# Diffraction Notes

No. 5
November 1988


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## RESIDUAL STRESS DISTRIBUTIONS IN INCONEL 600 TUBING

The data presented are part of a more extensive study of residual stress distributions in U-bend tubing used in steam generators. (1) The results, however, are typical of the residual stress and cold work distributions produced by many grinding and forming operations.

Two Inconel 600 tubing samples were investigated. A straight sample (0.S25 O. O. x 0.040 wall) was examined in the mill annealed, cross-roll straightened and ground condition to determine the macroscopic residual stress and cold work distributions as functions of depth resulting from plastic deformation during grinding; AU-bend sample (0.75 0.0. x 0,040 wall) was formed to a 2.5 in. radius after 0.D. grinding. The room temperature yield strength of the alloy was on the order of 30 ksi.

A technique was adopted for both residual stress and percent cold work measurement employing the diffraction of chromium K-beta radiation from the (311) planes. The K-beta technique eliminated the problem of doublet separation in K-alpha techniques normally used for stress measurement.

Because diffraction data were collected with fixed x-ray optics, instrumental broadening was constant. The problem of separation of sample and instrumental peak broadening was avoided by developing an empirical relationship between the percent cold work present in the sample and the measured (311) diffraction peak width using samples of Inconel 600 tubing first annealed and then deformed in tension to known levels of true plastic strain. (2)

X-ray diffraction residual stress measurements were made in the straight tubing sample as a function of depth in the longitudinal direction. The diffraction peak angular positions were determined using a five-point parabolic regression procedure after correction for the Lorentz polarization and absorption effects and for a linearly sloping background intensity. The value of the elastic constant, E/(1+vl, for the crystallographic direction normal to the (311) planes of Inconel 600 was determined experimentally. (3) .

Material was removed for subsurface measurement by electropolishing. The results were corrected for the effects of the penetration of the radiation employed for stress measurement into the subsurface stress gradient (4) and for stress relaxation which occurred as a result of material removal. (5)

The cold work and longitudinal residual stress distributions measured to approximately 0.017 in. beneath the surface of the straight sample are shown in FigUre 1. Maximum compression of -21 ksi occurs at a depth of approximately 0.002 in. A peak tensile stress on the order of +8 ksi was observed at a depth of 0.010 in.

The degree of cold work, approximately 16 percent at the surface, decreases exponentially with depth. The yield strength distribution produced by cold working can be estimated from a true stress/strain curve for the alloy.

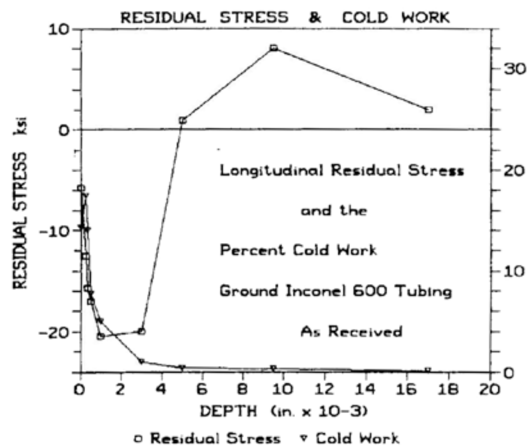


Figure 1

The macroscopic residual stress, percent cold work and the corresponding estimated yield strength distributions are presented in Figure 2 on an expanded scale to a depth of 0.003 in. The yield strength was found to range from nominally 95 ksi at a depth of 0.0001 in. to approximately 35 ksi, the original mill annealed value, at a depth of 0.003 in., decreasing nearly linearly with depth.

