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CRACK GROWTH THROUGH LOW-CYCLE FATIGUE LOADING OF MATERIAL ARMOX 500T

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This paper presents microstructure analysis of the creation and growth of cracks in uniaxial load. Analyse were done for steel Armox 500T (armour sheet). Results show that cracks are present quit early in steel lifetime. First micro cracks occur before the 200th cycles, whereby crack growth is progressive during further loading. Also it can be seen that after a certain number of cycles there are more longer cracks then shorter ones.

Key words: steel Armox 500T, low-cycle fatigue, crack growth, damage, structure

INTRODUCTION

In industry, researchers look for different ways to describe material lifetime as best as possible. For that purpose, different numerical models have been developed by means of which we can define material lifetime. But for validation of numerical methods and determination of specified material parameters of methods and specified material parameters for fatigue mechanics, it is necessary to perform measurements. The most frequently used and cost effective methods for damage determination are non-destructive testing (NDT) methods. These methods are well known methods used to determine damage with micrography, density, modulus of elasticity, acoustic emission, stress amplitude, creep, microhardness, electrical resistance, energy accumulation, crack toughness, etc. [1-7]. To better understand what is happening in the material through lifetime, we performed measurements which enabled analysis of cracks in given material lifetime. The main purpose of these measurements was to determine when a micro crack really occurs and how it proceeds through material lifetime. For monitoring crack initiation and growth, it is necessary to understand the principal process of crack initiation and determine material structure. In solid state, steels and their alloys have a true crystal structure with ordered atoms. Atoms are arranged in a repetitive three-dimensional pattern, whereby each atom is connected to the nearby atom or ion [8, 9]. Atoms are linked with bonds resulting from electromagnetic field interactions. Sufficient internal shear stress causes formation of slips between atoms which occur on a so-called slip plane. Incurred movements are caused by motion of dislocations resulting in plastic deformation, which is then followed by accumulation of dislocations. This can cause formation of micro cracks leading to propagation of cracks [8, 10-12]. Propagation of cracks depends on material structure [13, 14]. Consequently, for the analysis of crack initiation, armoured alloy steel Armox 500T with high tensile strength was used.

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MATERIAL AND EXPERIMENTAL DATA

For realization of measurements, steel Armox 500T (Table 1) was used. Steel Armox 500T was tested in delivered state with tensile strength 1 789 N/mm^2. The shape of the specimen tube and proceedings of cyclic loading were in accordance with standard ASTM: E 606/E606M-12.

Table 1 **Chemical composition of Armox 500T / wt. % [15]**

Element	Max. element content
C	0,32
Si	0,1-0,4
Mn	1,2
P	0,015
S	0,01
Cr	1,0
Ni	1,8
Mo	0,7
B	0,005

Also taken into account in the design of the specimen tube were the requirements on how to fix a specimen to the measurement equipment, influence of buckling and dimensions of blank materials (Figure 1).

The straight part of the tube was designed to enable attachment of an acoustic emission sensor and has no influence on initiation and propagation of cracks under cyclic testing.

Uniaxial tension compression tests were performed on dynamical uniaxial tension compression machine Instron 8820 [16]. The strain of specimens was controlled with extensometer Instron Dynamic 2620-603 with

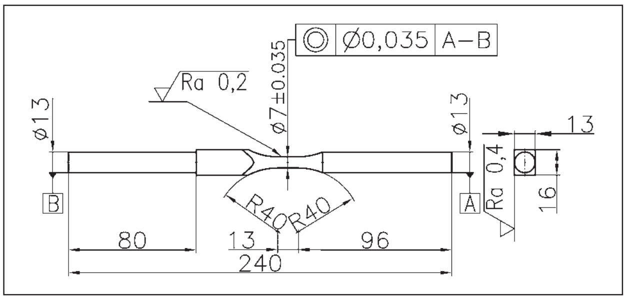

Figure 1 Armox 500T Specimen

Figure 2 Etched specimen

gauge length 10 mm and travel of ± 1 mm. All measurements were performed at room temperature (20 °C) with constant strain rate 90 %/min (triangle waveform) and controlled strain ratio R = - 1. For all specimens, the strain amplitude of 1 % was applied. For monitoring the number of cracks through specimen lifetime, the loading process was interrupted at certain cycles. Terminations were performed every 200 cycles until the end of specimen lifetime. The measuring range of specimen (Figure 1, length 13 mm) was prepared for microstructure analysis of specimens (Figure 2). The samples were longitudinally cut, brushed, polished and etched. As shown in the analysis, cracks are more visible on the etched specimens (Figure 3) than on the polished ones (Figure 4). However, since cracks are often confused with the bonds between crystal grains, it is likely that some mistakes are made.

Identification of cracks was performed with optical microscope Wolpert Wilson® Instruments Tukon™ 2100B. Maximum zoom of the optical microscope is 600 %. Identification of cracks was conducted on the edges of specimens, because it is the only way we can assure that the cracks we see are really cracks. Otherwise, smaller cracks are easily mistaken for crystal grains. Identification of cracks was performed on all edges of specimens (see Figure 4), thereby increasing the range of data set for analysis. With both materials, we also performed identification of cracks in the unloaded state, in which, however, no cracks were detected.

