mechanical properties of the steel**

| $^{R}$p0,2 | $R_m$ | $A_5$ | Z | Hardness |
|---|---|---|---|---|
| / MPa | / MPa | / % | / % | / HV 10 |
| 489 | 633 | 26 | 72 | 217 |

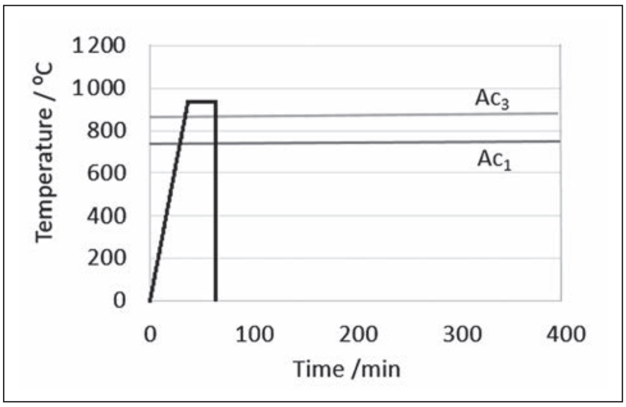



**Figure 2** Laboratory furnace thermal cycle

## EXPERIMENTAL PROCEDURE

Gas metal arc welding process with low heat input was simulated. The FG HAZ microstructure was investigated. It was prepared by using a laboratory furnace. The applied weld thermal cycle is shown in Figure 2. Before apply heat treatment, physical defect (Vickers indentation) was made.

Heat treatment is applied in this conditions *T* = 870 ˚C and held for 45min, after that specimens were cooled into water. Short cooling time ensured the martensitic transformation. Applied heat treatment after Vickers indentation release residual stresses influenced by artificial made defect.

Fifteen specimens with a groove were prepared for plane bending fatigue tests. The groove in the middle of the specimen causes the stress concentration during loading like a weld toe at real weld. Other authors reported that the stress concentration due to the weld toe was approximately 1,74 [8,9] for gas metal arc welding. In order to obtain the same stress concentration in the specimens, the specific geometry of the groove was used.

The groove was designed according to equations suggested by Peterson and Young [10,11]; in that way the theoretical stress concentration factor was calculated by using the equations 1 and 2, when the specimen was loaded by bending.

$$K_t = K_1 + K_2 \cdot \left(\frac{h}{D}\right) + K_3 \cdot \left(\frac{h}{D}\right)^2 + K_4 \cdot \left(\frac{h}{D}\right)^3 \qquad (1)$$

The factors $K_1$,$K_2$,$K_3$and $K_4$ depend on the type of loading (tension, bending, torsion, etc.), *h*-depth of the groove, *D*-specimen thickness, *d*- distance inside thickness to the groove and *r* - radius of groove. In the case of bending loading $K_1$, $K_2$, $K_3$ and $K_4$ are calculated by equation 2 [11], where:

$$0{,}5 \leq h/r \geq 4{,}0$$
$$K_1 = 0{,}721 + 2{,}394 \cdot \sqrt{h/r} - 0{,}127\ h/r$$
$$K_2 = -0{,}426 - 8{,}827 \cdot \sqrt{h/r} + 1{,}518\ h/r$$
$$K_3 = 2{,}161 + 10{,}968 \cdot \sqrt{h/r} - 2{,}455\ h/r$$
$$K_4 = -1{,}456 - 4{,}535 \cdot \sqrt{h/r} + 1{,}064\ h/r \qquad (2)$$

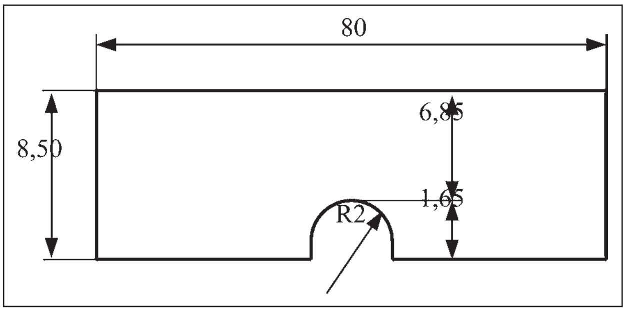



**Figure 3** Specimen for plane bending fatigue test

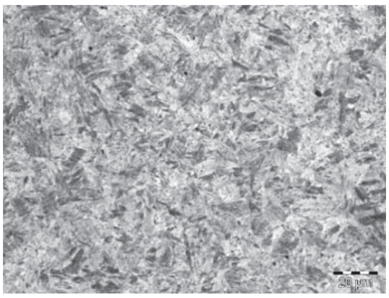
Geometry of the grooved specimens used for this investigation is shown in Figure 3. The groove causes the stress concentration of 1,74 during bending loading.

