Investigation of the Effects of Elastic Pres-Stressing Technique on Magnitude of Compressive Residual Stress Induced by Shot Peen Forming of Thick Aluminum Plates

C.F. Barrett and R. Todd

Metal Improvement Company
10 Forest Avenue
Paramus, New Jersey 07652

ABSTRACT

Investigation of effects of elastic pre-stressing technique on magnitude of compressive residual stress induced by shot peen forming on 17.3mm thick, 7075 T-7651 aluminum alloy plate. Profile of residual stress in concave and convex surfaces were determined while shot peen formed plate remained in curved condition. The information obtained shows the residual stress profile as it exists in the formed plate rather than usual relaxed condition.

Key Words:

Elastic strain peening, free state peening
Compressive residual stress
Compressive stress profile
Pre-stressing technique

The objective of this study was to obtain some fundamental information on the differences in magnitude and distribution of residual stresses induced by elastic pre-stress shot peen forming as compared to free state shot peen forming on thick aluminum plate.

Elastic pre-stress shot peen forming technique involves the shot peening of a part while it is statically stressed in direction of curvature required in final shape of part. By mechanically curving the part to be formed, within the elastic range of the material, smaller radii of curvature can be generated with the same peening parameters. Pre-stressed radii are critical and are developed mathematically and checked experimentally so that the material's yield point is not exceeded prior to peen forming. Mechanical or hydraulic devices are used to deflect the workpiece and are usually designed for specific applications. Pre-stressing increases the contour from peen forming in one direction and sharply decreases the compound contour normally resulting from free state peening. The radius of curvature resulting from this method can be up to four times the radius obtainable by peen forming without an applied external load.

For this study a machined plate 508mm x 762mm x 17.3mm thick of 7075 T-7651 aluminum alloy was used (See Fig. 1). A portion of the 508mm width was pre-stressed to 1700mm radius and peen formed using elastic pre-stressing technique to produce a curvature of 10160mm. See Figs. 2 & 4 for peening parameters. Based on mechanical property data, the radius at which upper fibres would yield was calculated to be 1458mm. To assure that the 1700mm radius was actually within the elastic range of material the panel was tested by elastically deflecting panel to 1700mm radius. When load was released the panel returned to flat shape. No yielding or set was observed. The 1700mm radius computed to a stress level equal to 87% of tensile yield strength.

All specimens for determining the sub-surface residual stress distribution were of a rectangular configuration cut from the 508mm x 762mm plate (See Fig. 1). Two plates 305mm x 127mm and two smaller plates were cut from the 508mm x 762mm plate. The larger plates were from the pre-stressed peened area. The smaller plates, to be used for free state peening, were cut from the unpeened area and free state peened to the same parameters as the 305mm x 127mm plates. One set consisting of the larger and a small plate were examined by x-ray diffraction using the "window" method. This other similar set was examined by x-ray diffraction using a partial dissecting method, where metal removal was done by alternately milling and electro-polishing to a depth of 5.1mm. The depth was selected for examination, using partial dissection method, to determine if there were any anomalous reactions to strain peening into the core of metal. No definite conclusion can be drawn as this study did not include investigation of residual stress distribution in plate prior to peening.

The plate size 305mm x 127mm was chosen to be compatible with x-ray diffraction machine for measuring strains perpendicular to grain using the "window" method. The other 305mm x 127mm plate was selected for measuring strains in both directions (See Fig. 4) using the partial dissection method. This plate had to be cut into 152mm x 127mm to accommodate the x-ray diffraction machine. In order to measure stress relaxation that could occur during cutting of 305mm x 127mm plate in half, electrical strain gauge rosettes were applied to the measurement sites at opposite ends on the concave and convex faces, and the strain relaxation which occurred was recorded. The stress relaxation calculated employing Mohr's circle for strain indicated a maximum of 0.48 Mpa in any direction and was not considered significant.

