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Thermographic detection of damage initiation of cyclically loaded parts

by M. Švantner*, J. Skála*, L. Muzika*, P. Čížek**

* University of West Bohemia, Univerzitní 8, 30614 Plzen, Czech Republic, msvantne@ntc.zcu.cz
** MATERIÁLOVÝ A METALURGICKÝ VÝZKUM, Pohraniční 693/31, 703 00 Ostrava- Vítkovice, Czech Republic, petr.cizek@mmvyzkum.cz

Abstract

The contribution is focused on thermographic detection of initiation of plastic deformation and damage of cyclically loaded parts. Plastic deformation of material is connected with heat generation, which can be utilized for thermographic inspection. Location of critical parts and initiation time can so be detected at different technological tests before damage. A procedure for highlighting of an indication based on Fast Fourier Transform is introduced in the contribution. Procedure and results of thermographic inspection of cyclically loaded physical model of welded pipes are presented.

1. Introduction

Deformation of materials is connected with thermo-elastic and thermo-plastic effects, at which a heat is generated in the materials due to their deformation. The thermo-elastic effect is connected with elastic strain, it is reversible and it mostly leads to a small temperature response. The thermo-plastic effect is connected with plastic strain, it is irreversible and the thermal response is generally greater compared to the thermo-elastic effect. These effects can be used for a thermographic inspection of mechanically loaded parts [1].

An intensity of a thermo-mechanical effect depends on loading conditions, material properties and a geometry of a loaded part. The thermographic stress analysis is often used at cyclic loading, at which a heat generation results in measurable temperature differences. There are two basic approaches: a thermographic inspection of fatigue properties [2] and a thermographic stress analysis [3]. This contribution is focused on thermographic stress analysis of a cyclically loaded part. This inspection is based on thermographic measurement of immediate mechanically induced temperature changes. A thermal response of a plastic deformation is generally more intensive than an elastic deformation response. It brings a possibility to detect critical loads or critical positions on mechanically loaded complex geometry parts.

The inspection and evaluation procedure in this contribution is demonstrated on a cyclically loaded experimental welded part. The goal of the experiment was to find an evaluation procedure, which could be able to detect a critical load causing a plastic deformation, a location where cracks occurrence and damage could be expected and to detect a possible crack creation at the position. The experimental procedure is described and benefits of applying advanced evaluation methods are demonstrated. It is shown, how these methods can enhance a displaying of a thermal response even in the case if temperature changes are very small and a recording frequency is lower than loading frequency.

2. Experiment description

The experiment was performed with a test piece composed of two pipes welded perpendicularly to each other. Both pipes were made form a construction steel with a yield stress about 300 MPa. One of the pipes ("thicker") was fixed. The outer diameter of the pipe was 100 mm, wall thickness was 16 mm. The second pipe ("thinner") was welded perpendicularly to the fixed pipe, its diameter was 50 mm and the thickness of its wall was 8 mm. The pipe was cyclically loaded with a load applied at a free end of the pipe, perpendicularly to the pipe and parallel to the fixed pipe. The load amplitude was increased in three steps: 18, 21 and 24 kN. Duration of each loading step was about 30 min and the loading frequency was 4-5 Hz.

A simple numerical model was created for an estimation of a maximum stress position and a level of the maximum stress compared to the yield stress of the used steel. The model did not assume cyclic loading or properties of the weld. Static loading (the amplitude) and material geometry made as one continuous part were assumed in the simplified model.

The temperature of the tested sample was measured continuously by a thermographic camera during each loading step. A bolometric camera Optris PI 400 with a 13° lens was used. The detector resolution was 382x288 px, spectral range of the camera was 7.5-13 um and the temperature resolution was (based on a device documentation) 0.1 K. The camera measured a location near the weld at a side of a tensile loading, where a maximum induced stress was supposed. The sampling frequency of the IR camera was 1 Hz. It was supposed that a thermal response could be very small. Thus, an advanced evaluation of the thermographic signal was applied. One of the goals of the experiment was to detect a crack initiation and its subsequent developing. Thus, a number of consecutive signal intervals of a length about 200 samples were taken from the IR camera record at each step. A Fast Fourier Transform (FFT) based evaluation was applied to each taken data interval (for all steps) for highlighting a possible temperature changes due to plastic deformation or crack occurrence.