Vickers hardness of specimens was measured by using load of 9,81 N on instrumented Zwick machine. Fatigue tests were done on the plane bending machine (RUMUL) in order to obtain a fatigue limit and behavior of FG HAZ material during cycle loading. Fatigue crack growth tests were done on the RUMUL cracktronic machine in order to obtain threshold for crack propagation and Paris curve, and finally, analysis of the microstructure was performed on light microscope (Leica WILD M10).

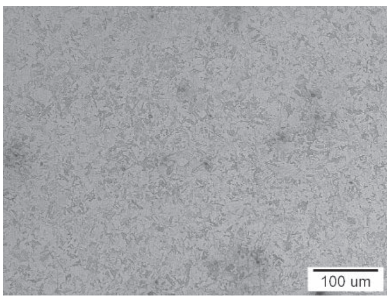
## RESULTS AND DISCUSSION

Microstructure was analyzed by the light microscope at magnification of 100 ×. The microstructure consists of small laths martensite, as shown in Figure 4. Builds-up are of long martensitic laths. The average size of crystal grains is approximately 11 µm.

Hardness was 380 HV10. Results are shown in Figure 5, presenting the curve force versus depth.



a)




b)

**Figure 4** Microstructure of FG HAZ material; light micros.: a) 20× and b) 100×

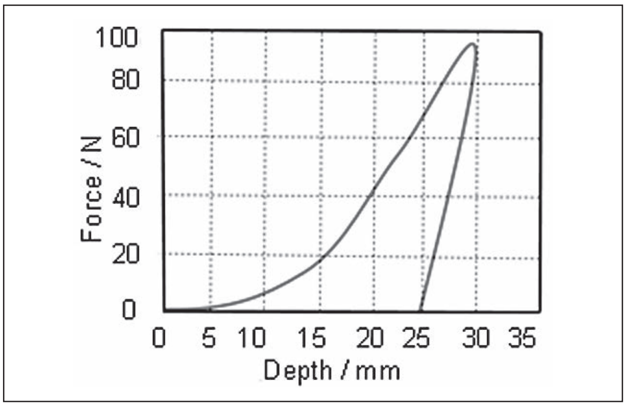



**Figure 5** Force versus depth during Vickers indentation

It was not possible to measure the tensile strength and a yield stress by mechanical testing, because simulated HAZ region was too small.

They were calculated approximately from the hardness by applying equations from the BS 7448-2 [12] and equations proposed by Pavlina and Tyne [13], but in such cases error occurs up to 10 %. Equations 3 and 4 refer to the BSI standard and equations 5 and 6 were proposed by Pavlina and Tyne.

$$R_{p0.2} = 3,8 \times HV - 221 \quad (3)$$

$$R_m = 3,15 \times HV + 93 \quad (4)$$

$$R_{p0.2} = 2,876 \times HV - 90,7 \quad (5)$$

$$R_m = 3,734 \times HV - 99,8 \quad (6)$$

Where HV is the Vickers hardness number. The yield stress and the ultimate tensile stress are presented in Table 3.

Table 3 **Yield stress and ultimatetensile strength FG HAZ and base material**

| Material | $R_{p0,2}$/ MPa | $R_m$/ MPa |
|---|---|---|
| FG HAZ | 1 223[(1)] | 1 290[(1)] |
| | 1 002[(2)] | 1 319[(2)] |
| Steel 17CrNiMo7 | 474 [(1)] | 761 [(1)] |
| | 519 [(2)] | 692 [(2)] |

[(1)]BSI 7448-2 standard (equations 3 and 4)

[(2)] Proposed by Pavlina and Tyne (equations 5 and 6)

Results of fatigue testing on bending machine are shown in Figure 6.

