# OBSERVATIONS ON SHOT PEENING RESIDUAL STRESSES IN 17 Cr - 7 Ni AUSTENITIC STAINLESS STEEL AND THEIR REDISTRIBUTION VIA MECHANICAL LOADING

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ABSTRACT

Residual stress-depth profiles obtained from a 3/4 hard 17 Cr - 7 Ni austenitic stainless steel shot peened at 0.018 A (mm) and 0.020 N (mm) intensities exhibited similar compressive surface residual stress levels; however, the depth of compression was much greater for the higher intensity peening. After static loading in tension to about the 0.02 percent offset yield stress level, surface residual compressive stresses were the same as for the as-peened condition; however, subsurface compressive stresses for both peening intensities reduced in magnitude for a given depth. After static and cyclic bending to surface strain levels in tension and in compression, equivalent to the 0.02 percent yield stress level, surface residual compressive stresses remained about the same as for the as-peened condition; however, subsurface residual compressive stresses were greatly reduced in magnitude and were the same at a given depth irrespective of peening intensity.

KEYWORDS

Stainless steel, shot peening, residual stress, static strain, cyclic strain, uniaxial loading, bending loading.

INTRODUCTION

The work reported herein is part of an on-going investigation intended to provide an understanding of conditions under which shot peening residual stresses may be relaxed or redistributed by static and cyclic loading experienced by aircraft dynamic components. The material chosen for investigation was AISI type 301 stainless steel sheet in the 3/4 hard condition. Results include residual stress-depth distributions for two shot peening intensities with subsequent mechanical loading via static tension and static and cyclic bending. Observations of residual stress alteration and redistribution are presented; however, no analysis of the mechanics or mechanisms involved has been made or proposed herein.

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## MATERIAL

The material for this investigation was 0.8 mm thick AISI type 301 stainless steel sheet cold worked to the 3/4 hard condition. The hardness typically was equivalent to HRC 40-41 corresponding to a nominal tensile strength of about 1250 MPa. The material had been sheared into strips about 7.5 mm wide by 240 mm long. The uncut surfaces of the strips had been mechanically polished to a surface finish of 0.0001 mm AA prior to shot peening. The residual stress resulting from the polishing was about 550 MPa in compression at the surface decreasing to zero within about 0.01 mm beneath the surface.

Average strength properties obtained from uniaxial tension tests of duplicate strip specimens were as follows:

| | Strength (MPa) | Uniaxial Total Strain |
|---|---|---|
| Proportional Limit | 660 | 0.0041 |
| 0.02% Offset Yield Stress | 780 | 0.0049 |
| 0.2% Offset Yield Stress | 1100 | 0.0087 |

## EXPERIMENTAL PROCEDURES

### Shot Peening

Air blast peening via hand held nozzle was performed over the central 75 mm of the length of strips, first on one face and then on the other. Four strips were peened simultaneously in each peening run. Almen saturation curves were generated to give two different peening intensities, 0.018 A (mm) and 0.020 N (mm). The higher intensity (0.018 A) was obtained using 170 cast steel shot while the lower intensity (0.020 N) was obtained using GP 60 glass beads. Coverage of 200 percent was used for peening at both intensities.

### Strain Gage Application

Single element, 120 ohm electrical resistance strain gages, CE 06-125UN-120, were bonded to the center of one face of each strip used in subsequent mechanical loading experiments. The gage elements were oriented to sense longitudinal strains via appropriate potentiometric apparatus employing a Wheatstone half bridge configuration.

### Mechanical Loading

Axial tension loading of two specimens was performed on a hydraulically actuated universal testing machine equipped with an electrical resistance load cell and a standard tensile extensometer to obtain the tensile properties reported in Section 2. Additionally, one specimen each representing the two peening intensities were strained to a total strain of 0.0048 as determined via strain gage. One specimen for each of the two peening intensities was also strained from cantilever bending to a maximum tensile surface strain of 0.0048 as determined from a strain gage bonded to the face strained in tension. It was assumed that a compressive strain of the same magnitude was obtained on the opposing location of the face strained in compression. Finally, one specimen for each of the two peening intensities was subjected to cyclic cantilever bending (R = O) for 10,000 cycles to a maximum tensile surface strain of 0.0048 as determined from strain gages in the same fashion as for the static cantilever loading.