The x-ray diffraction method was used to determine the residual stresses. A small area or window approximately 25mm square was etched on convex and concave surfaces, not directly opposite, penetrating in a series of steps to a depth of 2.3mm. This "window" method was chosen to avoid release of the bending moment force which normally occurs when dissecting the entire surface. The window method removed only 3.3% of the surface area. While the part remained in formed shape, stresses at incremental depths were determined by removing finite layers from remaining surface. By using a sufficient number of steps, the stress distribution was plotted. All data obtained as a function of depth were corrected for the effects of the penetration of the radiation employed for residual stress measurement into the subsurface stress gradient, and for stress relaxation which occurred as a result of material removal. Electropolishing in a nitric acid-methanol electrolyte was used to minimize the alteration of the subsurface residual stress distribution. The precise measurement depths achieved on each specimen were intentionally different. Measurements were made by the two-inclined angle technique employing the diffraction of chromium K-alpha radiation from (311) planes of the face center cube structure of the 7075 aluminum alloy. Diffraction peak angular positions were determined employing a five-point parabolic regression procedure after correction for the Lorentz-Polarization and absorption effects, and for a linearly sloping background intensity.

Observations of Results:

Comparing the results of the compressive stresses developed by elastic pre-stress peening vs. free state peening obtained by the "window" method (See Figs. 2 & 3) are:

a. The convex side of pre-stressed peened plate had higher and deeper peak residual stress than the free state peened plate. The convex side of pre-stressed peened plate had -594 Mpa at depth of 0.41mm. The convex side of free state peened plate had peak residual stress of -405 Mpa at depth of 0.25mm.

b. Maximum depth of compression appears to be reasonably the same for strained peened vs. free state. The use of elastic pre-stress did not develop a deeper depth to the plastic deformation layer.

Comparison of the residual stresses measured using the "window" method (Fig. 2) vs. "partial dissection" method on convex surfaces (Fig. 4) shows:

a. Distinct difference in the magnitude of stress and profile measured in the direction perpendicular to grain, -594 Mpa vs. -470 Mpa (See Figs. 2 & 4). Possible explanation for this variance is the amount of relaxation experienced by the partial dissection method which removed 37.5% of surface area vs. 3.3% for "window" method, or possibly there were localized pre-existing fabrication stresses in this section of plate used for the partial dissection examination.

b. The depth of plastic deformation is approximately the same for all convex peened surfaces examined, (Fig. 2, 3 & 4). All specimens were shot peened with same parameters with exception of pre-stressing.

Comparison of residual stresses measured in perpendicular vs. parallel direction on convex surfaces (Fig. 4) shows:

a. The residual stresses in direction of curvature, perpendicular to grain, are larger than residual stresses parallel to grain.

b. Both peak residual stresses appeared at same depth below surface 0.41mm.

c. No significant difference was observed between the stress measured perpendicular and parallel to grain to a depth of 0.16mm.

Conclusions:

It appears that the magnitude of compressive stress developed is definitely related to the elastic strain employed during pre-stress loading. The depth to which the compressive stress occurs apparently does not significantly change with surfaces strained during peening. Based on this conclusion, it can be stated:

> In the application of elastic pre-stressing technique vs. free state peening to form identical curvature, the free state peening would require a deeper depth of compression to form the same curvature. In using elastic pre-stressing there would be less depth of compression due to the greater plastic deformation in the surface with a minimum in depth. The shallower depth of compression results in less reduction of yield strength for equivalent radius formed free state.

References:

Johnson, T. A. "Shot Peen Forming - A Production Process" ASTME Technical Paper MF 68-168, 1968

Skinner, R. D. "Stress-Peen Straightening of Complex Machined Aircraft Parts" ASTM, STP 647, 1977, p.p. 100-121

Barrett, C. "Shot Peen Forming", Oral Presentation, Westec, Los Angeles, California, March 1975

Lynch, J. J. "The Measurements of Residual Stresses", ASM, Thirty-Third National Metal Congress, Detroit, October 1951, p.p. 42-94

Prevey, P. S. "A Method of Determining the Elastic Properties of Alloys in Selected Crystallograph Directions for X-Ray Diffraction Residual Stress Measurements:, Advances in X-Ray Analysis" Vol. 20, Plenum Press, 1977, p.p. 345-354

Fuchs, H. O. "Shot Peening Effects and Specifications" STP 196, ASTM, 1962, p.p. 22-32

Fuchs, H. O. "Comparison of Mechanical Properties of Panels Which Have Been Strain Peened" Metal Improvement Company, Sept. 1980