3. Results

The numerical simulations showed that a position with a maximum stress concentration was located near the weld at the thinner pipe. It could be supposed that this region was intensively plastically deformed and it was confirmed by the experiment, that a failure occurred at this location. Von Mises stress intensity contours are displayed in Fig.1 a).

a) b) c)

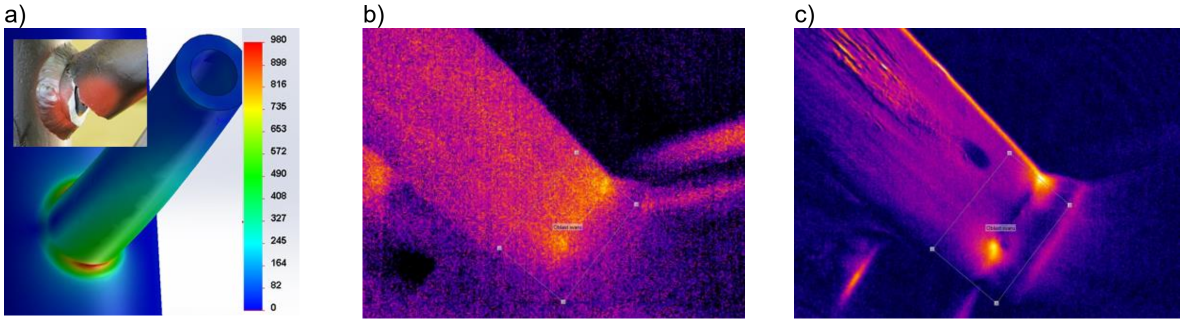

Fig. 1: *Stress intensity contours with a photography of damaged sample (a), a thermographic picture at load 24 kN (b), a defectogram evaluated using FFT at the load 24 kN (c) corresponding the thermographic picture.*

A quantitative evaluation of real stress intensity was not fully relevant because of simplifications of the model. However, the results suggested that the maximum stress intensity exceeded the yield stress even at the lowest load 18 kN. That was confirmed also by the thermographic measurement. A mean temperature of the sample changed during the experiment due to external conditions (room temperature). The mean temperature was not influenced by the loading process, because the region of high-deformation was too small compared to a mass of the part. However, a locally increased temperature was observed at the position of a supposed failure. An indication on thermograms was however very weak, as it is shown in Fig.1 b). These indications occurred at loading peaks only.

However, clear indications were obtained after advanced thermographic evaluation by the FFT procedure. Defectograms at different loading steps illustrated a failure progress during the experiemnt. Continuous indications at the position of supposed maximum stress were observed at a start of the loading procedure (18 kN), which was similar as the "indication" obtained by the numerical simulation. In the course of the experiment, as the load was increased, there was a stress/strain relaxation due to cracks occurrence or plastic strain redistributions. A crack creation resulted in stress relieving at the centre of the indication and stress peaks moved to roots of the crack. This effect was observed on defectograms at a higher load, as it is shown on the example in Fig.1 c) for the load 24 kN.

4. Conclusions

Possibilities of inspection of cyclically loaded parts were presented in this contribution. The plastic strain region determined by the thermographic method corresponded to the numerical simulations. It was demonstrated how the thermographic analysis can detect such a region and how an evolution of a failure (crack) of the inspected material can be observed. It was shown how FFT evaluation methods could highlight a thermal response and improve measurement outputs if a periodical load is applied. The measurement was successful even though the IR camera frame rate (sampling frequency) was lower than a loading frequency. This was because of shifts of sampling, which made it possible to record temperature peaks as well as a lower temperature at a load relieving (between two peaks) if a recording interval is long enough.

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