Residual Stress Measurements

X-ray diffraction residual stress determinations were made by the $\sin^2\psi$ technique[1] using Cr-$K_\alpha$ radiation to generate the (220) diffraction peak from the austenitic steel matrix. The basic equation [from reference (1)] for calculating residual stresses from x-ray data is:

$$\sigma_\phi = \frac{d_\psi - do}{do} \qquad \frac{E}{1+\nu} \qquad \frac{1}{\sin^2\psi}$$

where: $\sigma$ = Stress component in chosen direction, $\phi$

$\psi$ = Angle between normal to sample surface and bisector of incident and diffracted x-ray beam

d = Interplanar spacing for chosen crystal lattice planes ($d_\psi$ = d for a chosen angle; do = d for $\psi$ = o)

$\frac{E}{1+\nu}$ = experimentally determined constant relating elastic response of interplanar spacing of chosen lattice plane to stress

To the authors' knowledge, there is no published value of $\frac{E}{1+\nu}$ representing the (220) planes of AISI type 301 stainless steel. In this investigation a value of 139 X $10^3$ MPa determined previously by Prevey'[2] for AISI type 304 stainless steel was used for residual stress calculations. Because of similarity in alloy compositions, this is deemed a good substitution.

Five $\psi$ angles were used for residual stress measurements: 0, ±30, 45, and 60 degrees with ±4 degree oscillation at each angle. The approximate irradiated area for x-ray measurements was 4 mm in diameter. Precision errors for individual stress measurements in this investigation typically were of the order of $\pm 30$ MPa based on x-ray spectra counting statistics and of the order of $\pm 150$ MPa based on statistical uncertainty in least squares best fit of a straight line to $d$ versus $\sin^2 \psi$ data.

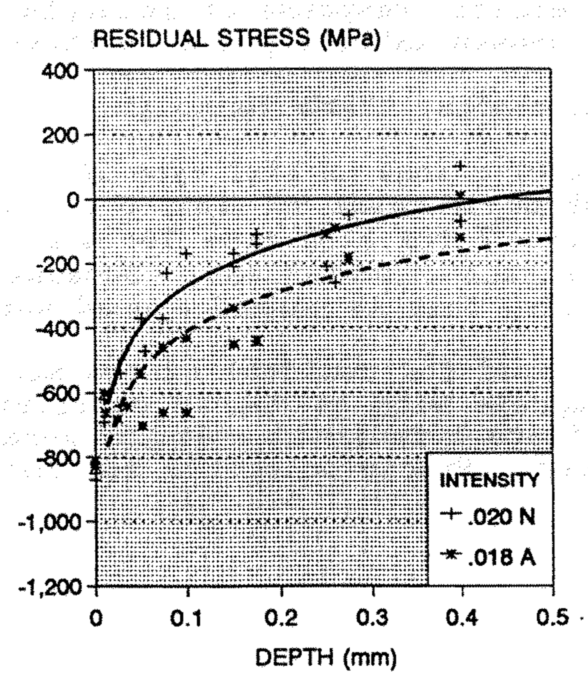
## RESULTS AND DISCUSSION

### As-peened Specimens

Surface residual stress from eight specimens peened to 0.018 A (mm) ranged from 690 to 910 MPa in compression. The average value was 830 MPa compression with a standard deviation of 70 MPa. For eight specimens peened to 0.020 N (mm) the range was 780 to 910 MPa compression with an average of 860 MPa compression and a standard deviation of 50 MPa. With consideration for the estimated precision error in measurement ($\pm$ 150 MPa), statistical "t" and "F" tests indicate that these results were quite consistent within each peening condition and that the surface residual stress values were the same for both peening intensities at better than 95 percent confidence.