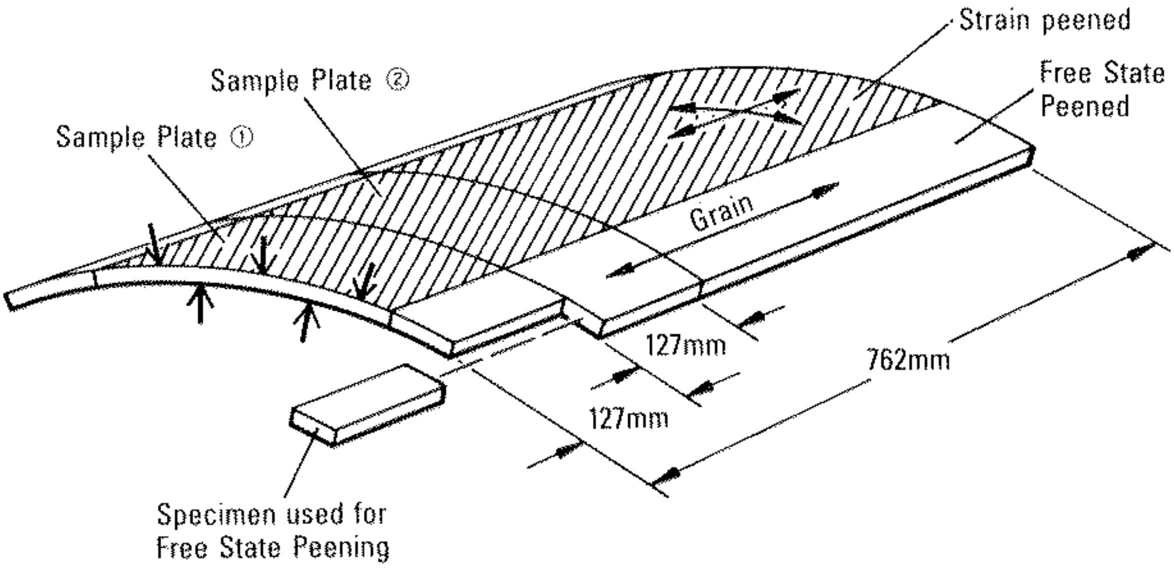

Fig. 1 Peened Formed Test Plate

PEENING PARAMETERS

Prestressed to 1700mm Radius

Shotpeened 3.2mm Diameter Ball
on Convex Side

0.8mm Dimple Diameter

60%—80% Coverage

Saturation Peened
0.6mm Shot at 5/6A Intensity
100% Coverage

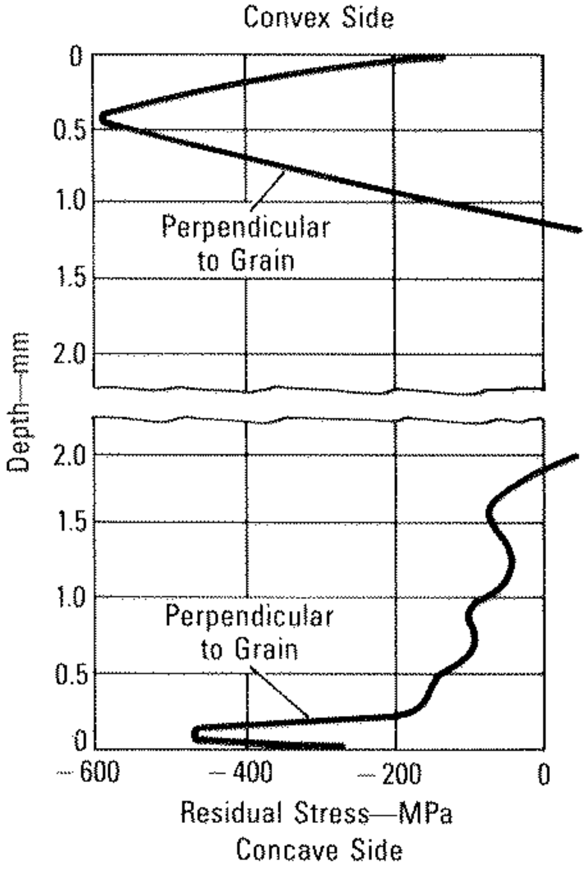

Fig. 2 Elastic Prestressed Peened Plate

PEENING PARAMETERS

Shotpeened 3.2mm Diameter Ball on Convex Side

0.8mm Dimple Diameter

