Detection of Fatigue in Aluminum with the Thermoelectric SQUID Method: A First Attempt

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The detection of fatigue damage in aluminum before crack initiation is a general NDE problem. It is, however, of special importance in connection with the aging aircraft discussion. This paper gives a hint to a possible solution of this problem.

The Thermoelectric SQUID Method [1], [2], [3] is a noncontacting NDE method. It has been proven capable of detecting material inhomogeneities in metals, especially segregations. These may even be subsurface. The physical effect used in this method is the Seebeck effect, due to which a thermovoltage is generated between two different contacting metals if these have two common boundaries at different temperatures. It is well known that the difference in these metals does not necessarily have to be a chemical difference. For example, a difference in crystallography or texture can also give rise to the Seebeck effect [4]. It was furthermore found that a fatigued region of aluminum within non-fatigued aluminum could be detected by the thermoelectric method with the standard contacting voltage readout [5]. The contacting readout, however, has drawbacks: requirement of mechanical contact, interface imperfections, necessity of proper electrode reference material and limitation to surface reaching inhomogeneities. A magnetic readout can be made non-contacting and should eliminate these problems and limitations. A preliminary test was performed to show the feasibility of this idea in the detection of a fatigued region in aluminium.

Experiment

Fig. 1 illustrates how the sample was prepared. An aluminium sheet of 2 mm thickness and 500 mm diameter was pressed to plastic deformation at one spot. This was done at a total of four times, i.e., forth, back, forth and back. Between the brass pressure bolt in use and the aluminum test sheet plastic plates were positioned to make sure that there was no material transfer from the brass to the aluminum. No visible cracks arose during this procedure. After the procedure, there was an unevenness of less than 0.2 mm of the surface in the treated region. The treated region was circular with a radius of about 10 mm.

Then, the sheet was placed on a turntable [3] and rotated at the rate of about one turn in four seconds. Above the sheet in a fixed position there were the SQUID sensor of the Magnetic Measuring System HMT [3] and a nozzle through which hot air of about 80 ^{o} C was blown. The nozzle was positioned at a radius of either 150 mm or 290 mm. This caused a positive and negative temperature gradient in the radial direction at the position of the treatment, respectively. The position of the SQUID system was changed in radial steps of 2 mm.

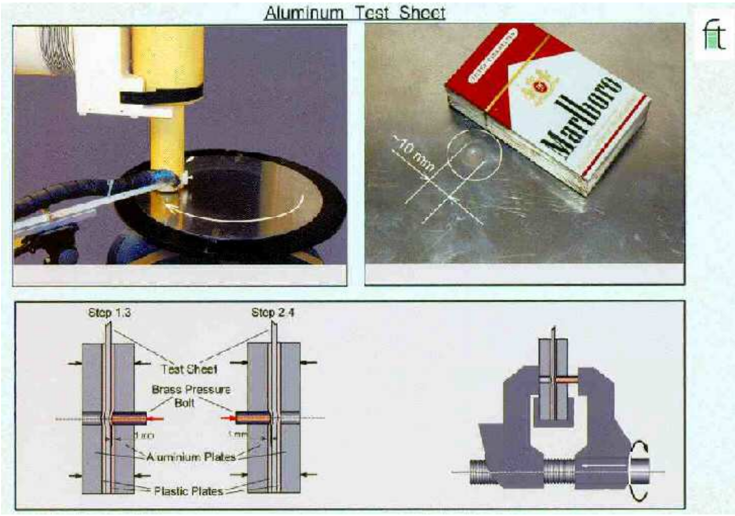

Fig. 1: Creating plastic deformation in the aluminum test sheet.

The results are shown in fig. 2 as A-scan and C-scan plots. The treated area is detected in all magnetic field plots with high signal-to-noise-ratio. Changing the heating radius from 150 mm to 290 mm and thus changing the sign of the temperature gradient causes a change of the sign of the magnetic field as expected.

