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FOCUS ON IMAGING

In Application

Use of DIC for Early Crack Detection in High-Cycle-Fatigue Testing

Introduction

In materials science, fatigue is the initiation and propagation of cracks in a material due to cyclic loading. Therefore, the identification of crack formation is an important feature during the fatigue test. Optical techniques for full field deformation and strain measurement offer the possibility of providing non-invasive valuable information on crack formation both during the test and in post-processing. This information is particularly important to evaluate the influence of environmental factors, such as exposure to radiation or H_2, on changes in the strength of materials. Using the example of a High-Cycle-Fatigue (HCF) test on a bent pipe segment, we show how DIC can provide valuable information on the development of a surface crack, at an early stage.

Experimental setup

The experiment was conducted at servo hydraulic tensile machine in axial force-controlled mode. The object, an injection pipe segment, is fixed in adapters that allow rotation of the clamping perpendicular to the load direction (see Fig. 1).

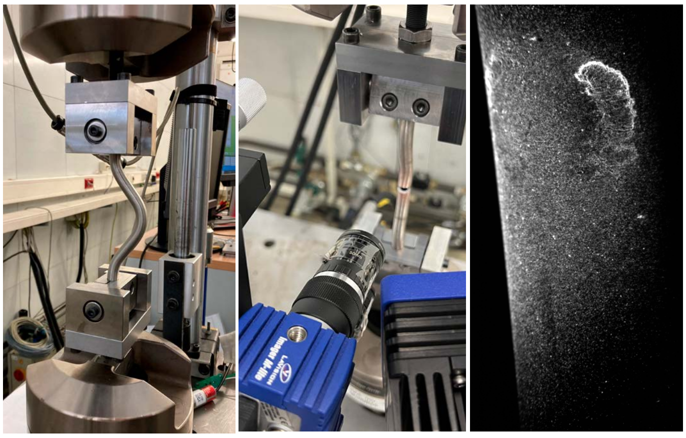

Figure 1: *Test object before the test (left), DIC system in front of the object after failure (middle) in the tensile machine and image of the object with photogenic pattern (right).*

For pattering the Photogenic Patterning method was applied. Using this technique, only the speckle pattern is generated on the surface and no base paint is required, even on highly reflective surfaces (see Fig.1). Therefore, the object surface itself is imaged without being covered fully by a base paint. This ensures that the crack is not detected in the base paint but on the object surface.
The StrainMaster Portable DIC System is located about 10 cm in front of the object. Using 5 MPx cameras at 17° stereo angle and 50 mm lens a field of view of about 23 x 17 mm is imaged.

Measurement

The sample was loaded at a testing frequency of about 1 Hz. At max load the tensile machine generates a trigger signal for the DIC system to capture images. Since the exact number of loads cycles leading to cracking and failure was not known, images were taken at each load cycle. For each load step the actual load and cross-head displacement of the tensile machine was recorded as an analogue signal and stored with the images.
After about 41.100 cycles or 11 h and 25 min the sample failed and the image acquisition stopped.

Results

Steps were removed from the entire series for the evaluation. Images were analyzed at the beginning and end with a high temporal resolution, while in the middle only one image was analyzed approximately every 17 minutes.
Fig. 2 shows the recorded force and position signal of the tensile machine over the evaluated steps. During the first few minutes, the control of the machine adjusts to the set force value. About 12 minutes before the failure, a change in the cross-head displacement signal can be recognized.

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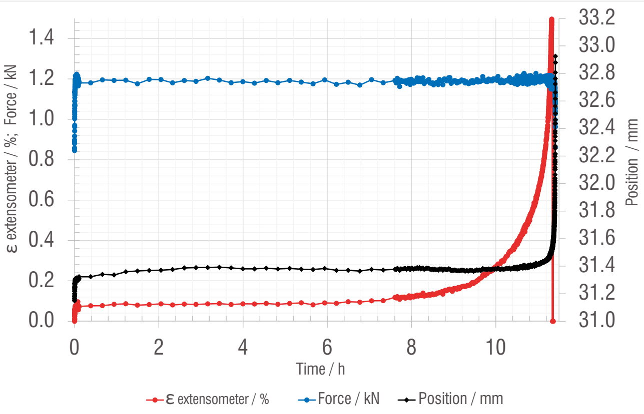

***Figure 2**: Force (blue), position signal (black) recorded at the evaluated steps and extensometer strain(red)*

However, at this time the crack is already visible in the raw camera images with a crack length of about 4.8 mm (see Fig.3). Looking at the series of raw images, the first indication of a crack can be detected about 2 hour before failure. Using postprocessing function already 4 hours before failure the initiation of the crack can be found.