Residual stress-depth distributions for two specimens at each of the two peening intensities are presented in Figure 1. As may be easily seen from this figure, both peening intensities gave about the same compressive surface residual stress. The depth of the compressively stressed layer was greater for the higher peening intensity (0.018 A). Moreover, the magnitude of compressive stress was markedly greater from about 0.03 to 0.25 mm depth for the higher peening intensity.

Figure 1 Residual Stress - Depth Distributions
As Shot Peened

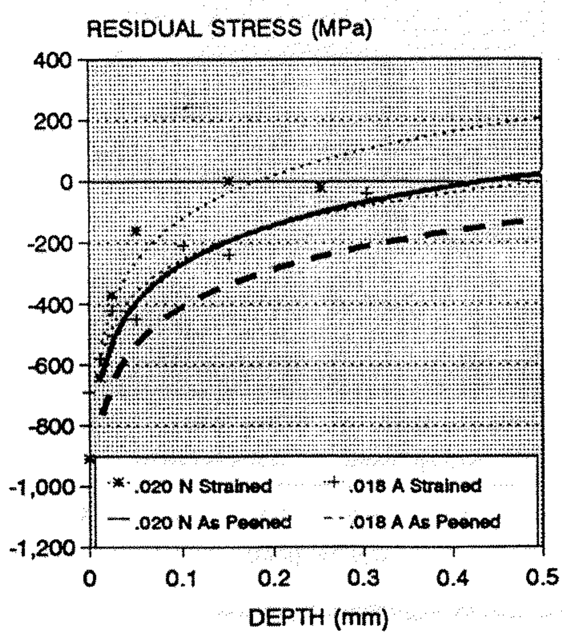



Curves generated by logarithmic regression

## Uniaxial Static Tension Loading

One specimen each for the two peening intensities was statically loaded uniaxially to a strain level of 0.0048. This level approximately corresponded to the strain experienced at the 0.02 percent offset yield stress level in tension testing of the material. Residual stress-depth distributions for these two specimens are presented in Figure (2) along with the distribution [reference Figure (1)] representing the as-peened conditions. The surface residual stresses after loading were about the same magnitude as before loading for both peening intensities. Most dramatic was the reduction in subsurface stress magnitudes for a given depth and the overall reduction in depth of the compressively stressed material which occurred in specimens of both peening intensities.

Figure 2 Residual Stress - Depth Distributions
Uniaxial Static Strain (0.0048) After Peening
Comparison with As Peened