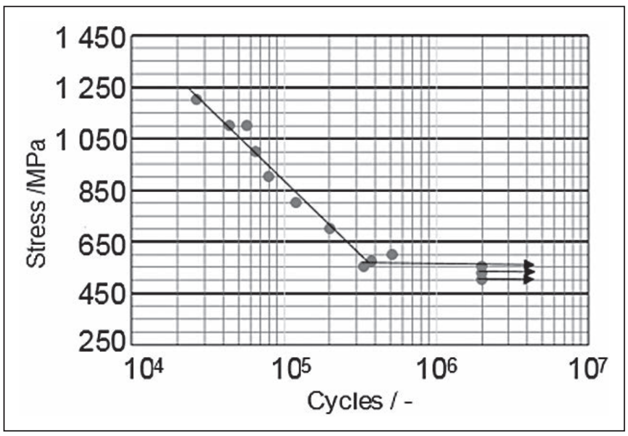



**Figure 6** S-Ncurve of the FG HAZ

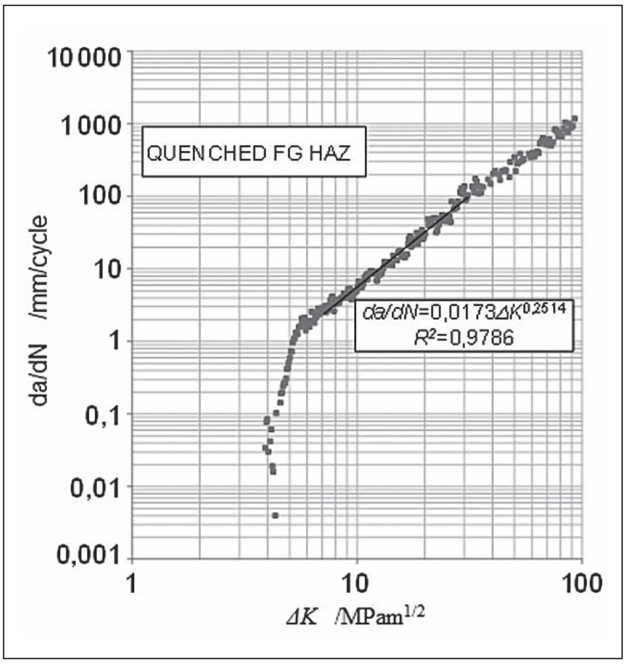



**Figure 7** Paris curve of FG HAZ (quenched)

Load ratio *R* was 0,1 due to moment bending. The continuing line represented the S-N curve of the FG HAZ microstructure. The fatigue limit was 525 MPa. This was the lowest stress limit beyond which specimen did not break after 2 million cycles.

Specimens of 10×10×80 mm were used for the fatigue crack growth test. Before starting the experiment, special thin foil crack gauge was attached on one side of the specimen. It was used for measuring the crack propagation during the loading. The2 mm long pre-crack was prepared with the low Δ*K*. The crack threshold was obtained step by step by reducing Δ*K* from Δ*K*, which was used for pre-crack creation. Results are shown in Figure 7. Crack threshold was low, only 4,33 $MPam^{1/2}$for quenched specimen. Test was continued by increase of ΔK until the breakage of specimens. Obtained Paris curve represents FG HAZ material behavior in case of crack and speed of eventual crack propagation. Paris law is valid in the middle liner part and is explained by equation 7.

$$da/dN = C\, \Delta K^m \quad (7)$$

The constants C and m were obtained after evaluation from the *da/dN*-ΔK diagram. Evaluation reveal that constants of quenched specimen were: $C$=1,73·$10^{-11}$ and $m$= 2,514 of the FG HAZ material.

## CONCLUSION

Artificially defected specimens with simulated microstructure of fine grain heat affected zone were fatigue tested. Microstructure, mechanical properties, fatigue limit and crack growth is investigated and analyzed. The FG HAZ microstructure consists of laths martensite. Its hardness is 380 HV10. The fatigue limit of the FG HAZ material is 525 MPa relatively low, according to its yield stress. It is only 41,34 % of the yield stress. If compared to the unaffected base material, it is on two third of its yield stress, which is acceptable for welded joints. The threshold for crack propagation is low, $\mathbf{\Delta K}_{th}$ = 4,33 MPam$^{1/2}$for quenched specimen. Crack propagation at fine grain HAZ was faster and it's resistivity to stop crack initiation was lower because of the weak boundary barrier.

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**Note:** Responsible translator: Martina Šuto, MA in English and German language, University of Osijek, Osijek, Croatia