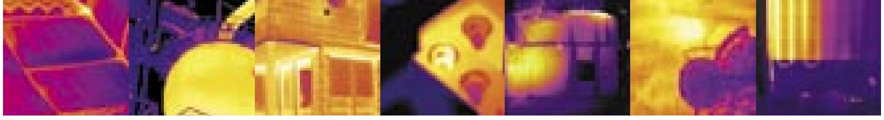

FLIR APPLICATION STORY

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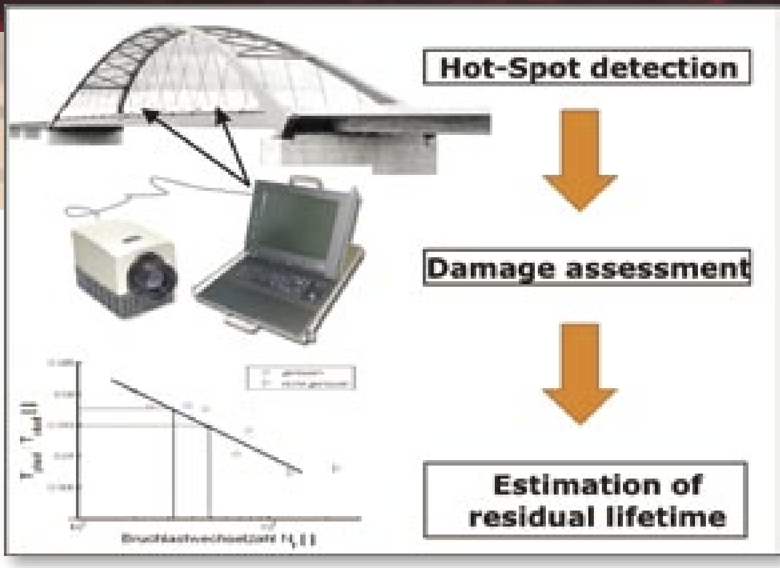


FLIR Systems R&D camera used to detect metal fatigue damage in construction steels

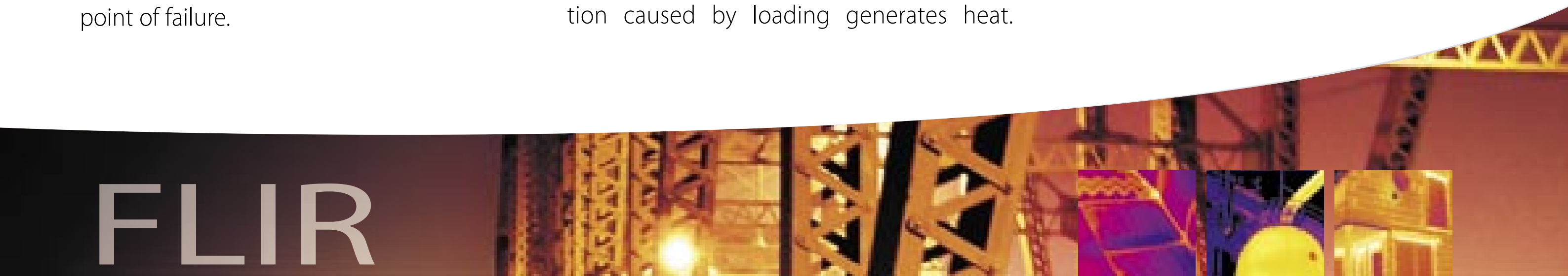
Metal constructions such as bridges, offshore platforms or airplanes have to resist heavy varying loads. The operational limit of these constructions is often determined by the occurrence of cracks in critical spots of the structure. This is caused by so-called metal fatigue. It occurs when the material is subjected to permanent cyclical loads, like heavy trucks or trains passing on a bridge, or repeated take-off and landing of an airplane.

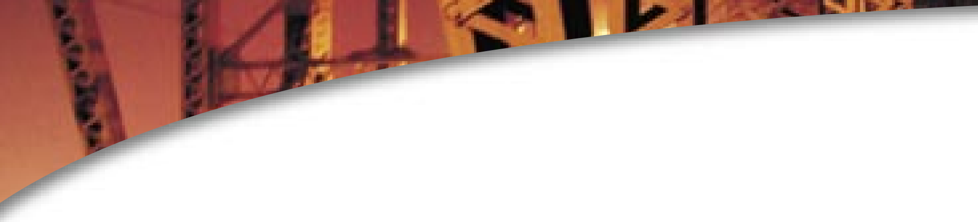
Metal fatigue depends on many factors such as geometry, surface integrity, residual stress etc. However, these parameters are inexact and lead to widely differing prognoses about the real time span such a construction can stand and, eventually and more seriously, its point of failure.

What are the driving mechanisms that make metal "tired"? Metal fatigue is marked by local plasticity of the material. Repeated loads on the metal provoke microscopical irreversible deformations leading to slip bands which during the further fatigue process can become very small cracks. These microcracks can subsequently grow into real macrocracks. Due to the fact that this stress concentration is local, these plastic deformations are confined to local hot spots (for example, notches or welding seams) while the rest of the structure might remain and behave completely elastic.

Moreover, according to the law of thermodynamics, the plastic deformation caused by loading generates heat.

