Influence of overloads on the crack formation and propagation in EN AW 7475-T761

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Abstract. To investigate the influence of single overloads on the fatigue behavior of EN AW 7475-T761 experiments at different base loadings and different overload spacings have been undertaken. Independent of the base load the introduction of tensile overloads enhances the cyclic lifetime. The formation and propagation of cracks was investigated by a DC potential drop method. The potential-drop vs. cycle number plot shows a distinct plateau region which covers about 80 % of the total lifetime. The remaining 20% are determined by the propagation of a macroscopic fatigue crack leading to a significant increase of the potential. Fractographic investigations have shown that cracks are formed after a couple of cycles and the plateau-region can be correlated with the propagation of short fatigue cracks. The introduction of overloads leads to a retardation of the crack propagation rate of short as well as long fatigue cracks leading to an increased fatigue lifetime.

Introduction

The knowledge of the fatigue behavior under spectrum loading is essential for realistic life time predictions. A first step is the understanding of the influence of single overloads on the fatigue behavior. Therefore, a lot of investigations concerning the propagation of long fatigue cracks have been undertaken. It is well known that the introduction of single overloads leads to a retardation of the crack propagation rate [1-5]. The latter is attributed to internal stresses in front of the crack-tip and crack closure effects [6-9]. Due to the fact that the propagation of long fatigue cracks covers only a small part of the total lifetime it is important to investigate the influence of single overloads on the crack formation and the propagation of short fatigue cracks. In this work the influence of single overloads on the crack formation and the propagation of short and long fatigue cracks was studied at different base loadings and overload spacings using the DC potential drop method.

Experimental details

The experiments were undertaken with specimens of an AW7475-T761 clad sheet material. The thickness of the sheet material was 2.88 mm, including 80 µm clad (AW 7072). CCT-specimens with a continuous radius between the ends and a test section width of 20 mm were machined from the sheet material. As shown in figure 1 a hole with a diameter of 4 mm was introduced as a starter notch. In a distance of 3.5 mm to the middle of the starter notch pins for potential drop measurements have been mounted into the specimens.

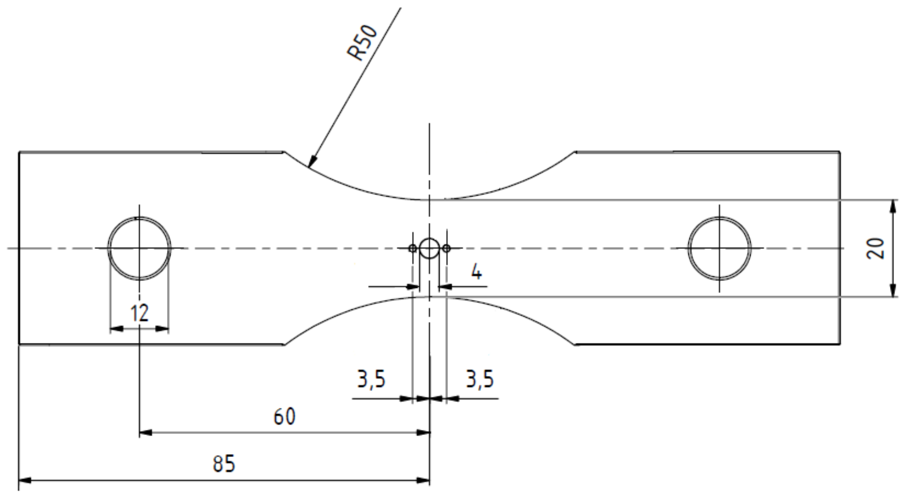


Fig.1. CCT-Specimen with pins for potential drop measurements.

The fatigue tests have been performed using a servo-hydraulic testing machine with maximum stresses of σ_{BL} = 160, 180, 200, 240 and 280 MPa and a load ratio of R=0. Overloads with a maximum stress of σ_{OL} = 150% of the base load were introduced in equally spaced cycle numbers N_{OL} as shown in figure 2. The spacing N_{OL} between the overloads was 100, 1000 and 10000 cycles, respectively.

