Topography and Fracture Studies of Surfaces Shot Peened at Different Intensities

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Introduction

The purpose of this investigation was to determine the relationship between precision shot peened surface topography, test specimen surface condition, increased peening intensity, saturation, broken media content, peening impact angle, and fatigue life. Test results are compared statistically as specimen fatigue life versus specific condition.

Procedure

Test specimens were shot peened in accordance with the tolerances listed in Table 1.

VARIABLE	TOLERANCE
Inter-Strip Hardness	1.5 HRC
Intra-Strip Hardness	2.0 HRC
Flatness	+/- 0.0001"
Thickness	+/- 0.001"
Width	+/- 0.0025"
Length	+/- 0.015"
VARIABLE	**TOLERANCE**
Air Pressure	+/- 1.0 PSI
Turntable Speed	+/- 0.5 RPM
Nozzle Distance	+/- 0.25 Inches
Angle of Impact	+/- 2.0 Degrees
Nozzle Orifice Dia.	+/- 0.002 Inches
Media Flow	-
Glass Bead	+/- 3.0 Grams/Min.
Steel Shot	+/- 3.0 Oz./Min.
Stroker Speed	+/- 0.25 "/Min.
Cycle Time	+/- 1.0 Second

Table 1: Process Variable Tolerances

Results and Discussion

Fatigue life versus Almen intensity for aluminum alloy 7075-T6 axial fatigue test specimens with a 143 HBN hardness tested at 58 KSI stress is shown in Figures 1 and 2. Figure 1 represents a test specimen gauge section in the lathe turned condition. Figure 2 represents the test specimen gauge section in the lathe turned and polished condition.

The data plots (Figures 1 and 2) each show particular peening intensity conditions and optimum peening intensity range which produce the maximum fatigue life for the specimens tested.

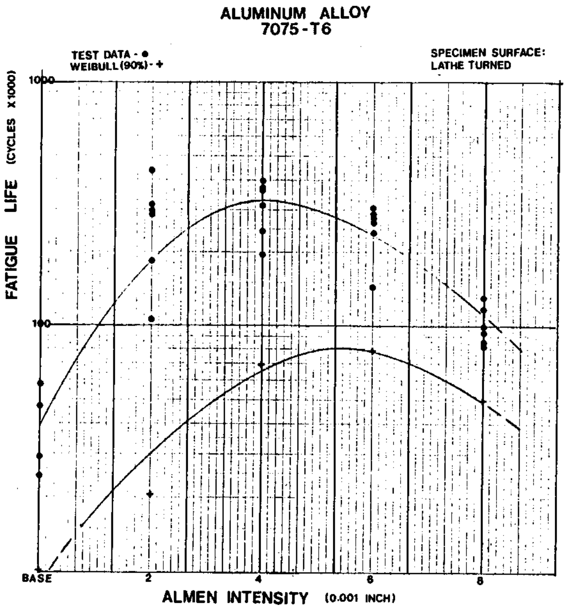

FIG. 1: Fatigue Life versus Almen Intensity. (Specimen surface lathe turned)

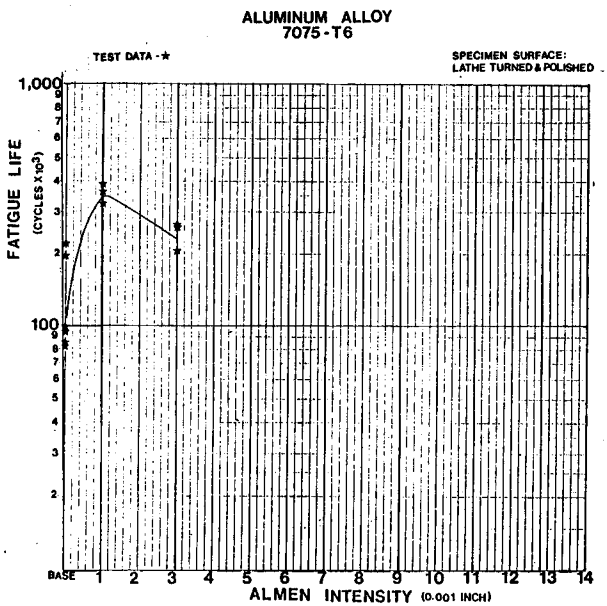

Fig. 2: Fatigue Life versus Almen Intensity (Specimen surface lathe turned and polished).