Phoenix IR camera placed on testbed, specimen is covered by messing sphere for thermal shielding





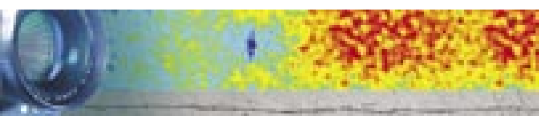
The strong interdependence of fatigue, plasticity, mechanical damping and the heat generation makes infrared thermography a promising method to show fatigue-related surface temperature variations.

Can metal fatigue be observed, measured and maybe formalized thanks to infrared? And what is the influence of cyclic plasticity on the temperature signal ? A research team based at the Technical University of Braunschweig (Germany) set up a research project to provide some answers.

Measuring fatigue damage

The goal of the long-time scientific project is to thermographically detect, describe and eventually quantify fatigue phenomena such as cyclic plasticity, slip bands and microcracks. The test setup consisted of a servo-hydraulic testing machine connected to a FLIR Systems Phoenix infrared camera placed on an automated positioning system. An additional video-light microscope is used for parallel light-microscopic investigation. A series of uniform pieces of general purpose construction steel with a thickness of 20 mm served as specimen. The pieces were subjected to fatigue tests with sinusoidal loading at different load levels (stress amplitudes). The fatigue loading was interrupted every 20,000 load steps. A microscopic scan of the specimen's surface was then triggered. Before each scan, a series of infrared images was taken during the applied loading. Fatigue tests were finished after 10^6 load cycles or upon presence of a macrocrack in the specimen. The only preparation of the steel specimen consisted of the application of some emissivity coating to avoid reflectivity. The researchers used the lockin thermography method. The mechanical loading of the testing machine was thereby used to generate a periodic temperature in the tested specimens. An in-house developed data processing program minimized the detector "noise" to better discern the very minimal temperature variations.

The infrared images of the fatigue-loaded specimens revealed the early development of highly localized cyclic plasticity even before slip bands can be seen under the microscope. "Temperature changes due to cyclic plasticity can be measured by an infrared camera", says engineer Justus Medgenberg, of the Braunschweig University's Institute for the rehabilitation of buildings and structures, "and cyclic plasticity can be considered as a first indicator of fatigue damage". The test findings were then used to calibrate numerical models of the material behavior. This numerical modeling should serve the development of a procedure which allows to determine the damage degree of critical spots.



The camera settings

As temperature differences caused by cyclic plasticity are very small, the testing required a camera able to measure and image the temperature variations of a few mK. The infrared camera used during the testing was a FLIR Systems Phoenix 640x512 pixel with an InSb detector, equipped with a 25 mm lens and extender ring. During the testing, the camera scanned at an integration time of 2 milliseconds and at a frame rate of 412.5 Hz. As the test specimen was moving, a motion compensation scheme up to sub-pixel level was implemented. Further data processing included two-point non-uniformity correction, calibration, filtering and a separation of thermoelastic and thermoplastic temperature variations.

Conclusions

Fatigue damage, cyclic plasticity and the temperature evolution during fatigue loading are highly interdependent. "We have seen that high-resolution thermographic detection can be applied to assess the hot spots and contribute to new prediction methods of fatigue-loaded structures", says research project leader Prof. Thomas Ummenhofer. "It is a complex and challenging application of thermography, but it is possible with a high-speed, high-resolution scientific infrared camera offering a wide range of features to optimize its output."

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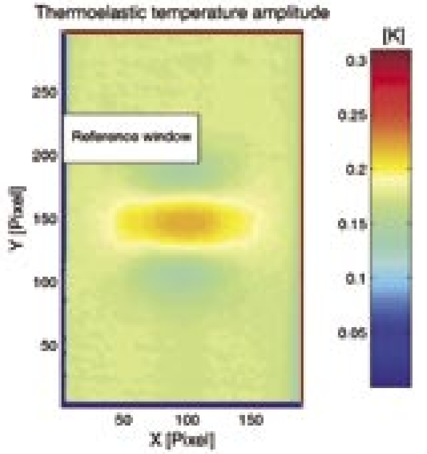
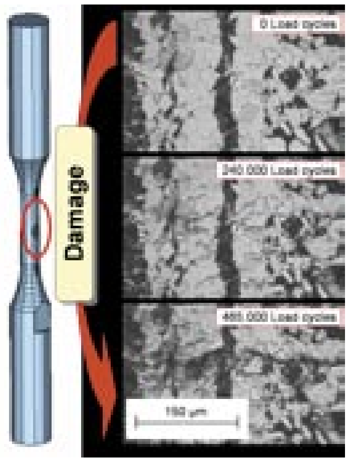
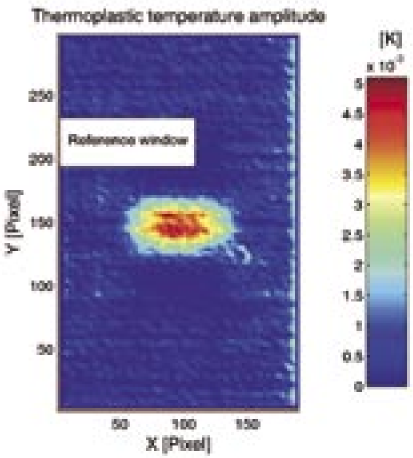
Thanks to Joachim Sarfels, Area Sales Manager, FLIR Systems Germany, for providing contact and support



Visualization of thermoelastic temperature variation of the specimen



Test specimen: 20 mm steel pieces and damage evolution under the microscope



Separated temperature change up to 5 mK due to local plastic deformation in course of the fatigue loading

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