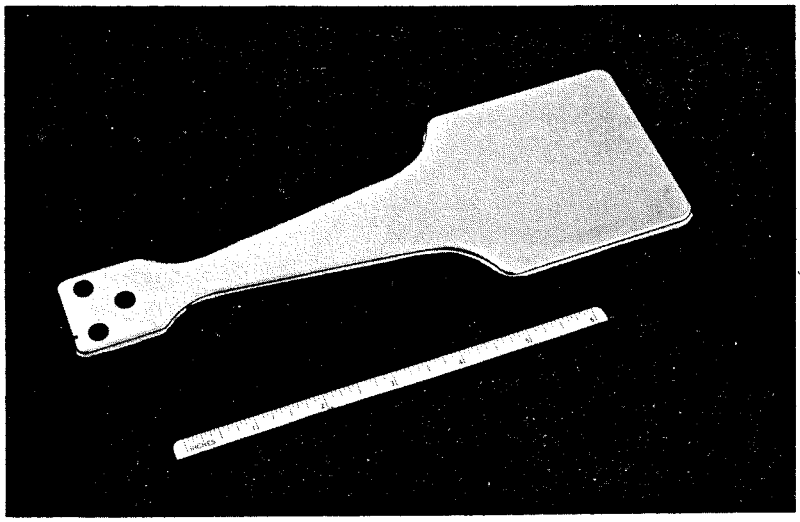

Fig. 1 — Repeated bending fatigue specimen as die forged.

Effect of Shot Peening Variables on Fatigue of Aluminum Forgings

By Neal L. Person

NUMEROUS ARTICLES and reports show that shot peening increases the fatigue strength of many metallic materials. However, few reports deal with the separate effect of peening conditions, such as shot size, intensity, coverage (time of peening), and shot density. We shall present data showing how these variables affect 2025-T6 die forgings.

Test specimens were die-forged specially for this study (Fig. 1) at our Kaiser-Erie (Pa.) Works. Forging flash, which laid along the mid-thickness plane of the specimen, was removed by machining using a Tensilkut machine. Three holes were drilled in the smaller end of the specimen to allow it to be fixtured in the Krouse tester. Average tensile properties from two specimens machined from the tapered portion of two fatigue specimens were: ultimate tensile strength, 382 MPa (55 400 psi); yield strength, 266 MPa (38 600 psi); and elongation, 15.8% in 51 mm (2 in.).

Shot peening was done on all sides of the tapered test section by a commercial shop. Table I lists the shot sizes and Almen intensities used. We used steel shot size ranging from S-110 to S-550 (0.28 to 1.40 mm [0.011 to 0.055 in.] in diameter) and one size glass shot (0.51 mm [0.020 in.] in diameter).

Almen intensities were 0.38 mm (0.015 in.) N, 0.18 mm (0.007 in.) C and values from 0.08 to 0.28 mm (0.003 to 0.011 in.) A. The appendix describes the relationship among these Almen intensity scales, as well as gives a description of the other terms used in connection with shot peening, e.g., saturation and coverage.

To study the effect of coverage, we selected the S-110 shot size, which was found to give the longest fatigue life when used to peen to 0.20 mm (0.008 in.) A Almen intensity (100% coverage). We also evaluated specimens peened to 80, 200, and 400% coverage.

To study the effect of shot density (i.e., shot weight per unit volume), we selected glass shot of approximately the same diameter as the S-230 cast steel shot and attempted to shot peen to the same Almen intensity achieved with the latter. We could not reach that intensity with the lighter shot, however. Intensity with the glass shot was measured on the N-scale which is only approximately related to the A-scale. Nonetheless, the correspondence was about 0.13 mm (0.005 in.) A for the glass shot versus 0.18 mm (0.007 in.) A for the S-230 shot.

Description of Testing Procedure

At least eight specimens of each type were tested by Krouse repeated-bending at a given stress level,

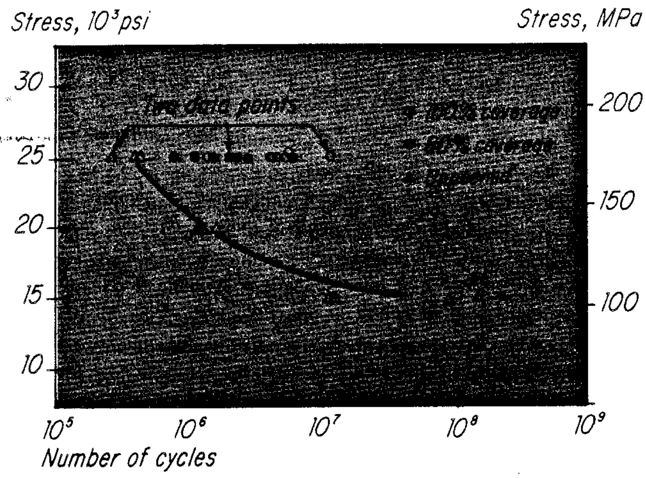

Fig. 2 — S-N plot for die forged aluminum alloy 2025-T6 specimens in three conditions: unpeened, and peened with S-110 cast steel shot to 100% coverage (0.20 mm [0.008 in.] A Almen intensity) and 80% coverage. Alternating stress; R = -1.