Figure 1 shows a data scatter band of 100,000 cycles to 425,000 cycles at the 0.002A intensity. As peening intensity increases to 0.004A the data scatter narrows to 200,000 to 400,000 cycles. The 0.006A peening intensity shows a data scatter of 150,000 to 300,000 cycles while the 0.008A intensity shows a data scatter of only 80,000 to 130,000 cycles.

The data obtained shows increased peening intensity has a positive direct effect on workpiece fatigue life up to an optimum range. Peening intensities greater than the optimum range result in a negative effect on fatigue life.

It is hypothesized that the specimen compressive zone increases as a function of increased peening intensity to the optimum peening intensity resulting in internal fatigue fracture initiation sites. Greater peening intensities than the optimum intensity produce induced specimen surface damage resulting in surface fatigue fracture initiation sites. The induced specimen surface damage is in the form of peened surface extrusion folds (PSEF). (1) (2) This shift of failure modality from internal to surface fatigue failure initiation results in less than optimum fatigue life.

Figure 2 shows the optimum peening intensity of 0.001A for the test data obtained.

It is the opinion of the authors that the specimen surface condition relative to smoothness and lack of surface discontinuities is a contributing factor to the quantitative position of optimum peening intensity and maximum fatigue life. The specimens in the lathe turned and polished surface condition required a 0.001A peening intensity to attain optimum (Figure 2) compared to a required peening intensity of 0.004A to produce optimum in specimens which had a lathe turned surface (Figure 1).

These opinions are substantiated by scanning electron microscopy evaluation.

Test specimen fractures were analyzed on an SEM with the fracture surface at a 45 degree angle to the electron beam at 50X magnification.

A typical surface initiation fracture site is shown in Figure 3. A typical internal initiated fracture site is shown in Figure 4.

Figure 3, specimen 1387, shows the fracture periphery of the baseline test specimen (unpeened) with obvious machining marks on the specimen surface which are stress concentration sites resultant in surface fracture initiation and a sharp jagged fracture periphery.

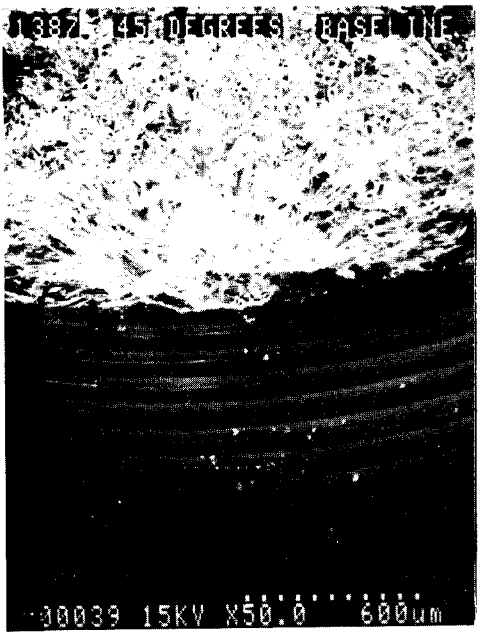

Figure 3

Figure 4

Figure 4, specimen 1400, shows the fracture of a test specimen with the third highest fatigue life of the 0.006A intensity test specimens exhibiting an internal initiated fracture site with the typical interior conical fracture through shear planes within the test specimen. A very interesting observation is made of test specimen 1405 in Figure 5. This specimen was peened at the same 0.006A intensity as specimen 1400 shown in Figure 3, however, the fracture initiation site is of surface origin, rather than internal origin. This specimen exhibited the lowest fatigue life value (150,000 cycles) of the specimens in the 0.006A intensity group. The explanation for the surface failure of specimen 1405 is the amount of induced surface damage. Primary crack nucleation is identified with PSEF as found by Luo, Noble and Waterhouse.