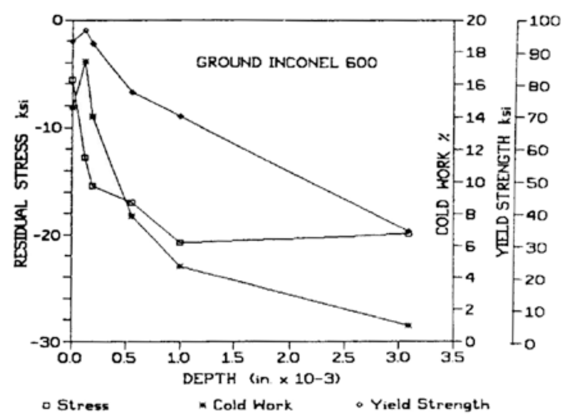


Figure 2

Based upon earlier work, [6] a pronounced stress gradient was anticipated around the circumference of the U-bent tubing sample. A special fixture was constructed to allow the tubing to be positioned with an accuracy on the order of +- 1 deg. Around the circumference for residual stress measurement in either the longitudinal or circumferential direction at the apex of the bend. A one inch length of the tubing taken at the apex was mounted in the fixture by potting the sample to a steel shaft so that the axis of rotation coincided with the center of the oval cross section of the U-bent tubing. Electrical resistance strain gages attached to the surface of the sample indicated sectioning stress relaxation in either the longitudinal or circumferential directions on the order of +- 1.0 ksi, less than the random error in residual stress measurement.

The longitudinal surface residual stress distribution, plotted to expand the scale near the neutral axis as a function of 1_Cos $\theta$ ($\theta$ = 0 at the extrados) is shown in figure 3. U-bend deformation of the surface previously cold worked by grinding produces -85 ksi, more than twice the yield strength of the annealed alloy, between the intrados and the neutral axis, and the tensile stresses reaching +2- ksi between the neutral axis and the extrados. An extremely large stress gradient exists in the vicinity of the neutral axis.

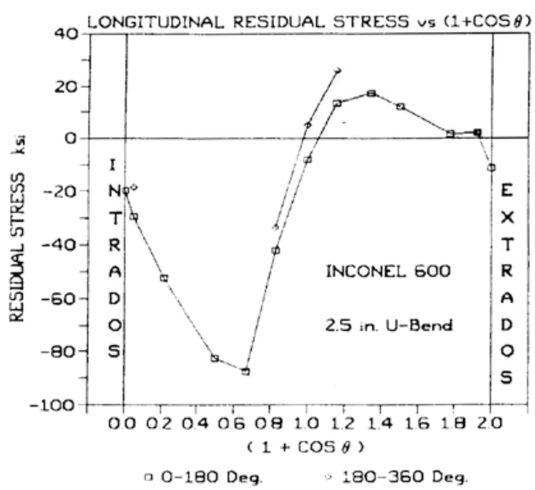


Figure 3

(1) P. S. Prevey, "Surface Residual Stress Distributions in As-Bent [nconel 600 U-Bend and Incoloy 800 90-Deg. Bend Tubing Samples," EPRI, 1981.

(2) P. S. Prevey, "Measurement of Subsurface Residual Stress and Cold Work Distributions in Nickel Base Alloys," Proceedings.of1he ASM Conference on Residual Stress in Design, Process and Materials Selection, pp. 11-19. 1987.

(3) P. S. Prevey, ADV.IN X-RAY ANAL., Vol. 20, 1977. pp.345-354. .

(4) D. P. Koistinen and R. E. Marburger, Trans. ASM, Vol. 51, 1959, p. 537.

(5) M. G. Moore and W. P. Evans, Trans. SAE. VOl. 66, 1958, p. 340.

(6) Berge, et.aL, "Residual Stresses in Bent Tubes for Nuclear Steam Generators," Corrosion, NACE Vol. 32, 9, (Sept. 1976).

## IMPROVED TESTING SERVICE - POLE FIGURES

Lambda Research has made important progress in software and graphics for pole figure determinations. Our new procedures conform to ASTM E81-77, if a random reference sample is available. In addition, random reference samples can now be prepared from powder in our laboratory. Enhanced data collection and reduction software maintains uniform 2 degree resolution throughout the central 70 degrees of the Schulz back-reflection pole figure and presents data in both true times-random and normalized scales.

## PERSONNEL NEWS

Douglas G. Carr has been promoted from Senior Laboratory Technician to Research Engineer. Doug has been with Lambda Research for over four years and has a B.S. in Chemistry and Biology, as well as an Associate Degree in Computer Programming from Raymond Walters College where he graduated Summa Cum Laude.