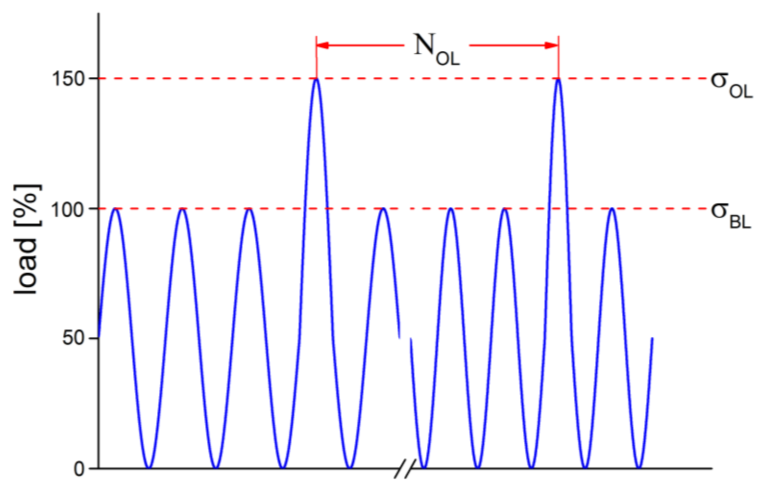


Fig.2. Fatigue tests with overloads.

For the crack detection and crack length measurement the DC potential drop method was used. Therefore, a constant current of about 50 A was conducted through the specimen. The potential drop was measured between the pins next to the hole in the specimen using a Keithley 2182 nanovoltmeter. The initial potential drop was about 0.3 mV. To avoid temperature effects, the fatigue experiments were performed in a specimen chamber which was cooled by a fan to a constant temperature.

Results

In figure 3 the total lifetimes of the fatigue tests with different overload spacings N_{OL} compared to fatigue tests without any overload are shown. Independent of the overload spacing the introduction of overloads enhances the total lifetime N_f on all loading levels. The highest increase of the lifetime with more than 200 % is found with an overload spacing of N_{OL} = 1000 cycles, followed by the tests with an overload spacing of N_{OL} = 100 cycles which show an increase of more than 130 %. With about 60 % the lowest increase in lifetime is found in the experiments with N_{OL} = 10000 cycles.

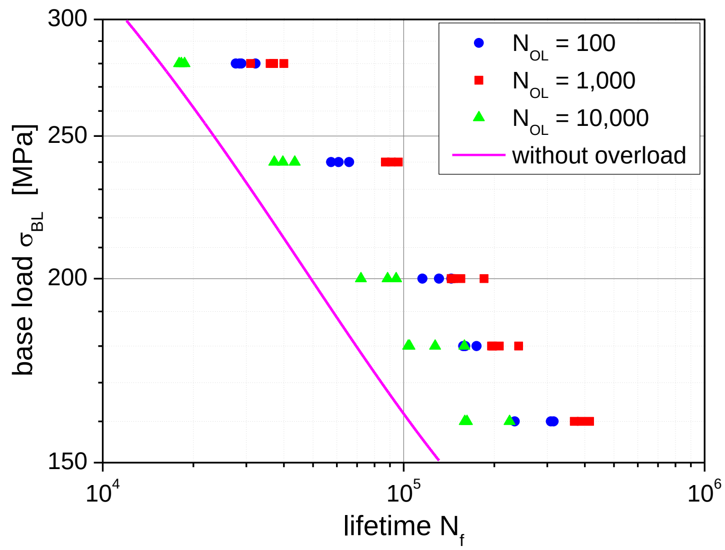


Fig.3. SN-plot of the fatigue tests with and without overloads.

In figure 4 the run of the normalized potential drop U/U_0 vs. number of cycles for a fatigue test with a base load of σ_{BL} = 160 MPa and an overload spacing of N_{BL} = 100 is shown. A slight increase of the potential at the beginning of the test is followed by a distinct plateau-region which covers the main part of the cyclic lifetime. The plateau-region ends with a detectable increase of the potential. This increase is caused by the formation and propagation of a macroscopic crack, finally leading to a catastrophic failure of the specimen.

