Analysis of Residual Stresses

Applications

Axles and wheels	Heat treated metals
Bolts and clamps	Plated surfaces
Cemented carbides	Shrink fit components
Composites	Springs
Ground/machined surfaces	Tube surfaces
Fasteners	Weldments

Background

Residual stresses are known to influence a material's mechanical properties such as creep or fatigue life. Sometimes, the effect on properties is beneficial; other times, the effect is very deleterious. Therefore, it is important to be able to monitor and control the residual stresses.

Two different techniques are commonly used for measuring the residual stresses. The most popular technique is a special type of X-ray diffraction (known as the $sin^2\ \Psi$ method), which is used to measure the stresses in fine grained crystalline materials. An alternate method, the hole drilling method, is most often used when the X-ray technique is not appropriate. Each method, along with its advantages and disadvantages, is described in this note.

The X-ray Diffraction Method

The $sin^2\ \Psi$ method is a sensitive and accurate technique to measure residual stresses in a fine grained, polycrystalline material. As shown in Figure 1, the position of a diffraction peak will shift as the sample is rotated by an angle Ψ. The magnitude of the shift will be related to the magnitude of the residual stress. Thus, if there is no residual stress, the shift will be zero. The relationship between the peak shift and the residual stress σ is given by

$$\sigma = \frac{E}{(1 + \upsilon)\ sin^2\ \Psi}\ \frac{(d_n - d_0)}{d_0}$$

where E is Young's modulus, υ is Poisson's ratio, Ψ is the tilt angle, and d_i are the "d" spacings measured at each tilt angle. If there are no shear strains present in the sample, the "d" spacings would change linearly with $\sin^2 \Psi$ and a least squares fit to the curve (for multiple values of Ψ) would give σ. However, if shear strains are present, a splitting of the plot will occur and the analysis is more complicated. Finally, if the sample is rotated in-plane, it is possible to determine the principal stresses and their directions.

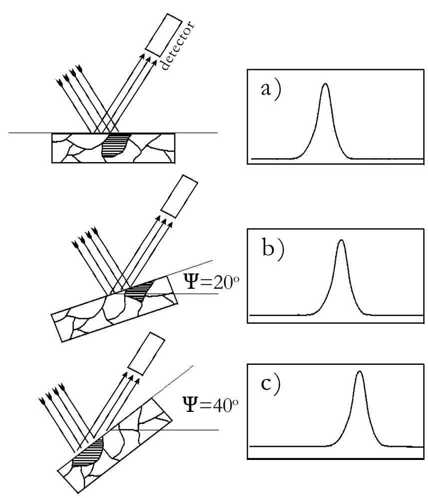
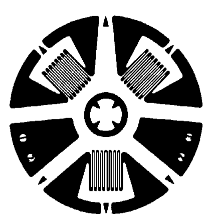


Figure 1 - Shift of diffraction peak with change in Ψ value. Note that as Ψ increases in b) and c) above, the position of the diffraction peak shifts further and further away from its usual position in a).

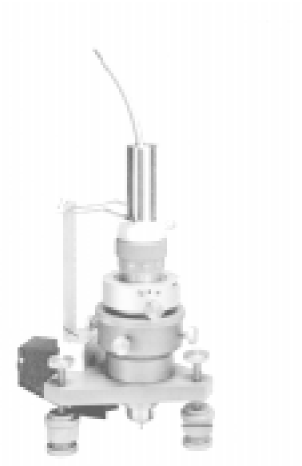
The Hole Drilling Method

There are many situations where X-ray diffraction is not useful for measuring residual stresses. These include non-crystalline materials, large grained materials, nano-materials, textured, or heavily deformed metals. In these cases, other mechanical methods such as the hole-drilling method is used.

The hole-drilling method (ASTM Standard E837) relies on stress relaxation when a hole is drilled into the center of a rosette strain gage such as that shown below. When the material is removed by drilling, the extent of the strain relief is monitored by the gages and the direction and magnitude of the principal stresses can be calculated.



Rosette Gage (Magnification: 4x)



A special high speed air turbine drill (shown above) is used to first locate the drill to within 0.001" of the rosette center and then to remove material to a controlled depth. At each depth increment, the strain relief on each of the gages is measured and converted into stress. As subsequent material removals occur, the stress distribution as a function of depth can be estimated.

The hole drilling method is used in those situations where the residual stress is relatively uniform over the drilling depth. Thus, it is not intended for situations where the residual stress is superficial.

The accuracy of the hole-drilling method is directly related to the ability of locating the hole accurately in the center of the rosette. As an example, if the hole is no more than 0.001" off center, the residual strain error is less than 3%. In practice, the location accuracy is better than this, so the overall accuracy in residual stress measurements is quite good.

Another important consideration in this method is the ability to drill the relief hole so as not to introduce new stresses. This is best achieved in hard materials by use of a high-speed turbine drill which avoids excessive rubbing of the cutting surface against the hole wall. As a result of careful design of the tool, the holes have flat bottoms and straight walls as required by ASTM E837.

The hole drilling method has many advantages, but it also has many disadvantages. Of particular concern is that the method is valid only up to about 50% of the yield strength of the test material. Thus, great care has to be exercised when selecting testing methods.

Our Pledge

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