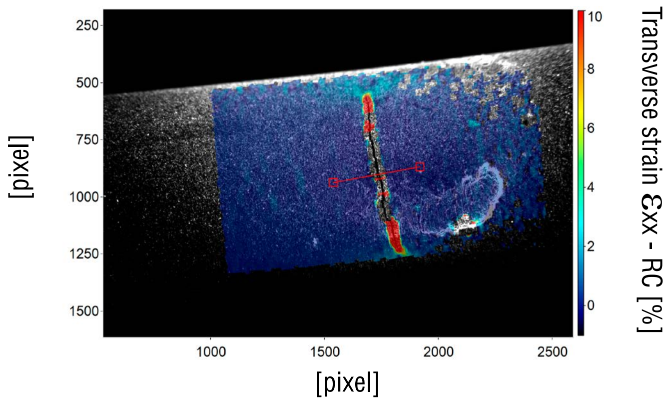

***Figure 3**: Image of the crack area, overlayed with strain field and position of extensometer (red line), 12 minutes before failure.*

Defining a video extensometer, of about 3.7 mm length, at the crack position (see Fig. 3), allows the determination of the strain between the end points of the extensometer over the experiment. The extensometer strain is plotted in Fig. 2 as well. About 4 h before failure, a slight change in slope of the signal can be detected, which corresponds to the first visual appearance of the crack.

For further analysis gauges, of about 0.5 x 2.5 mm² size, were placed above (max) and below (base1, base 2) of the crack (see Fig. 4). The calculated strains within those gauge areas are shown in Fig. 5.

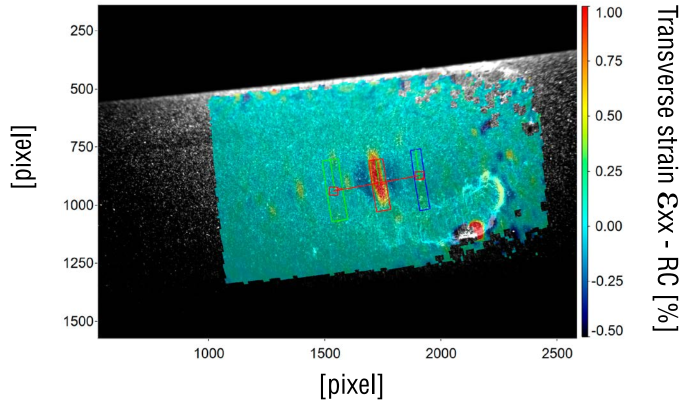

***Figure 4**: Image of the crack area, overlayed with strain field and position of extensometer (red line), and gauge elements (red: max, green: base 1, blue: base 2) about 4 hours before failure.*

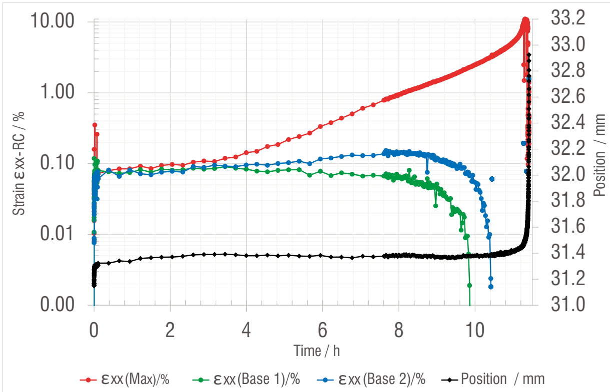

***Figure 5**: Strain inside the gauge areas (log. scale) and position signal (black) recorded at the evaluated steps.*

The separation of the strain values at the crack location to the base material can be detected 8 hours before failure already. However, the initiation of the crack happens later. About 4 hours before failure, a relaxation of the areas below the crack, combined with a reduction in the strain values, can be detected.

Conclusion

In order to predict the fatigue life of components, the understanding of crack initiation and growth during a fatigue test are important. The information accessible from the tensile machine are very limited here and optical techniques, like Digital Image Correlation (DIC), can give better and more detailed information. The use of a speckle technique, which does not require base code (Photogenic Patterning), ensures a reliable determination of the crack initiation.

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