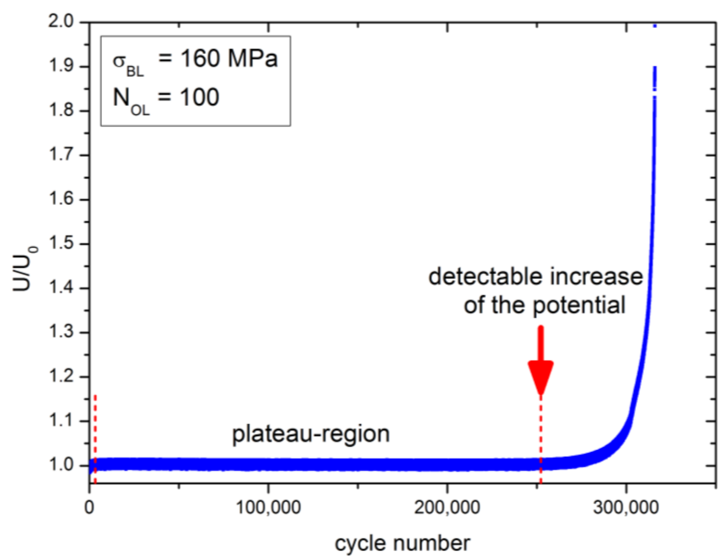
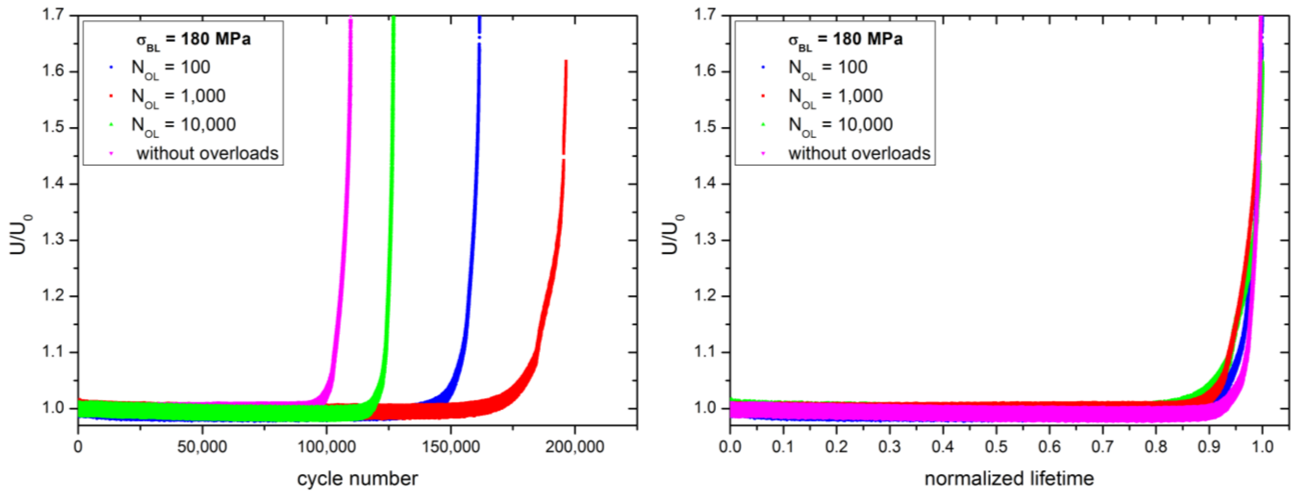


Fig.4. Potential drop vs. cycle number for a fatigue test with overloads. The plateau region is marked by the dashed red lines

Figure 5 a shows potential-drop curves for fatigue experiments with a base load σ_{BL} = 180 MPa and three different overload spacings N_{OL}. The length of the plateau-region varies due to the different overload spacings and dominates the cyclic lifetime. In figure 5 b the potential drop is plotted against the normalized lifetime. It is clearly visible that the plateau-region covers more than 80 % of the cyclic lifetime for all overload spacings N_{OL}. The end of the plateau-region reflects in the start of the propagation of a macroscopic fatigue crack, indicated by a significant increase of the potential. In case of the experiments without overloads the plateau-region ends at about 90 % of the lifetime, the introduction of overloads shifts the beginning of macroscopic crack propagation to 80 % - 85% of the cyclic lifetime.



(a) (b)

Fig.5. Potential drop vs. cycle number for fatigue test with a base load of σ_{BL} = 180 MPa.

The crack length a was calculated from the measured potential drop U/U_0, the specimen width w, the half spacing between the potential grips y and the length of the starter notch a_k using the Johnson-Formula [1].

$$a = \frac{w}{\pi} \cdot arccos\left(\frac{cosh\frac{\pi \cdot y}{w}}{cosh\left(\frac{U}{U_0} \cdot arcosh\frac{cosh\frac{\pi \cdot y}{w}}{cos\frac{\pi \cdot a_k}{w}} \right)} \right) \tag{1}$$

At higher base loadings in the plateau-region a slight increase of the potential and, therefore, of the crack length can be observed. In figure 6 the crack length for an experiment with a base load of σ_{BL} = 280 MPa as a function of the cycle number is shown. At the beginning a fast increase of the crack length up to 0.2 mm is visible. In the plateau-region a slight increase of the crack length of about 0.1 mm can be observed. At higher cycle number the crack propagation rate increases up to catastrophic failure of the specimen. The crack length in the plateau-region exhibits a great scatter of about ±0.08 mm around the mean value.