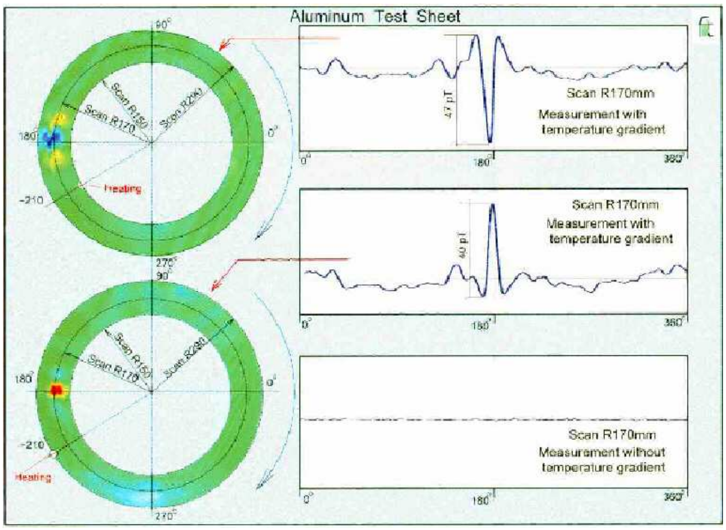

Fig. 2: Measuring results using the Thermoelectric SQUID Method.

Relevance to Fatigue

The treatment of the aluminum sheet in this experiment was a local plastic deformation. A typical fatigue treatment on the other hand would be made by sustained cycling at significantly lower stress levels. However, it has been shown before by contacting readout that low cycle plastic deformation and moderately high cycle fatigue in titanium gives a very similar thermoelectric behaviour [6]. Figure 3 shows the measured thermoelectric voltage in a plastically deformed (a) and cyclically fatigued (b) Ti-6Al-4V bar. Both measurements were done at a damaged and undamaged location along the 1/4"x1/2"x8" bar by approximately minus 70 ^{o} C cooling and contact readout. The plastically deformed specimen was stressed to 2% maximum strain in a three-point bending configuration in 10 full cycles, which corresponds to approximately 33% of the fatigue life before crack initiation. The fatigue cycled specimen was loaded to a maximum stress of 80 ksi at 8 Hz repetition frequency at a total of 52,000 cycles, which corresponds to approximately 40% of total fatigue life before crack initiation. In spite of the significant scatter of the data caused by the inherent contact uncertainties of the conventional readout technique, the damaged and undamaged sites are clearly separable in both cases and the effect of plastic deformation is essentially the same as that of cyclic fatigue.

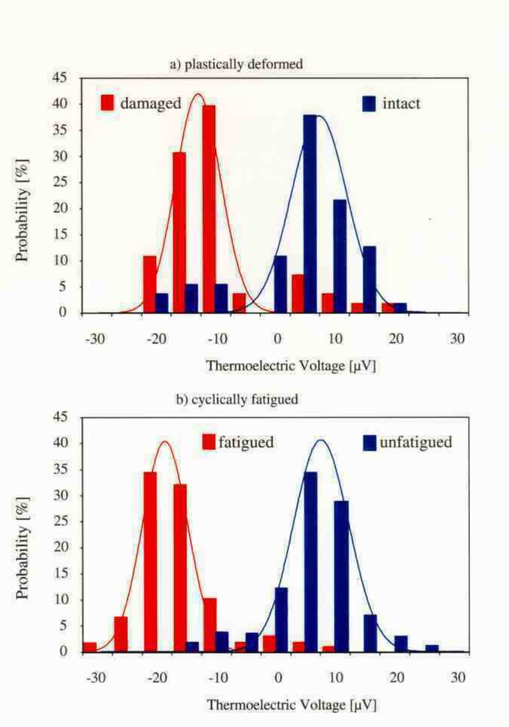

Fig. 3: Probability of thermoelectric voltage measured with a contacting method on Ti-6Al-4V bars. a) plastically deformed and b) cyclically fatigued sample, both compared with untreated samples.

Conclusions

Microstructural changes in aluminum have been generated by plastic deformation at a level below crack initiation. It has been shown that these local microstructural changes can be detected by the non-contacting Thermoelectric SQUID Method. It is known from former experiments with a contacting readout [6] that the thermoelectric behaviour of low cycle and moderately high cycle fatigued metals is very similar. Therefore it is highly probable that at least moderately high cycle fatigue can also be detected by the Thermoelectric SQUID Method significantly before crack initiation. Direct test on moderately high cycle fatigued aluminum samples by the Thermoelectric SQUID Method are planned for the future.

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