RESULTS AND DISCUSSION

Results of the analysis of the crack initiation and propagation process are shown in diagrams (Figure 5 and Figure 6). Diagram (Figure 5) presents the sum of all cracks occurring through the lifetime of steel Armox

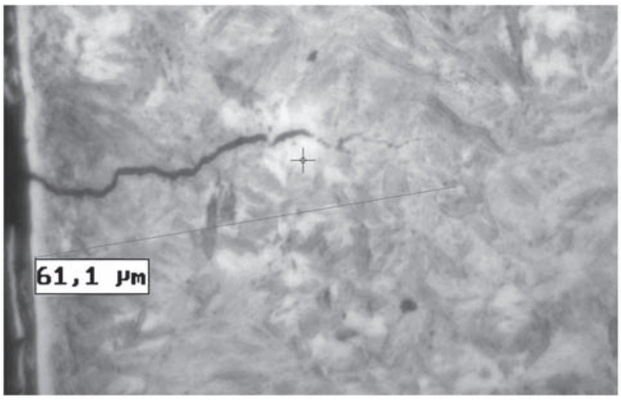

Figure 3 Etched specimen Armox 500T

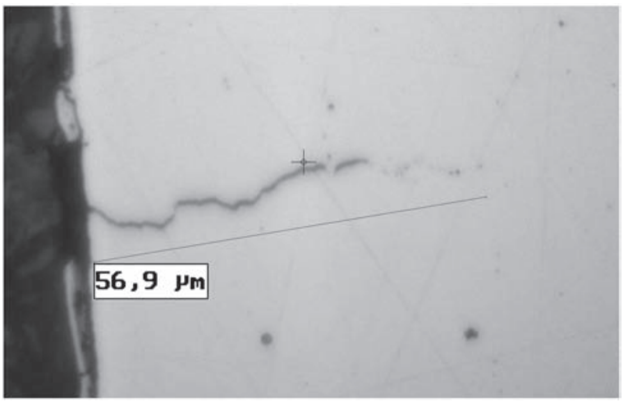

Figure 4 Polished specimen Armox 500T

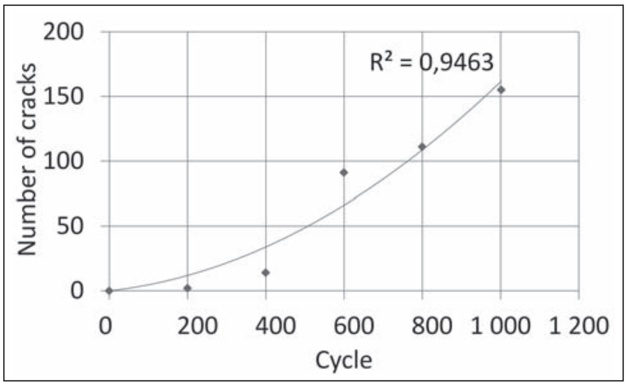

Figure 5 Number of cracks depending on the number of cycles

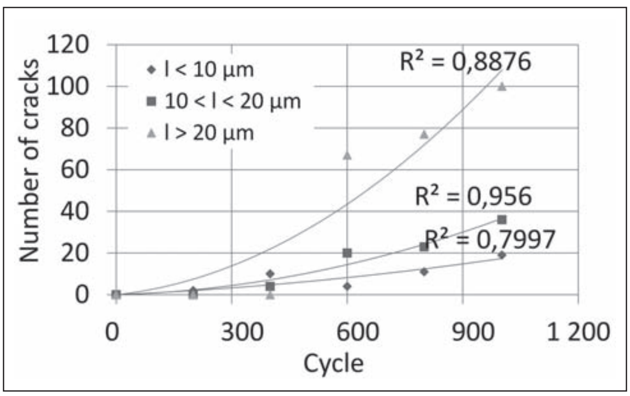

Figure 6 Number and length of cracks

Figure 7 Structure of steel at zoom of 600 %

500T. Specimen analysis has shown that at the 200th load cycle first micro cracks begin to appear. Previous research [2] showed that macro cracks are clearly visible during the early stage of material lifetime, due to which we can assume that micro cracks appear earlier.

The growth trend is progressive, which in Figure 5 is shown with polynomial regression. Derogation (R^2 – statistical distribution of the polynomial curve position according to the real value) from the selected polynomial regression is 0,95.

Steel Armox 500T transfers high loads, but according to the definition of toughness [12] we cannot say that it is Figure 7 Structure of steel at zoom of 600 %tough. In Figure 7, it can be seen that material Armox 500T has a more martensitic structure with a distinctive lenticular shape of grains [9]. Martensites are known to have higher strength and are fragile. Their tetragonal body central cubic crystal structure has no close packed slip planes, due to which dislocations can easily move [11].

It can be seen that after a certain number of cycles in material Armox 500T there are more longer cracks then shorter ones (Figure 6).

The number of long cracks at fracture of steel Armox 500T is 100, medium 39 and short 19. The growth trend of short, medium and long cracks is progressive (Figure 6). Derogation (R^2) from the selected polynomial regression is from 0,80 for short cracks to 0,96 for medium long cracks. At the beginning of a material lifecycle, we cannot expect long cracks since they must first generate. Long cracks were created by short cracks during cycle fatigue. The first long cracks begin to appear midway through lifetime.

CONCLUSIONS

The paper presents microstructure analysis of the creation and growth of cracks in uniaxial load specimens subjected to alternating cycle fatigue at constant amplitude and constant velocity of deformation. Microstructure analyses were performed in longitudinal sectional measuring areas of specimens at every 200 load cycles until fracture. The first micro cracks up to 10 μm long occur before the 200th cycles, whereby crack growth is progressive during further loading. Cycle fatigue to fracture formation of a high number of long cracks (over 20 μm) is more dominant. Long cracks appear midway through lifetime. The presented measurement results will benefit researchers who study initiation and propagation of cracks in materials. The results of analyses performed can be used to compare results of numerical mathematic methods on the macro scale level.

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