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INFLUENCE OF SEVERE PLASTIC DEFORMATION ON STRUCTURE AND PROPERTIES OF THE STEEL WAC 1008

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ABSTRACT
Main aim of this paper is to describe the plastic deformation executed by ECAP on low cycle fatigue of steel WAC 1008. Among others was attention fixed on mechanical properties after this treatment. Experiments were planned and realised at the temperature ranging from room temperature up to 280 °C. After application of deformation the structure was investigated in dependence on accumulation of deformation and deformation temperature as well as abovementioned final properties. Accumulated (logarithmic) deformation varied from the value 2 to 8. Mechanical properties were investigated by conventional tensile test and penetration test. Selected samples were subjected to low-cycle fatigue.
Keywords: ECAP, steel WAC 1008, low-cycle fatigue

1. INTRODUCTION
It is well known a positive influence of ECAP technology on final material properties namely non ferrous metals but steel as well. However not many works is focused on achieved fatigue properties after that treatment. This paper wants to contribute to knowledge distribution about austenitic stainless steel WAC 1008 behaviour under ECAP.

2. EXPERIMENTAL
A series of samples made of austenitic stainless steel WAC 1008 was processed by the ECAP technology. Basic chemical composition is given in the Table 1 and mechanical properties in the Table 2. The samples were manufactured with the following dimensions: ϕ 12 mm, length 60 mm. They were pushed through the ECAP matrix by 2 to 8 passes [1].

Table 1. Basic chemical composition of the steel (%)

C	Mn	Si	Cr	Mo	B	Ti
0.035	0,65	0.23	0.10	0.07	0.002	0.001

Matrix had channel diameter 12 mm and angle 105°. Pressure in the matrix varied around approx. 740 MPa. Temperature of extrusion varied from room temperature up to 280 °C. After extrusion material was taken from the samples for metallographic testing and testing bars were manufactured for testing of mechanical properties. In order to expand the existing findings the testing bars were exposed to intensive magnetic field and impact of magnetic field on change of mechanical properties was investigated by tensile test. The sample was after eight passes subjected to structural analysis.

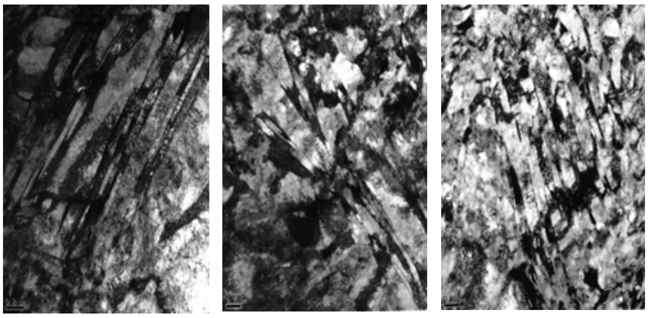
Table 2. Mechanical properties of the steel WAC 1008 before ECAP (20 °C)

Steel grade	E [GPa]	Rp0.2 [MPa]	Rm [MPa]	A [%]	KV [J]	HB
WAC 1008	190	380	505	25	90	210

The samples were determined for investigation of influence of the ECAP technology on fatigue properties. Individual samples were subjected to different number of passes: 3 pieces had 4 passes, 4 pieces had 5 passes and 3 pieces had 6 passes. Test samples for testing of low-cycle fatigue had diameter of the measured part 5 mm and overall length 55 mm.

3. RESULTS AND THEIR ANALYSIS

Structures were analysed from the viewpoint of the course of strengthening and restoring processes. Fig. 1 documents deformed sub-structure of the steel WAC 1008 after ECAP deformation by 4 to 8. Metallic matrix contained sub-grains of uneven size. Size of sub-grains was smaller than 0.1 μm in most cases, only exceptionally some sub-grains/grains of the size of approx. 0.5 μm were observed.



a) b) c)

Figure 1. Structure of steel WAC 1008 after ECAP. Logarithmic deformation: 4 (a), 6 (b) and 8 (c)

Density of dislocations in metallic matrix was very high, presence of particles of precipitate was not found. In cases when neighbouring grains showed approximately identical diffraction contrast, it can be expected that angle of disorientation is only several degrees, while in case of significant changes of contrast rather high angular disorientation is probable.