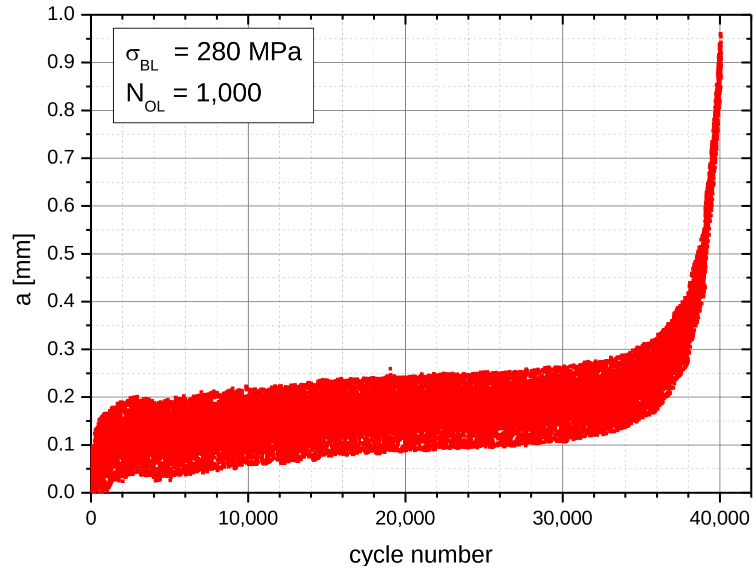


Fig.6. crack length vs. cycle number for fatigue test with σ_{BL} = 280 MPa and N_{OL} = 1000.

To get more information about the crack propagation during the fatigue experiment, crack surfaces have been investigated using a SEM. Figure 7 shows an overview of the crack surface of one side of a specimen loaded with σ_{BL} = 280 MPa and an overload spacing of N_{OL} = 1000 (same specimen as in figure 6). On the crack-surface traces caused by the overloads are visible. With rising crack length the marks get more pronounced. Starting from the final fracture the cycle-number of the overload-marks can be determined.

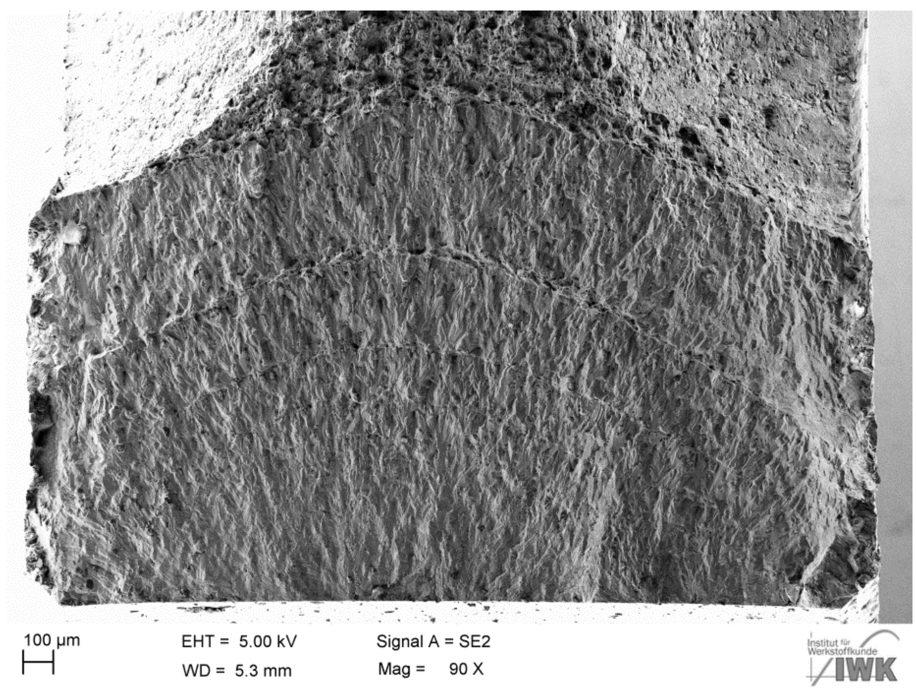


Fig.7. Crack surface of specimen loaded with σ_{BL} = 280 MPa and N_{OL} = 1000.
Overload induced crack traces are visible.