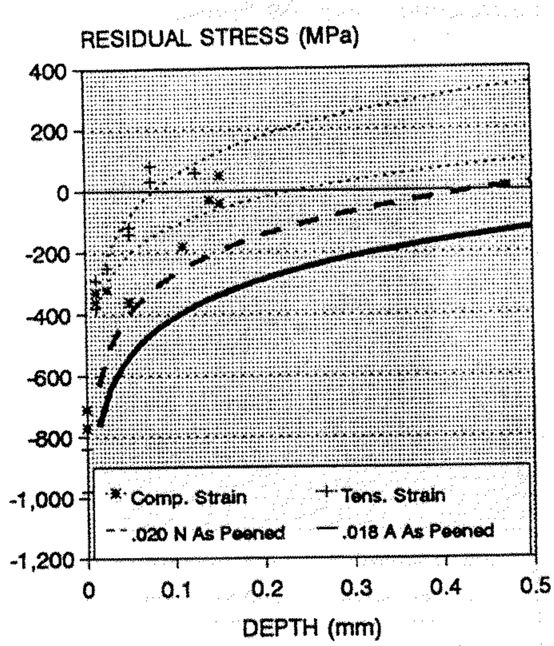



Curves generated by logarithmic regression

## Static Bend Loading

One specimen each for the two peening intensities was statically loaded in cantilever bending to a maximum surface strain level of 0.0048 on the tension face. This level corresponded approximately to the strain at the 0.02 percent offset yield stress in tension testing. Residual stress-depth distributions are presented in Figure (3) along with the distributions [reference Figure (1)] for the as-peened conditions. Within experimental error, the residual stress-depth distributions for the strained specimens were the same irrespective of prior peening intensity and whether straining was in tension or compression. Surface residual stresses after straining were the same, within experimental error, as before straining. Subsurface compressive stresses, however, were greatly reduced in magnitude for a given depth and the depth of the compressive layer was greatly decreased relative to the as-peened specimens. Effects were similar for both tension and compression strains; however, tensile straining resulted in somewhat greater stress redistribution than compressive straining.

Figure 3 Residual Stress - Depth Distributions
Bending Static Strain (0.0048) After Peening
Comparison with As Peened

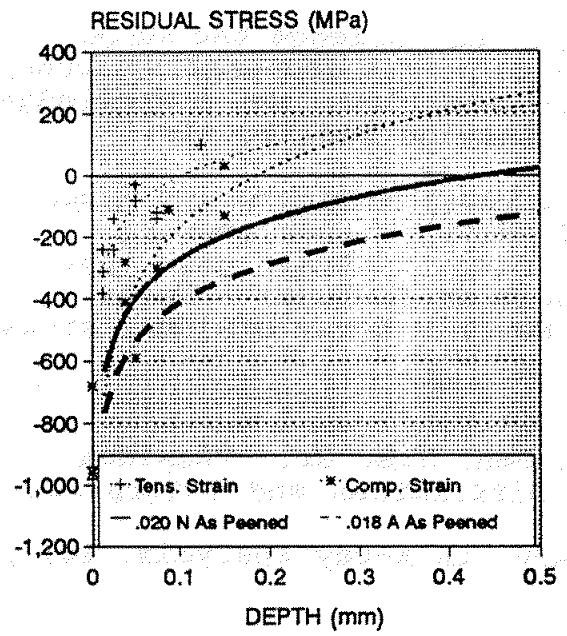



Curves generated by logarithmic regression

## Cyclic Bend Loading

One specimen each for the two peening intensities was cyclically loaded in cantilever bending (R = O) for 10,000 cycles to a maximum surface strain level of 0.0048 on the tension face. This level corresponded to the strain experienced at the 0.02 percent offset yield stress level in tension testing of the material. Residual stress-depth distributions for these two specimens are presented in Figure (4) along with the distribution [reference Figure (1)] for the as-peened condition. As found for static bending, surface residual stresses for strained specimens were about the same as for the as-peened conditions. The magnitudes of subsurface compressive stresses and the depth of compression were also markedly reduced irrespective of prior peening intensity. Within experimental error, the residual stress-depth distribution for cyclic bend straining was the same as for static bend straining.

Figure 4 Residual Stress - Depth Distributions
Bending Cyclic Strain (0.0048/R=0) After Peening
Comparison with As Peened




Curves generated by logarithmic regression

CONCLUSIONS

Surface residual stresses obtained by peening to 0.018 A (mm) and 0.020 N (mm) intensities were the same; however, the depth of compressively stressed material was markedly greater for the higher intensity peening.

Uniaxial static tension loading of peened specimens to a strain level corresponding to the 0.02 percent offset yield stress resulted in a reduction in magnitude of surface and residual stresses with a net decrease in the depth of the compressively stressed material for both peening intensities.

Static bend loading of peened specimens to a surface strain level corresponding to the 0.02 percent offset yield stress resulted in a dramatically greater reduction in subsurface residual stresses and depth of compressive layer than obtained from uniaxial loading to the same strain level. The magnitudes of surface residual stresses, however, were the same as for specimens in the peened condition. Tensile strains from bending loading produced similar but somewhat greater effects than compressive strains. Cyclic bend loading at R = 0 of peened specimens for 10,000 cycles at a maximum surface strain corresponding to the 0.02 percent offset yield stress resulted in the same residual stress-depth distributions as for specimens loaded to the same level in static bending.

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