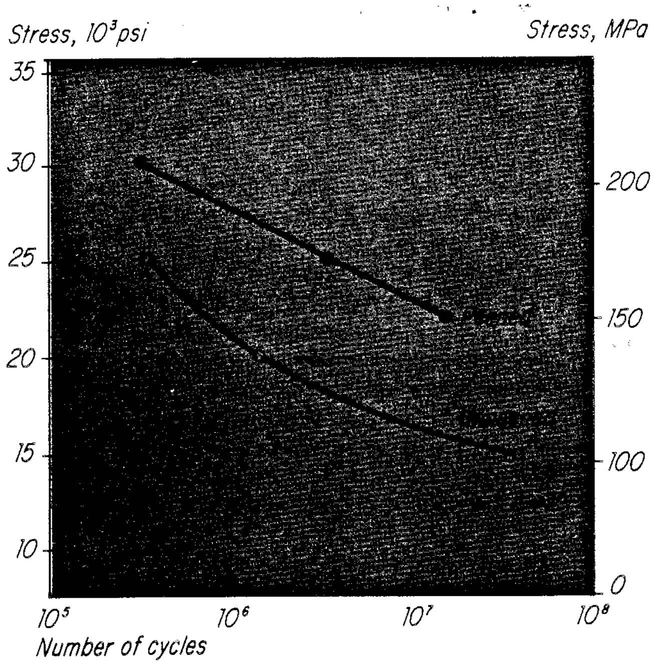

Fig. 3 — Log-mean S-N curves for peened and unpeened 2025-T6 specimens. Alternating stress; R = -1.

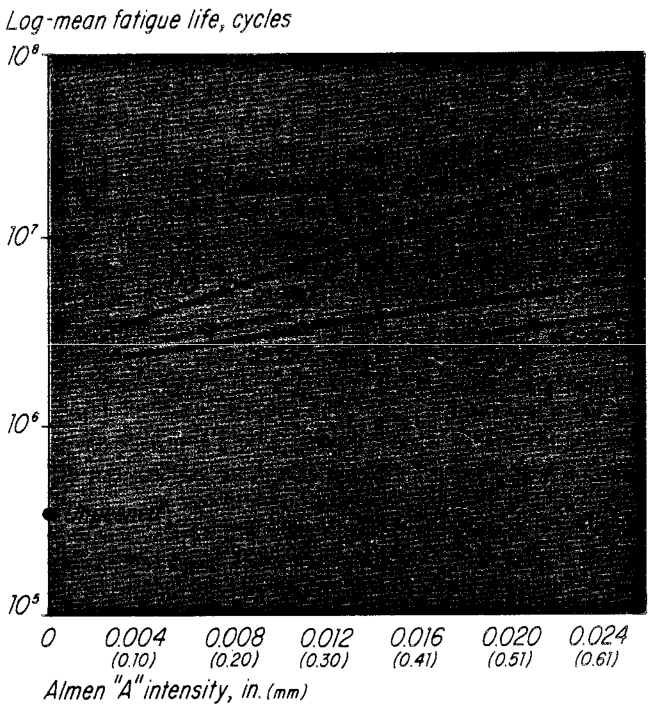

Fig. 4 — Effect of Almen intensity and shot size on fatigue life where coverage is 100%. Alternating stress = 172 MPa (25 000 psi); R = -1.

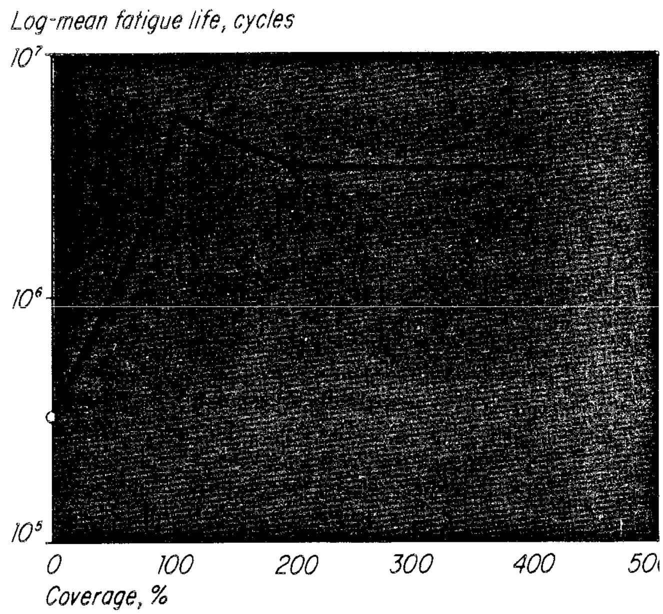

Fig. 5 — Effect of coverage on fatigue life with S-110 shot and Almen intensity (for 100% coverage) of 0.20 mm (0.008 in.) A. Alternating stress = 172 MPa (25 000 psi); R = -1.

and their log-mean fatigue lives compared.