The transition of all specimen failures to surface fracture initiation sites at the 0.008A (Figure 6, specimen 1399) peening intensity is consistent with the hypothesis of a fracture failure transition zone just above the optimum peening intensity. All surface fracture failures at successively higher peening intensities are resultant from induced peened specimen surface damage (PSEF).

Figure 7 shows the data plot of fatigue life versus workpiece saturation at 195 KSI stress for 4340 Alloy Steel (vacuum arc remelt) with a 48/50 HRC hardness and the specimen gauge section in the ground condition.

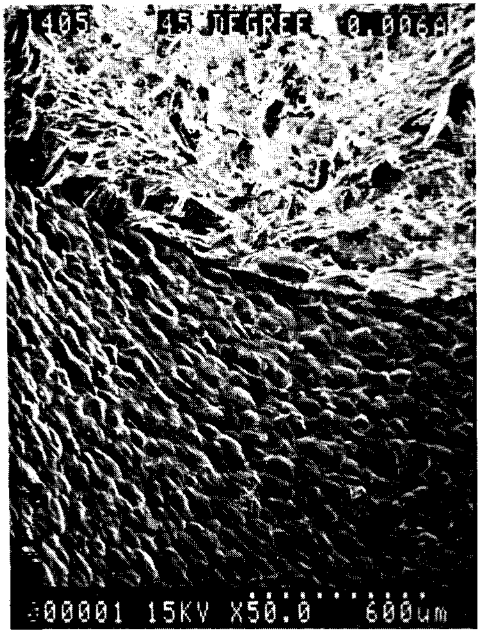

Figure 5

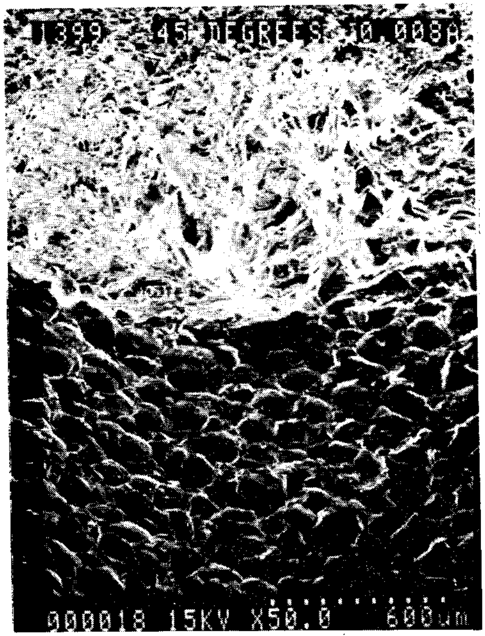

Figure 6

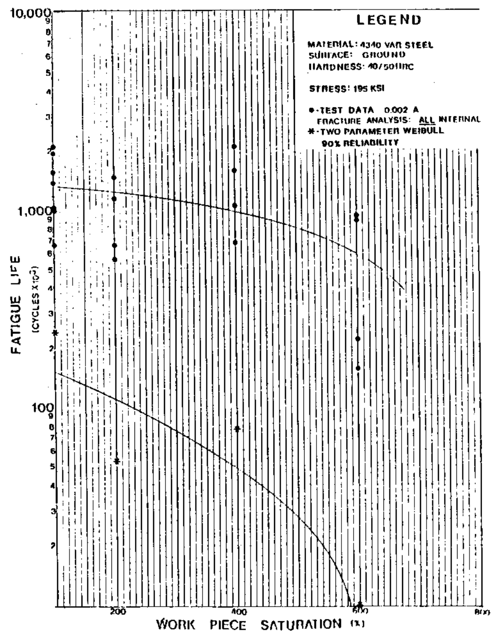

FIG. 7: Fatigue Life versus Workpiece Saturation.

Observation of the data plot shows relatively negligible affect of saturation of 400 percent as related to 100 percent. A definite negative affect on specimen fatigue life can be seen at 600 percent workpiece saturation.