At a higher magnification also less pronounced marks can be found. In figure 8 the region near an incipient crack is shown. The mark induced by the overload Nr. 10 is labeled by arrows. After 10000 cycles the crack length at the surface was about 85 µm and in the depth more than 50 µm. On the right hand side the 7th overload can be discovered, on the left hand side even the second one (N = 2000), too. This result demonstrates that an incipient crack is generated in less than 2000 cycles. Consequently, the plateau-region in the potential vs. cycle-number plot has to be correlated with the propagation of small fatigue cracks.

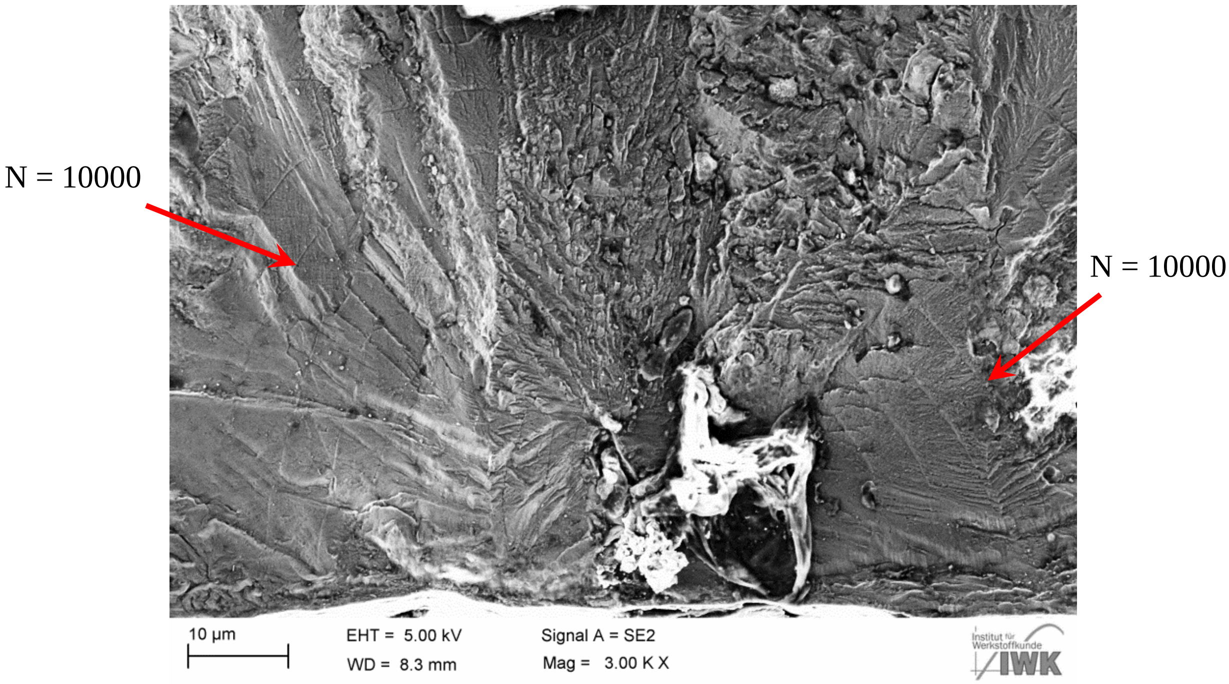


Fig.8. Crack surface of specimen-loaded with σ_{BL} = 280 MPa and N_{OL} = 1000.

After the 30th overload, i.e. at the end of the plateau region the propagation of a macroscopic crack takes place.

In figure 9 the crack length vs. the cycle number of a specimen cycled with a base load of 160 MPa and an overload spacing of N_{OL} = 1000 is compared with a specimen fatigued with the same base load but without any overload. In the latter case a strong increase of the crack length with the cycle number due to the rising stress intensity can be observed. However, taking overloads into account the slope of the crack length vs. cycle-number curve is considerably smaller. The introduction of overloads causes a spontaneous crack acceleration followed by distinct crack retardation. The crack acceleration is visible in form of steps in the diagram. The height of these steps also rises with the crack length. The spontaneous crack acceleration is followed by distinct crack retardation. The last overload at 416000 cycles causes the final fracture of the specimen.

