N92-13839

EXPERIMENTAL DETERMINATION OF RESIDUAL STRESS

by

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Residual stresses in finished parts have often been regarded as factors contributing to premature part failure and geometric distortion. Currently being investigated are residual stresses in welded structures and railroad components. High residual stresses formed in welded structures due primarily to the differential contractions of the weld material as it cools and solidifies can have a profound effect on the surface performance of the structure. In railroad wheels, repeated use of the brakes causes high residual stresses in the rims which may lead to wheel failure and possible derailment.

The goals of the study were: (1) to develop strategies for using X-ray diffraction to measure residual stress; (2) to subject samples of Inconel 718 to various mechanical and heat treatments and to measure the resulting stress using X-ray diffraction; and (3) to measure residual stresses in ferromagnetic alloys using magnetoacoustics.

X-ray diffraction is an effective nondestructive method for the measurement of residual surface stress. In crystalline materials, the residual stress causes a difference in the lattice spacings from the stress-free values. It may be shown (ref. 1) using elasticity theory that the residual stress is related to the difference in the measured d-spacing by the equation

$$\sigma_\phi = \frac{E}{(1+\nu)\sin^2\psi} \frac{(d_i - d_n)}{d_n} \qquad (1)$$

where σ_ϕ is the calculated residual stress in the ϕ direction, d_n, the spacing of the planes parallel to the surface of the sample, d_i, the spacing of the planes whose normal makes an angle ψ with the normal to the surface, E, the Young's modulus, and ν, the Poisson's ratio. E and ν are material constants obtained from the appropriate tables. Since the angular position 2θ of the diffracted beam is measured directly with a diffractometer, it is convenient to express equation (1) in terms of 2θ rather than plane spacings. The relation between the spacing d and the diffraction angle θ is given by Bragg's law which states

$$d = \frac{\lambda}{2\sin\theta} \qquad (2)$$

where λ is the wavelength of the incident radiation. Substitution of Bragg's law into equation (1) leads to

$$\sigma_\phi = \frac{E \cot\theta}{2(1 + \nu)\sin^2\psi}(2\theta_n - 2\theta_i) \qquad (3)$$

where $2\theta_n$ is the observed value (in radians) of the diffraction angle in the normal measurement and $2\theta_i$ its value in the inclined measurement. Thus a measurement of $2\theta_n$ and $2\theta_i$ at a given diffraction peak allows a determination of the residual stress.

The X-ray diffraction system was used to determine residual stresses in samples of Inconel 718. Samples studied were a flat plate, an annealed flat plate, and a flat plate bent in the form of a semicircle. Although the stress in the annealed sample was negligible, stresses in the flat and bent samples were considerably higher. A concern in the investigations was the low intensity of the diffraction peaks in the desired angular range using molybdenum K_α radiation. Mechanical treatments of the surfaces of the samples produced no significant increase in the relative intensities of the diffraction peaks.

Low-field magnetoacoustic interaction has been successful in the investigation of residual stress in Fe-alloys (ref. 2). Young's modulus in ferromagnets depends not only on the degree of magnetization, but also on the stress; therefore, the acoustic natural velocity, which is E dependent, directly relates to the stress state. In this experiment, as a time-dependent magnetic field was passed through ferromagnets subjected to fixed amounts of stress (tension and compression), acoustic waves in the pulse-echo mode were propagated through the samples. Since it can be shown that the fractional change in natural velocity is approximately equal to the fractional change in frequency of a phase-locked acoustic wave, a pulsed-phase-locked-loop acoustic interferometer was used to measure the fractional frequency shifts of the acoustic waves as a function of the external magnetic field.

In the magnetoacoustic experiments, the magnetization was chosen to be parallel to the uniaxial stress axis. Compressional and shear acoustic waves were propagated perpendicular to the stress axis through various Fe-alloys. Preliminary results show a correlation between the fractional change in frequency of the acoustic waves and the external field as a function of the different stress states. An analysis of the magnetoacoustic results is in progress.

References

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