PRACTICAL APPLICATION OF NONDESTRUCTIVE RESIDUAL STRESS MEASUREMENTS BY X-RAY DIFFRACTION

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ABSTRACT

A modified Integral Method was investigated as a means to nondestructively measure the subsurface residual stress distribution. The technique has been demonstrated to be feasible in aluminum alloys by comparison to established destructive measurement methods.

In the current effort a thorough study of higher energy radiations was conducted to obtain deeper penetrating radiations on titanium and nickel base alloys. Higher energy radiation used in conjunction with the modified Integral Method would provide nondestructive subsurface residual stress measurement in components composed of these alloys. Results of the study show a nondestructive x-ray residual stress method providing measurements to depths of 0.0028 to 0.003 in. (51 to 76 μm) is not technically feasible.

INTRODUCTION

Previous studies [1-4] have been directed at developing nondestructive residual stress measurement x-ray diffraction (NRSM XRD) methods of recovering the underlying residual stress distribution from measured non-linear lattice spacing vs. $\sin^2ø$ data. Work prior to 1989 is reviewed by Eigenmann, Scholtes and Macherauch.[4] Attempts have been made to estimate both high stress gradients and shear components acting normal to the surface through the depth of penetration of the x-ray beam. All such methods assume some functional form to describe the subsurface strain (or stress) distribution, and seek to find the form of that function which best describes the observed attenuation weighted integral of lattice spacing with depth.

An integral method capable of recovering a generalized approximation of the stress as a function of depth has been described by Wern and Suominen.[5] The method of analysis can be applied to strain data obtained by x-ray diffraction or mechanical means, such as center hole drilling.[6] The Wern method is a means of nondestructive determination of the full triaxial state of stress within the depth of the x-ray penetration, allowing for both a full stress tensor and variation in all of the stress components with depth. Published results show that the necessary equilibrium condition (σ_{33} = 0 at the surface) is achieved in the preliminary tests, even though this condition is not required by the method of solution. The method also does not depend upon lattice spacing measurements at extremely small grazing angles, minimizing defocusing errors in peak location, error due to surface roughness, and the difficulties of the LaPlace transform solution method.

The Integral Method was proposed for NRSM in nickel and titanium alloy turbine engine components. It provides a stable solution of the subsurface residual stress profile, and a modified version of the method has been successfully applied in XRD measurements in shot peened and machined 7050-T6 aluminum alloys and ceramics.[7] The method is based upon approximating the unknown z-profile of strain using Fourier trigonometric series expansion. No prior knowledge of the residual stress distributions is required and the stress distribution is not forced to follow a linear pattern. Standard XRD equipment can be used to collect the data.

The Integral Method has been demonstrated at Lambda Research using Cu and Cr K_α characteristic radiations as a means of determining the surface and near surface residual stress gradient nondestructively.[7] A

7050-T6 aluminum alloy was chosen deliberately for the method development effort due to the range of penetrations easily achievable with available x-ray tubes. Coupons were mechanically polished or shot peened to produce shallow and deep compression, respectively. A third sample was electrically discharge machined (EDM) to produce surface and near surface tension.

The relative depth of penetration in 7050-T6 aluminum is nominally 5 times that of the proposed IN100 and Ti base alloys of interest in the present application. Radiation energies of 20 keV and greater are required to provide adequate depth penetration in the proposed alloys. Results of the study of higher energy radiations with the modified Integral Method are shown in the following section.

RESULTS AND DISCUSSION

Computation of Diffraction Patterns

Three alloys were chosen for this investigation – Ti-6Al-4V, Ti-6Al-2Sn-4Zr-6Mo and IN100. Diffraction patterns were calculated using the Powder Pattern Power Theorem for each alloy for a range of higher energy radiations.

The patterns for IN100 at 10, 15 and 20 keV are shown in Figure 1. Peak intensities decrease as the radiation energy and Bragg angle increase as predicted by the Powder Pattern Power Theorem. The measurable diffraction peaks shift to lower angles for higher energy radiations and the error in stress measurement increases rapidly with reduced 2è, as shown in Figure 2. An energy of nominally 20 keV is required to achieve a penetration depth of 25 μm (0.001 in.) in IN100 for diffraction peaks located at high Bragg angles (~160 deg.) where high precision strain measurement is possible. Penetration depths decrease considerably for peaks at lower angles.

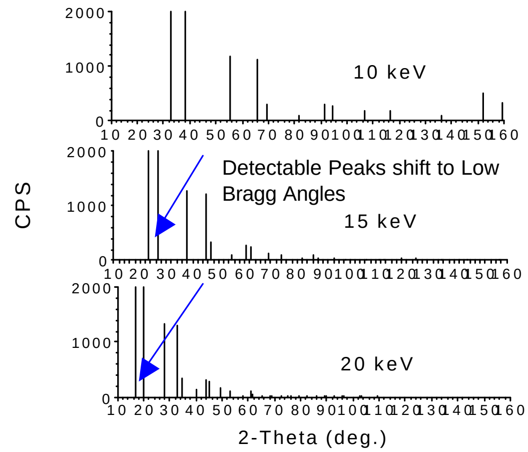

FIGURE 1 - Computed diffraction patterns with 10, 15 and 20 keV radiations for IN100 showing a shift in peak position to lower angles for higher energy radiations.

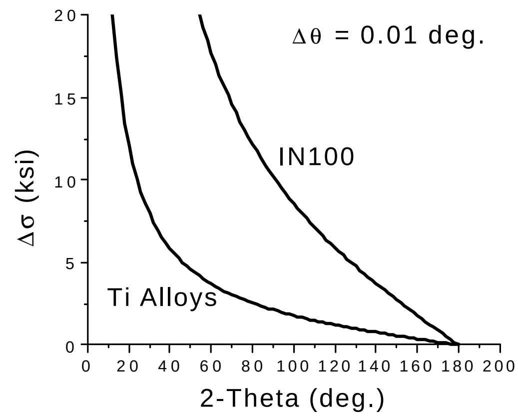

FIGURE 2 - Error in measured residual stress vs. Bragg angle for 0.01 deg. error in fitted peak position showing large errors at low angles.

CONCLUSIONS

- Several factors as listed below severely limit any appreciable increases in x-ray penetration depths over and beyond those currently used for IN100, Ti-6-4 and Ti-6-2-4-6 alloys.

- The error in stress measurement increases with lower Bragg angles restricting any use of lower order higher intensity peaks.

- At higher radiation energies the peak intensities dramatically decrease as a result of the structure factor in the Powder Pattern Power theorem. This significantly limits the maximum energy that can be used while still providing a measurable peak intensity. Peak intensities are not acceptable for measurement at radiation energies providing adequate penetration depths in Ti and Ni alloys.

- A practical radiation source that would produce the higher energies found to provide acceptable peaks in the high Bragg angles is not available as a sealed x-ray tube.

- A non-destructive x-ray diffraction method of measuring to depths of 0.002 to 0.003 in. in IN100, Ti-6-4 and Ti-6-2-4-6 does not appear to be feasible.

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