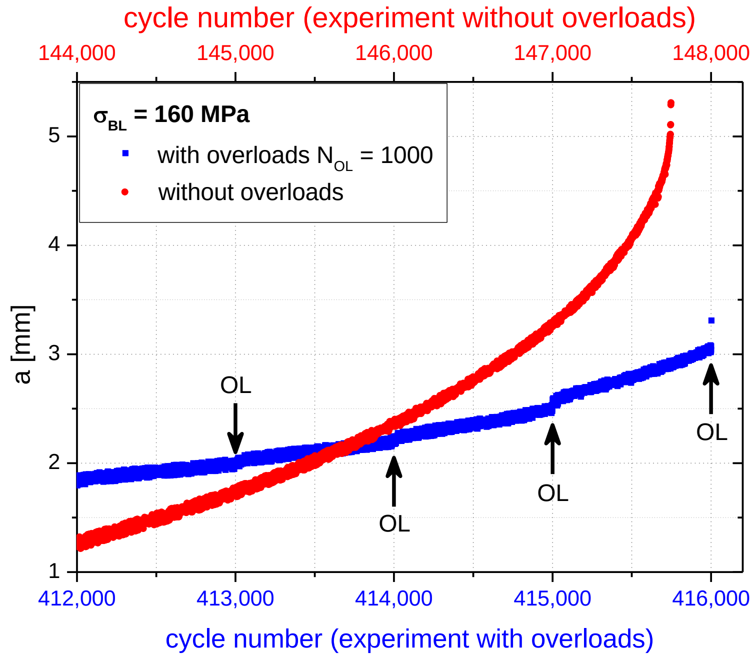


Fig.9. Crack length vs. cycle number of specimens with and without overloads.

Discussion

The experiments have shown that the introduction of single tensile overloads enhances the fatigue lifetime of EN AW 7475-T761 specimens. The influence of overloads on the fatigue crack propagation was investigated in many studies [1-5, 11, 12]. Due to the overload a crack acceleration followed by distinct crack retardation can be observed [11, 12]. The latter can be explained by the formation of compressive stresses in front of the crack tip caused by the overload [6, 7, 13]. This compressive stresses reduce the effective stress intensity and, therefore, the crack propagation rate is decelerated. In case of multiple overloads, depending on the overload spacing N_{OL} sequence effects have to be taken into account. A second overload is influenced by the internal stresses in front of the crack tip caused by a single overload as far as the crack tip remains in the influenced region. The spacing between the overloads N_{OL} determines the interaction and the amount of the influence. In case of the experiments performed in this work, the highest lifetime and, therefore, the greatest influence is achieved with an overload spacing of N_{OL} = 1000. When the spacing between the overloads is smaller (N_{OL} = 100) the interaction of the overloads takes place before the point of maximum crack retardation is reached. Consequently, the crack propagates faster and the total lifetime is reduced. In case of longer spacings (N_{OL} = 10000) the interaction of the overloads takes place after the point of maximum crack retardation and, finally just a little interaction between the overloads takes place.

The investigations concerning the influence of overloads on the fatigue behavior are discussed in the light of the propagation of long fatigue cracks. In the experiments undertaken in this study the propagation of long fatigue cracks covers less than 20 % of the total lifetime. Most of the cyclic lifetime is concerned with the formation of a macroscopic long crack. The fractographic studies have shown that the plateau region and therefore nearly the complete rest of the cyclic lifetime can be contributed to the propagation of short cracks. Unfortunately the DC-potential drop method is insensitive to investigate the propagation of short cracks. Therefore, the small increases in the crack length in the plateau-region don't lead to a considerable increase of the potential drop. Solely at higher base loadings a noticeable increase of the potential in the plateau region can be found. However, the investigation of the crack surfaces of specimen loaded with overloads has shown that in the plateau region even at low base loadings the propagation of short fatigue cracks can be observed. In case of experiments without overloads it can be assumed that in the plateau-region the propagation of small fatigue cracks takes place, too. With this consideration crack formation can be neglected and nearly the complete cyclic lifetime can be contributed to crack propagation. Therefore, the influence of periodic overloads nearly covers the complete lifetime which is in accordance with the experimental results where the region of macroscopic crack propagation as well as the plateau region is influenced by the overloads in the same matter.

For fatigue lifetime predictions taking periodic overloads into account, solely the crack propagation has to be taken into consideration. The effect of single overloads seems to be the same in case of long and short fatigue cracks. This allows a common description of the influence of single overloads on the propagation behavior of long and short fatigue cracks and therefore the lifetime of cyclic loaded specimen.

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