3.1. Mechanical properties

Samples after ECAP with number of passes (4, 5 and 6) were used for investigation of influence of the ECAP technology on fatigue properties of the steel WAC 1008 with special focus on the area of low-cycle fatigue. Mechanical properties change in dependence on numbers of passes, strength properties (Rp0.2 and Rm) distinctly increase, plastic properties described by narrowing almost do not change (tab.3). Micro-structural condition for increasing of strength properties in investigation of steel is fine grain and its stability [2]. Several methods for grain refining and limitation of its growth are known at present – phase transformations, re-crystallisation, big plastic deformations (deformation of alloys with duplex structure, distribution of phases in duplex alloys, dispersion segregated particles), etc. Selection of methods of grain refining and slowing of its growth is in individual cases given by state and properties of structure [3]. Increasing of strength properties in dependence on grain size is determined by the Hall-Petch relation:

$$\sigma_y = \sigma_o + k_y d^{-\frac{1}{2}} \qquad (1)$$

where : σ_0 the particle friction stress, and it is the yield stress for the limit $d \rightarrow \infty$, k_y the slope of the line and it is known as the dislocation locking parameter, which represents the relative hardening contribution due to grain boundaries.

Table 3. Change of mechanical properties of steel WAC 1008 after the 2^{nd} to 5^{th} pass

Number of ECAP passes	$R_{p0.2}$ [MPa]	R_m [MPa]	E [GPa]	A [%]	Z [%]
Initial state	380	505	190	25	-
2	899	916	179	22	68
3	970	998	180	15	60
4	1 063	1 099	179	15	60
5	1 103	1 140	182	15	60

3.2. Tests of low-cycle fatigue

Testing specimens for determination of the Manson – Coffin curve and curve of deformation strengthening were prepared from extruded samples after 2 to 6 ECAP passes. Apart form extruded samples the initial state was tested as well. The aim was to determine influence of number of ECAP passes on shape and position of the Manson-Coffin curve and curve of deformation strengthening. Altogether 10 samples were processed after application of the ECAP technology (3 samples after 4 passes and 6 samples after and 4 samples after 5 passes) and 12 samples with initial structure.

Test of low-cycle fatigue were performed according to the standard ASTM E 606 at laboratory temperature on servo-hydraulic testing equipment MTS 100 kN by „hard" method of load in alternate traction – pressure. During these tests a constant amplitude of total deformation ε_{ac} was preserved. Tests of low-cycle fatigue were realised at constant rate of total deformation ε_{ac} = 4.10^{-3} s^{-1}. Longitudinal deformation of testing specimens was read by the sensor MTS 632-42C-11 with the basis 12 mm. During loading of individual testing specimens hysteresis curves were read and recorded (dependence stress – deformation), from which after rupture of individual testing specimens the level of elastic (ε_{ael}) and plastic deformation (ε_{apl}) for N_f /2 was evaluated. After completion of each test the number of cycles till rupture N_f was recorded and from hysteresis curve for approximately N = N_f/2 for the chosen amplitude of total deformation ε_{ac} there were deducted amplitude of plastic deformation ε_{apl}, amplitude of elastic deformation ε_{ael} and amplitude of stress σ_a [4]. Curves of service life expressed in the form were plotted from experimental data:

$$\varepsilon_{ac} = \varepsilon_{ael} + \varepsilon_{pl} = \frac{\sigma'_f}{E}(N_f)^b + \varepsilon_f (N_f)^c \tag{2}$$

Cyclic curves stress-deformation were also determined for complex assessment of response of steel after the ECAP to alternating plastic deformation in traction – pressure:

$$\sigma_a = k.\varepsilon_{apl}^n \tag{3}$$

Manson-Coffin curves of service life were plotted from the obtained values, as well cyclic curve of deformation strengthening. These values characterise deformation behaviour of material for prevailing time of its fatigue service life and they are therefore material characteristics. Results of individual test of low-cycle fatigue were processed in a form of graphic diagrams (Fig. 2 to 4).

