Thermographic Inspection of Tension and Bend Cyclically Loaded Samples

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Abstract: Fatigue properties are among the very important material parameters, whose testing is expensive and time consuming. Thermographic inspection of the cyclically loaded samples could possibly be a method, how to reduce the expenses of fatigue tests. Principles of cyclic loading thermographic inspection and methods of evaluation are presented in this contribution. Research works, developed software and devices for tension and bending cyclic tests are introduced.

Keywords: Thermography; Fatigue Testing; Cyclic Loading; Mechanical Testing.

1 Introduction

Components under cyclic mechanical or thermo-mechanical loading can be damaged by a fatigue degradation process. This process has a cumulative character. Fatigue fractures can occur in a material during its long-time cyclic loading, even if the load is below its yield strength. This can be critical in many technical applications, where a cyclic loading of components takes place. Fatigue properties of materials are therefore an important material characteristic, which is often required for example in energy industry.

Basic material mechanical properties can be determined by standard test methods, by a static or dynamic tensile test for example. Determining the material fatigue properties is, however, more complicated. Fatigue damage can occur under standard mechanical limits of the materials based on loading frequency and time (number of cycles). Moreover, other factors, which are not so important in the case of static loading, have more significant influence on material fatigue properties. Surface treatment can play a significant role for example. Fatigue tests are therefore very important, however, they are also very expensive and time-consuming with regard to its long-time character. New methods and testing procedures are therefore developed, which could bring some time and cost savings. This contribution deals with infrared fatigue testing method, which is an alternative method for materials fatigue limit testing.

2 Thermographic Fatigue Testing

2.1 Tension Fatigue Test

Infrared thermography analysis is one of the developed methods for rapid fatigue testing. This contribution follows theoretical and experimental works, where the principles and some experimental results of the infrared fatigue testing were described [1]. It is based on thermo-mechanical coupling effect, where mechanical loading causes material temperature changes. These changes are reversible in the case of elastic loading and the temperature rises permanently in the case of plastic loading. Published results [2,3] and experiments performed at our workplace show that, in the case of cyclic loading, the temperature of an experimental sample rises even if it is in the elastic region.

A typical progress of the temperature measured on a steel sample during a simple cyclic loading test is shown in Fig. 1. A standard hydraulic fatigue measurement device MTS 500 kN was used for the sample loading. The steel sample with a diameter of 10 mm was asymmetrically loaded by a frequency 10 Hz and constant maximum amplitude about 600 MPa. The specimens were painted by a specific high-emissivity thermographic paint, which was tested for optical properties and mechanical stability under cyclic loading. The progress of the maximum temperature was measured by an infrared camera Micro-Epsilon TIM160. The temperature rises stepwise after the load is applied, it is constant or slightly rising during the subsequent constant cyclic loading and it rises just before the sample ruptures. The temperature profile at the individual process phases depends on the load, frequency, number of cycles, material, sample shape and other conditions. However, after applying or changing the load the temperature typically rises by tenths of a degree or several degrees. On the other side, the temperature rise before a rupture is often tens of degrees.

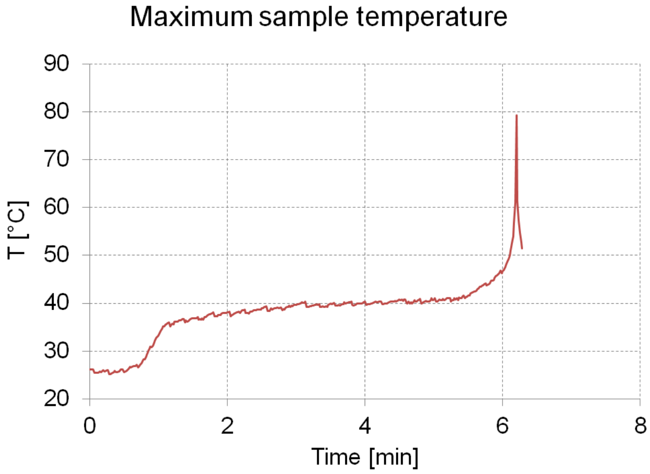

Fig. 1: Progress of maximum temperature of a steel sample during a cyclic loading test.

