Detecting cracks with differential thermographic imaging

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Development of a fatigue crack during rotating bending of a precipitation hardened aluminum alloy. Photographs at various numbers of cycles are shown for a test requiring 400,000 cycles for failure. The sequence in the bottom row of photographs shows more detail of the middle portion of the sequence in the top row. (Photos courtesy of Prof. H. Nisitani, Kyushu Sangyo University, Fukuoka, Japan. Published in [Nisitani 81]; reprinted with permission from Engineering Fracture Mechanics, Pergamon Press, Oxford, UK.)
The process of slip band damage during cyclic loading developing into a crack in an annealed 70Cu-30Zn brass. (Photos courtesy of Prof. H. Nisitani, Kyushu Sangyo University, Fukuoka, Japan. Published in [Nisitani 81]; reprinted with permission from *Engineering Fracture Mechanics*, Pergamon Press, Oxford, UK.)
Stress–life curves for completely reversed bending of smooth specimens, showing various stages of fatigue damage in an annealed 99% aluminum (1230-0), and in a hardened 6061-T6 aluminum alloy. (Adapted from [Hunter 54] and [Hunter 56]; copyright © ASTM; reprinted with permission.)
Steps in obtaining $da/dN$ versus $DK$ data and using it for an engineering application. (Adapted from [Clark 71]; used with permission.)
Crack growth rate test under way (left) on a compact specimen ($b = 51\text{mm}$), with a microscope and a strobe light used to visually monitor crack growth. Cycle numbers are recorded when the crack reaches each of a number of scribe lines (right). (Photos by R. A. Simonds, Virginia Tech.)
The strain-based approach to fatigue, in which local stress and strain, $\sigma$ and $\varepsilon$, are estimated for the location where cracking is most likely. The effects of local yielding are included, and the material’s cyclic stress–strain and strain–life curves from smooth axial test specimens are employed.

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Test specimen, extensometer, and grips for strain-controlled fatigue testing. (Photo by G. K. McCauley, Virginia Tech.)
Strain–life curves for failure, and for two specific crack sizes, in an alloy steel. (Adapted from [Dowling 79a]; used with permission.)
Thermoelastic Effect

Mechanical strain produces heating in compression and cooling in tension

Adiabatic conditions, heat conduction through the metal dissipates effect
Mitigated by higher frequencies

Temperature change is in the milli-Kelvin range


Infrared camera (Stress Photonics Deltatherm)
  Indium antimonide (InSb) sensor (liquid nitrogen cooled)
  Lenses are germanium which transmits infrared radiation
  128 x 128 focal plane array, 430 frames/second
  Parallel transfer to signal processing unit

SPU integrates images in synchronization with load reference signal (2X for plasticity)
  Phase adjustment facilitates synchronization
  Subtraction of max and min signal from each pixel produces differential thermographic image
  Values in image are proportional to stress on the surface

Software displays differential thermal image

Interpretation - changes in thermoelastic images represent changes in local compliance and damage generation
  As a crack initiates and grows, stresses around the crack redistribute and crack size and location become evident

Emissivity variations inherent on metal surfaces (and reflections of ambient light) are counteracted by spraying with ultra-flat black paint
Shallow notch cut with abrasive wheel to concentrate stress

Intentional control of where crack initiates

Blue areas show regions of low stress on opposite sides of growing crack

Determination of stress at one point calibrates stresses throughout image

Aluminum alloy 2024
Relaxation around fatigue crack becoming evident in differential thermography image at 35,000 cycles

15,000 cycles

52,500  55,000  57,500  60,000  Crack Visible*  

62,500

65,000  67,500  70,000

72,500  75,000  77,500  80,000  82,500  85,000  87,500

Final Fracture 87,769 cycles

* Crack observed through microscope using strobe light slightly out of sync
Absence of macroscopic stress concentrators requires all potential initiation sites to be observed in laboratory; in field, specimen may be scanned to determine condition.
Possible application to rotating-bending fatigue
Cracking precursors

Fatigue damage accumulates throughout structural life of fatigue critical components

Stress redistributions such as self organization of dislocations

Persistent slip bands

Possibly, stages of damage can be discriminated by thermal imaging techniques

Potential life prediction technique, not dependent on knowledge of load history (intercept present state)
Axial fatigue of round specimen of aluminum alloy

Example of crack detection at a location without an intentional stress raiser

Low stress (blue) in region where stress has relaxed due to crack

High stress (light yellow) on either side where stress has been transferred
This presentation describes differential thermography in which fluctuating load and infrared image are correlated (AC method)

An alternative application involves observing temperature change with time (DC method)

Flash and cool technique

By recording variations in cooling rate in the field of view, conductivity to surface from below is observed

Useful for evaluating corrosion loss in substructure and coating delamination

This infrared camera system has also been used to evaluate degradation in composite materials. The Stress Photonics website shows work done at University of Illinois Urbana-Champaign.
This presentation described the use of differential thermography to detect cracks in an object.

Cyclic stress produces corresponding cyclic response due to the thermoelastic effect, measured as a differential signal.

Each pixel in field of view responds to its local stress.

Cracks are apparent due to stress redistributions.

Possibly, may be extended to detection of crack precursors.