60%—80% Coverage

Saturation Peened
0.6mm Shot at 5/6A Intensity
100% Coverage

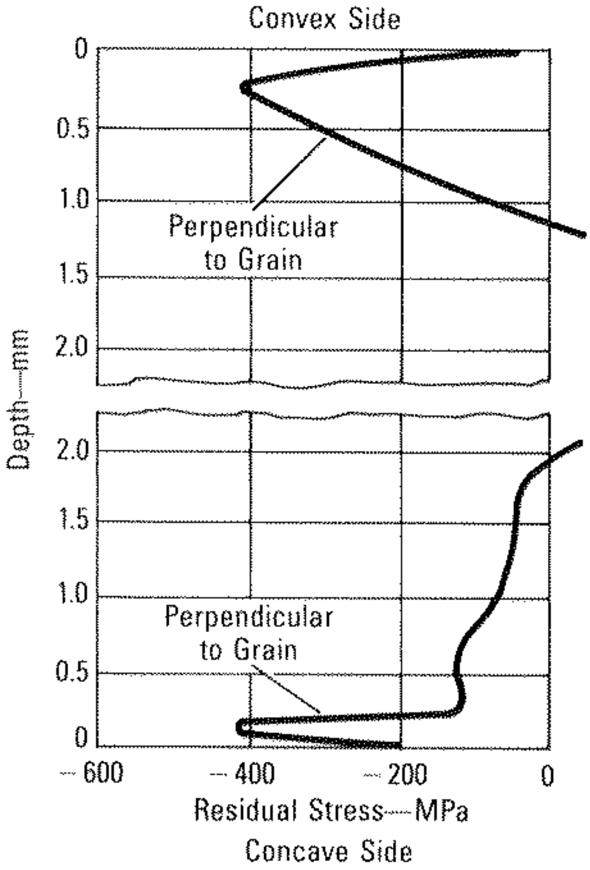

Fig. 3 Free State Peened

PEENING PARAMETERS

Prestressed to 1700mm Radius

Shotpeened 3.2mm Diameter Ball on Convex Side

0.8mm Dimple Diameter

60%—80% Coverage

Saturation Peened
0.6mm Shot at 5/6A Intensity
100% Coverage

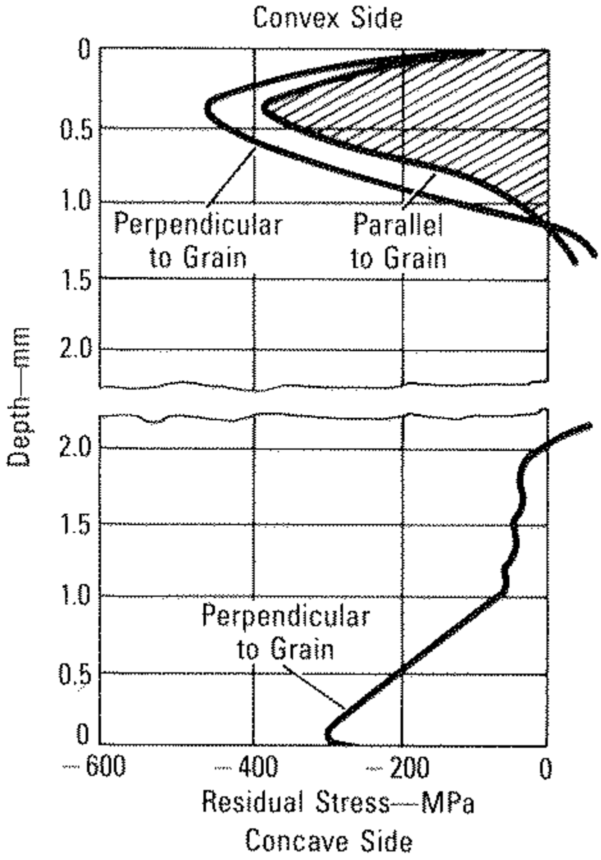

Fig. 4 Elastic Prestressed Peened Plate