The published results show that the magnitude of the temperature rise after applying or increasing the load is influenced by the fatigue limit of the sample at given testing conditions. There are several ways (described for example in [1,2] or [3]) how to evaluate this dependence. We performed experiments with identical samples where the load was stepwise increased from about 130 to 550 MPa. The temperature rise was evaluated at each increase of the load. An example of the evaluation is shown in Fig. 2. It is evident, that the load-temperature dependence can be divided in two regions, which differ by the slope of the temperature rise. It is expected that the transition between the two regions defines the fatigue limit of the material at the given conditions.

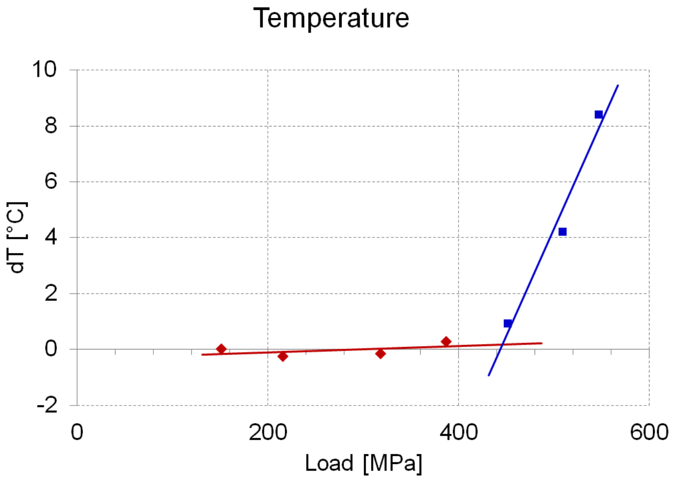

Fig. 2: Evaluation of temperature rise in individual steps under the stepwise increasing load during a cyclic loading test.

A comparison between the above described thermography method and a standard fatigue testing was performed with standardized cylindrical specimens made of 17123 equivalent steel. The specimens were 15 mm in diameter and they were painted by a specific high-emissivity thermographic paint. The loading frequency was 10 Hz and the load was increased in subsequent steps. A standard hydraulic fatigue measurement device MTS 500 kN was used for the sample loading and the temperature was measured by an infrared camera FLIR A320. Two tests were performed on identical samples. The fatigue limit was evaluated as an intersection of the lines given by linear regression of points in the two regions as presented in Fig. 2. The evaluation of the two tests brought results 683 and 692 MPa. A standard fatigue test was performed on the same material with a result 690 ± 10 MPa. Although the number of experiments is too small for the method generalization, the comparison brought very good agreement between the standard and thermography fatigue limit evaluation.

2.2 Cyclic Bending Loading Device

The bending test is more suitable than a tensile loading for surface treatment application [4] like shot peening, laser treatment or coatings. It also requires lower force load compared to tension tests and thus the measurement device requirements are lower. We expect that the bending test can be also more suitable for the thermographic measurement.

A 4-point bending measurement device was therefore developed for bending cyclic loading tests. It is a pneumatic device, which is completely electronically controlled. It is equipped by a sound insulating cover, electronically controlled reducing valve and diverter valve. The loading is realized due to load jaws and a pneumatic piston with compressed air supply regulated by the reducing and diverter valves. The load cell integrated between the load jaws and the piston measure the actual load during the cyclic loading. The device is controlled by a programmable logic controller with touchscreen or optionally by PC software. The maximum load frequency is 12 Hz, the maximum load force is about 2 kN. The load force measured by the load cell is collected using HBM Spider8 digital measuring device and the sample temperature is measured by an Optris infrared camera. The device control can be optionally realized by the PC software as well. The scheme of the measurement device configuration is in Fig. 3.

