**Assessment of Early Fatigue of Power Plant Material Using Acoustic Emission Method**

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**Abstract**

This work presents the application of the acoustic emission technique for detection and characterization of early fatigue damage. Specifically various manifestations of the localized plastic deformation that is the precursor of microcrack formation. A nuclear Cr-Ni-Mo-V low-alloy steel has been chosen for this study. The acoustic emission signal has been correlated with the defect formation mechanisms and the registration of loading (resonant) frequency changes of the tested specimen taken by RUMUL fatiguation machine. The work is focused on the analysis of the acoustic emission signal during opening and closure half-cycle.

**Experimental procedure**

**Materials and mechanical testing**

The material used in this study is a nuclear Cr-Ni-Mo-V alloyed steel, known as GOST 15Ch2NMFA. The smooth test specimens shown in Fig. 1a, were manufactured from the large compact tension specimens, taken from the forged rings of the reactor pressure vessel. Microstructure of the studied material, due to the applied heat treatment, is a mixture of heterogeneous Bainite and martensite (see Fig. 1b).

The bending fatigue tests were conducted on the resonance system RUMUL Cracktronic 8204/160 testing machine in high-cycle region at different stress amplitude levels ranging from 407 to 590 MPa. The fatigue cycle was sinusoidal with a frequency about 113 Hz and the stress ratio was set to \( R = -1 \).

**AE testing procedure**

Acoustic emission (AE) was monitored using an advanced Ipl data acquisition system with a total system gain of 80 dB, supplied by DAXEL Company. Two piezoelectric sensors (DAXEL, type: M012i) were fixed on each end of the specimen by Loctite glue (see Fig. 2).

The level of stress amplitude as a function of time were also recorded using the same data acquisition system (fifth channel of IPL system). Results include analysis of the number of AE events, count rate, amplitude, duration and RA parameter over time during load increasing/decreasing phase and linear source location.

**Results**

Figure 3 shows the most typical graphs of AE hit accumulation (black line) and count rate (various colors) at two stress levels, separated on types of sources. Large numbers of counts are emitted in the first period of fatigue life due to the movement and interaction of dislocations and persistent slip band formation – area A. The crack nucleation stage is characterized by low activity of AE signal with occasional peaks, and then, AE activity emitted by the growth and coalescence of the microcrack is increased – area B. After the initiation, there was an intense AE bands with a clear boundary above zero stress (see Fig. 4). AE signals in this band may be caused by crack-face grinding while the crack was closed.

A colorful distribution of load phases (see Fig. 5) was proposed to study the AE behaviour during load increasing phase (crack openings) and decreasing phase (crack closure). Most of the AE signals are generated at load decreasing phase, especially near zero load. It was found that at all stress levels, sharp increase of AE events at increase phase is observed, and it may become a warning signal of impending fatigue failure. The AE hits generated at decreasing phase are mostly constant before final fracture (see Fig. 6). However, the changes at increasing phase are also observed during nucleation stage (see Fig. 3 and 6, marked with an arrow).

In order to understand the AE generated in all stages, AE amplitude (duration) distribution analysis has been performed. The more significant differences are in the stages of fatigue. Low amplitudes about 58 dB are coming from the stage of nucleation and growth of the microcracks – area C. While the higher amplitudes about 64 dB, are emitted by the slip band formation in the first period – area A (see Fig. 7). The peaks amplitude detected may point to different mechanisms of fatigue damage. Figure 8 again shows duration distribution diagram. In this case, the frequency of occurrence peaks also occur due to microstructure changes at two duration levels. Relationships between the AE amplitude values and duration are given in Fig. 9. It is evident that AE signals with amplitudes 54 to 61 dB are generated from area A, while the signals coming from the microcrack propagation (area C), and decreasing phase, respectively. It is observed the same crack types occur at each stress level and in different stages of fatigue process, as illustrated by Fig. 10.

**Conclusion**

One objective of this research was to investigate the possibility of selection stages of the fatigue damage accumulation and to propose a methodology for the application of early fatigue damage evaluation in power plant material. The AE signal initially shows an increase due to the movement and interaction of dislocations and persistent slip band formation (area A), followed by steady state growth where the crack is nucleated (area B), and then finally growth and coalescence of the microcracks to the size of macrocrack (area C). The microcracks nucleation and their growth is accompanied by a low activity in count rate and cumulative AE hit and it seems difficult to detect the initiation of microcracks. In particular, it was found that at all stress levels, sharp increase of AE hits at load increase phase is observed, and it can be used as an indicator of nucleation and growth of microcrack. It was concluded that AE parameters are sensitive to the damage process (apart from the total activity) and should be further studied in order to lead to early warning against final fracture.

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