Diffraction Notes

Fall, 1987

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PRINCIPAL RESIDUAL STRESS DETERMINATION

As a tensor property, the macroscopic residual stress will generally vary with direction at any point on a body. In most residual stress investigations, the direction of interest is indicated by the stresses applied in service, or by the orientation of fatigue cracks. The residual stress distributions produced by some processes such as shot peening, induction hardening or carburizing may be quite uniform, so that the magnitude of the residual stresses produced is nearly independent of the direction of measurement.

Processes which are inherently directional, such as forming, grinding or turning, may induce residual stress fields which differ markedly in magnitude and even sign with direction in the plane of the surface. Such a stress field cannot be adequately described, and the maximum stress cannot be known, without a complete determination of the residual stress in all possible directions. A measurement in any given direction could yield results far from the maximum stress. To completely quantify such a stress field, the principal residual stresses can be determined both at the surface and as a function of depth. The residual stress in any direction can then be calculated from the principal stresses and their orientation relative to the sample geometry.

Figure 1 shows the condition of plane stress assumed to exist at either the original surface or any other which may have been exposed by electropolishing during subsurface residual stress measurement. The maximum and minimum principal stresses, σ_1 and σ_2, are always perpendicular to each other, and σ_1 makes some arbitrary angle to the sample axis. The stress in any direction is bounded by σ_1 and σ_2. Because the depth of penetration of the x-ray beam is very shallow (on the order of 0.0002 in.), the stress, σ_3, normal to the surface within this thin layer, is generally assumed to be negligible. (It is possible to determine the full stress tensor, with $\sigma_3 \neq 0$, but this requires prior knowledge of the unstressed lattice spacing of the material in the heat treated or cold worked condition of the surface layers, which usually cannot be known with sufficient accuracy.)

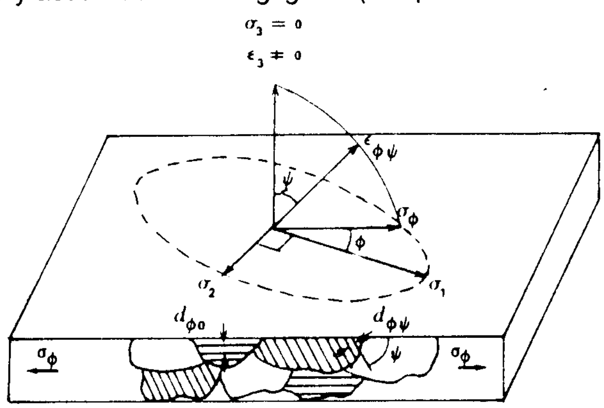

Figure 1

The stress in any direction defined by the angle Φ (taken to be a positive angle counterclockwise from the maximum stress, σ_1) is given by

$$\sigma_\Phi = \frac{\sigma_1 + \sigma_2}{2} + \frac{\sigma_1 - \sigma_2}{2} \cos(2\Phi) \quad (1)$$

If the stress, σ_Φ is measured at three known angles with respect to some reference direction on the surface of the sample, it is then possible to solve the resulting three equations in three unknowns for the minimum and maximum normal residual stresses, and their orientation with respect to the reference direction. A rectangular configuration using 0, 45 and 90 deg. is generally employed so that the measurement directions conform to the geometries of most samples, such as circumferential, 45 deg. and axial on cylindrical samples. However, software has been developed at Lambda Research to determine the principal residual stresses from measurements in any three arbitrary directions if the sample geometry prohibits the use of the rectangular configuration. Maximum accuracy in the calculations is actually achieved using 0, 60, and 120 deg.

To determine the principal stresses as a function of depth, layers are removed by electropolishing and the process is repeated to the maximum depth of interest. The subsurface residual stress distributions measured for the three orientations are independently corrected for penetration of the radiation into the subsurface stress gradient and for stress relaxation caused by layer removal. The corrected results are then recombined at each depth to calculate the principal residual stresses and their orientation as a function of depth.