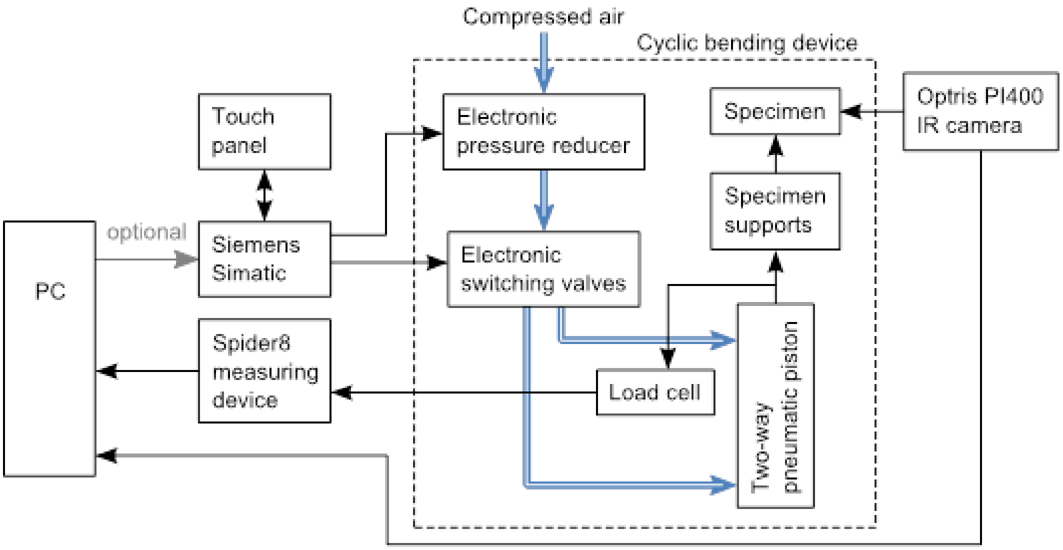

Fig. 3: Scheme of the developed measurement device for the cyclic loading test.

The data acquisition is realized by specifically developed software, which is able to control both the Spider8 measuring device and the infrared camera. The software is continuously developed and it is suited for cyclic loading thermographic measurement. It allows setting parameters for the load cell measurement, which is a strain gauge bridge type channel (bridge type, range, measurement frequency etc.). It is possible to set the temperature measurement range, infrared measurement parameters (emissivity) and parameters of displaying and storing the measured data. It is possible to add markers and notes to the measured data, which are displayed and saved to data files for subsequent evaluation.

A number of tests were performed in order to verify the device functionality and to test the procedures regarding the thermography cyclic loading test measurement. The experiments showed, that the device is usable for long-term bending tests with the maximum load up to 2 kN and frequency 10 Hz. Although a detailed evaluation and comparison were not performed yet, the results showed that the temperature increase is in range from tenths of degree to several degrees in case of steel samples. The thermography measurement accuracy is very important, thus, it was also confirmed that high emissivity paint should be used to enhance the thermographic measurement. We built on previous results obtained by the tension tests, where we selected thermographic paints with adequate mechanical properties for cyclic loading. We discovered by these experiments that cracks occurred on some of the thermographic paints and these are therefore not usable for the measurement of cyclically mechanically loaded objects. The selected paints DupliColor Supertherm and Super-Spray Very Well! were applied on steel bending test samples and its thermo-optical properties stability during cyclic mechanical loading was analysed. The samples were loaded with a cyclical load. The loading maximum was stepwise increased and did not exceed the plasticity limit of the material. The total number of cycles was about 150 thousands. It was determined that the emissivity changes before and after loading are in order of thousandths, that means negligible. It can be therefore concluded that the cyclic mechanical loading at the tested conditions does not influence the high-emissivity paints and can be used for the thermographic fatigue testing.

3 Conclusion

The comparison of the standard fatigue limit measurement and the thermographic fatigue limit measurement showed a good agreement. The fatigue limit was 690 ± 10 MPa by the standard test and 683 and 692 MPa respectively by the thermographic test. Tests made on the bending device showed that it is ready to perform cyclic bending testing supplemented by an infrared measurement. The experiments showed that the measured area of the samples should be painted by a high-emissivity thermographic paint for the infrared measurement. The thermographic paint reliability and mechanical and optical properties stability tests were performed and the most appropriate paint was chosen. Continuing experiments on the bending device are planned for the next future.

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