4. CONCLUSIONS

Mechanical properties of the steel WAC 1008 were determined by miniaturised tensile test, as well as by penetration test, selected samples were subjected to verification analysis of their chemical composition. Basic mechanical properties of the steel WAC 1008 were determined in dependence on number of passes. Series of experiments were also realised in order to verify influence of intensive magnetic field on structure and mechanical properties of this steel. Fatigue behaviour of the steel WAC 1008 was investigated after application of various number of passes through the ECAP tool, structural stability was preserved, however, fatigue service life in the area of timed fatigue strength decreased after application of ECAP. It follows from these results that materials with ultra-fine grain after intensive plastic deformation by the ECAP technology show at fatigue loading in the mode of constant amplitude of deformation (low-cycle fatigue) shorter fatigue service life in comparison with initial state.

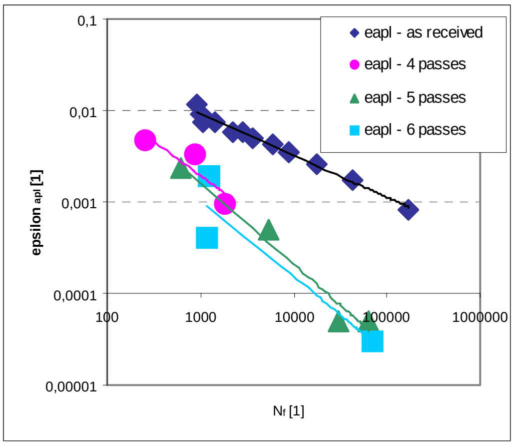


Figure 2. Curves of low-cycle fatigue $\varepsilon_{apl} - N_f$

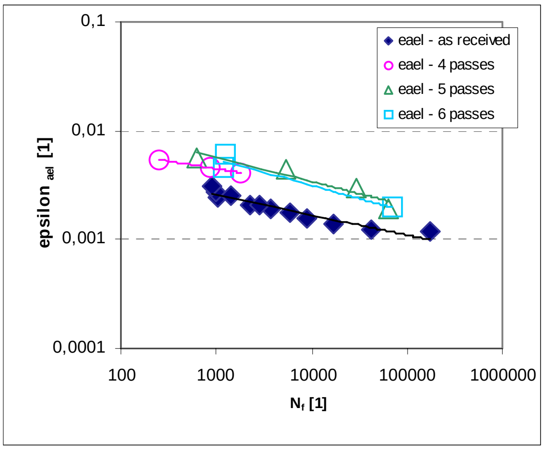


Figure 3. Curves of low-cycle fatigue $\varepsilon_{ael} - N_f$

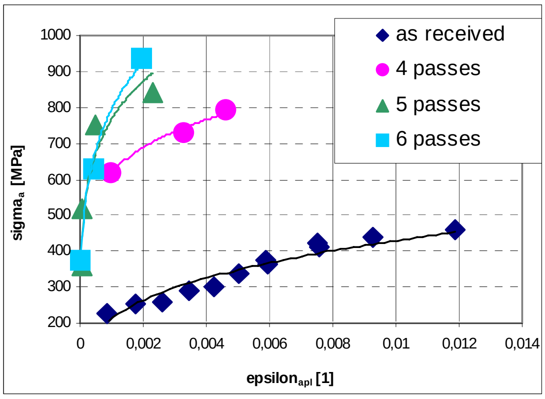


Figure 4. Curves of dependence between the amplitude of stress σ_a - ε_{apl}

Nevertheless, it is possible to regard as highly positive the fact, that ultra-fine grained structure shows comparatively good mechanical stability after fatigue test, which is given by the fact that grains in structure are so small, that they prevent forming of dislocation structure. It can be predicted on the basis of obtained results that, contrary to low-cycle fatigue the ultra-fine grained material will manifest at fatigue load in the mode of constant amplitude of stress (high-cycle fatigue) higher fatigue characteristics, particularly fatigue limit. Confirmation of this presumption requires, however, realisation of additional experimental works aimed at the area of high-cycle fatigue of investigated material WAC 1008 and detailed investigation with use of electron microscopy of possible structural changes in material after tests of high-cycle fatigue.

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