An example of the principal residual stress distributions produced by dry belt sanding of AISI 1018 steel is presented in Figure 2. The maximum and minimum surface stresses are nominally +200 and −180 MPa, respectively. The maximum stress remains in tension to a depth of nominally 8 μm, and is oriented within approximately 10 deg. of the sanding direction to approximately 20 μm. The minimum stress is always perpendicular to the maximum. At greater depths, the minimum and maximum normal stresses are nearly equal, indicating a uniform compressive stress in all directions.

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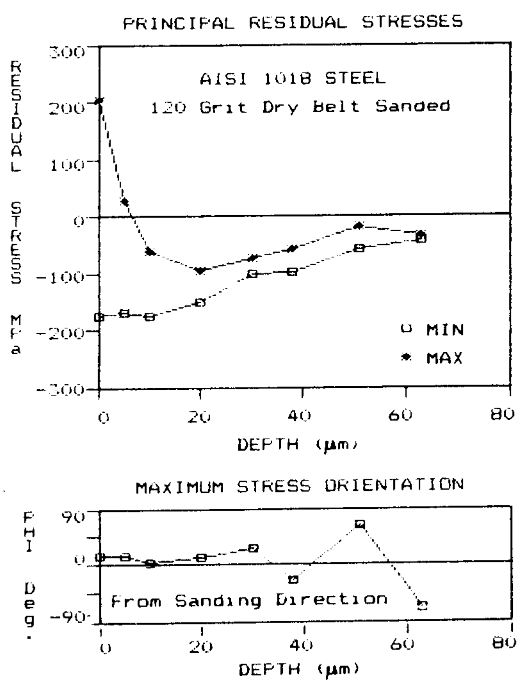

Figure 2

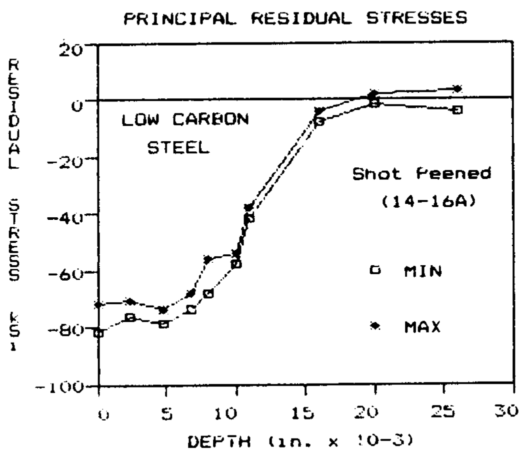

Figure 3

In contrast, the principal stress distributions produced by shot peening a low carbon steel plate with the shot stream oriented normal to the surface produces very uniform residual stresses as shown in Figure 3. The principal stresses are nearly equal throughout the compressive surface layer. Shot peening with the shot stream inclined to the surface can result in a stress field which varies in compressive magnitude with direction.

Once the principal residual stresses are known, the residual stress in any direction can be calculated from the Equation (1). This procedure can be used to determine stresses in directions which are not directly measurable because of the sample geometry, or to calculate stresses in directions other than those initially measured.

RESEARCH ENGINEER JOINS STAFF

Mr. Perry W. Mason has joined our staff as a research engineer. Perry holds a B.S. in Materials Science Engineering, and an Associates Degree in Civil Engineering. Perry is currently working in the laboratory, familiarizing himself with the procedures and techniques. Shortly, he will be assuming the direction of routine residual stress analysis projects.

LAMBDA TO ATTEND ASM METALS WEEK '87

Lambda Research will have a booth in the national laboratories section of the ASM Metals Week '87 Materials, Applications & Services Exposition to be held in Cincinnati, Ohio from October 13 through October 15. Our personnel will be on hand to provide information about the laboratory and discuss specific applications. We hope you will be able to attend the conference. See us at booth 1310.