Figure 8 shows the data plot (for the same 4340 Alloy Steel) of fatigue life versus broken particle content of the peening media. Cast steel grit per MIL-S-851C was added to S-070 cast steel shot per MIL-S-13165B, Table I in the percentages of 25, 50 and 75. All test data was obtained at 0.002A intensity.

It can readily be observed from the data plot that increasing amounts of broken particle content in the peening media negatively affects the resultant test specimen fatigue life. The induced surface damage is totally different than PSEF formation. The acicular broken particles produce deep angular impingements while PSEF consist of impingement peripheral plastic extrusion and overlap.

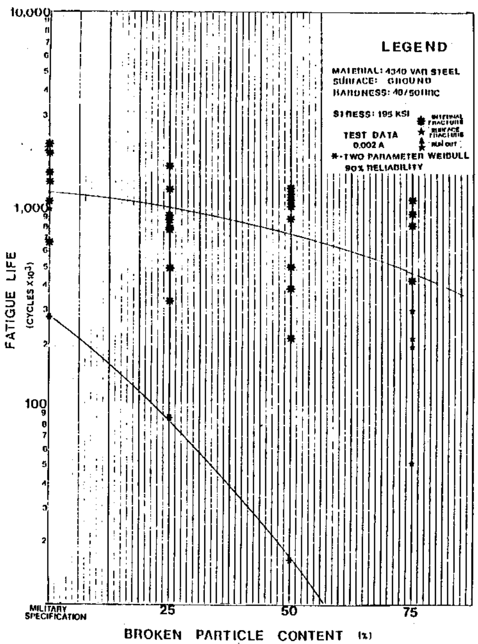

FIG. 8: Fatigue Life versus Peening Media Broken Particle Content.

Figure 9, shows the plot (for the same 4340 Alloy Steel) of fatigue life versus peening angle of impact.

A decrease in test specimen fatigue life and increased data scatter are observed as the peening angle to the workpiece surface decreases from 90 degrees. The induced surface damage produced is directional plastic metal flow on a portion of the circumference of the impingement normal to the peening angle.

This induced surface damage is the directional formation of PSEF as compared to those formed by 90 degree angle of impact.

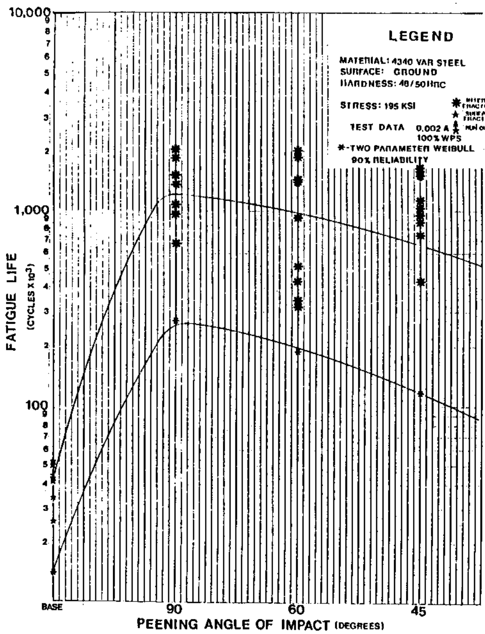

FIG. 9: Fatigue Life versus Peening Angle of Impact.

Conclusion

Several authors, including John Almen as early as 1943 (Shot Blasting of Metal Parts, SAE Transactions), and more recently Neil Person (Effect of Shot Peening Variables on Fatigue of Aluminum Forgings), G. Wigmore and L. Miles (The Use of Shot Peening to Delay Stress Corrosion Crack Initiation in Austenitic), R. Simpson and J. Cammett, and others identified the concept of optimum intensity range.

For many years, the general hypothesis was that there was something unique about the residual stress profile which generated optimum intensity range.

This investigation establishes that shot peen process induced surface damage effects the quantitative position of optimum intensity range. It also establishes the relationship and effect on axial fatigue test specimens of various materials and specimen surface conditions as they relate to peening intensity, workpiece saturation, broken particle content in peening media and peening angle of impact. The same effect was identified in four point bending specimens by Luo, Noble, and Waterhouse.