The test stress, 172 MPa (25 000 psi), was selected to be high enough that runouts were avoided. After we had completed these tests, several spare specimens were available; these were tested at 152 and 207 MPa (22 000 and 30 000 psi) to define the S-N curve. These specimens had Almen intensities of 0.38 mm (0.015 in.) N, 0.08 mm (0.003 in.) A, 0.28 mm (0.011 in.) A, and 0.18 mm (0.007 in.) C.

An S-N curve for as-forged and heat treated but unpeened specimens was also determined from about 0.5 to 50 million cycles to provide a baseline to compare the other data.

Property Benefits of Peening

Fatigue data show the expected large increase in fatigue life (strength) due to peening (Fig. 2). The relatively larger scatter in the peened specimen data is evidently a reflection of the greater specimen-to-specimen variation expected among peened specimens. Other groups of peened specimens showed about the same degree of scatter.

The two groups of peened specimens shown in Fig. 2 gave the longest and shortest log-mean fatigue lives (at 172 MPa [25 000 psi]). Of the nearly 100 specimens tested at this stress, representing a variety of peening conditions, even the one with the shortest life (800 000 cycles) had about 2.5 times longer life than the unpeened specimens. The longest log-mean life from peened specimens was 17 times greater than that of unpeened specimens.

Fig. 3 shows the log-mean S-N curve from all the specimens peened to saturation using the various peening test conditions. Peening increased fatigue strength 34 to 48 MPa (5000 to 7000 psi) over the range of 300 000 to 15 million cycles.

Effect of Peening Variables

For a given cast steel shot size, fatigue life increased with increasing Almen intensity, as shown in Fig. 4. Such was the case for both the S-110 and S-330 shot sizes. This plot also indicates that for the same Almen intensity, fatigue life increased with decreasing shot size. This result differs from that implied in Ref 1 which states that for equal intensity, larger shot sizes produce higher compressive stresses than smaller shot sizes in aluminum alloys; higher compressive stresses would be expected to tend to increase fatigue life.

Coverage (time of peening) determines fatigue lives in the manner shown in Fig. 5, for S-110 shot size and 172 MPa (25 000 psi) test stress. Full coverage (100%) resulted in the maximum log-mean life, as expected. With underpeening to only 80% coverage, fatigue life was only 38% of that at 100% coverage.

Overpeening also reduced peak fatigue life, but the rate of reduction is not as sensitive to coverage as underpeening. Thus, even when peening four times longer than normal, i.e., 400%, fatigue life is still about 80% of the full coverage value. All other things being equal, slight overpeening seems preferable to slight underpeening.

Results of our limited study on shot density showed that peening with lighter glass shot produced slightly longer life; however, the difference was not statistically significant.

In summary, shot peening greatly improves the fatigue life of aluminum alloy 2025-T6 die forgings. In our test at 172 MPa (25 000 psi) stress level, maximum improvement resulted with an Almen intensity of 0.20 mm (0.008 in.) A produced from S-110 cast steel shot. With the exception of coverage, only relatively minor decreases in life occurred when these conditions were varied, however. The peening variable that most drastically detracted from fatigue life improvement was underpeening (i.e., less than 100% coverage).

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Reference

1. *Metal Fatigue*, edited by George Sines and J. L. Waisman: McGraw-Hill Book Co. Inc., 1959, p 211.

Appendix

Almen intensity (peening intensity) is probably the first term that arises in discussing this subject. The value is determined from a standardized flat piece of metal that is peened to saturation while held in a prescribed manner in a solid block. The flat metal piece will be curved when it is released from the block, and the Almen intensity is defined as the arc height (millimetres or inches) of that curvature. For example, an Almen intensity of 0.08 mm (0.003 in.) A is the arc height of 0.08 mm (0.003 in.) resulting from peening an "A" Almen gage strip.

To provide a broad range of intensity measurements, different standardized gages are provided. For example, there are the "N" and "C" gages which are thinner and thicker than the "A" gage, respectively. The intensity measures from the different gage strips are only approximately related to one another; the "N" value is about 3 times the "A" value and the "C" value is about 0.3 times the "A" value.

The term "saturation" refers to the condition where peening has essentially reached its maximum effect. More precisely, for a specified arc height, saturation is said to be reached at the time (T) required to achieve that height when continued peening to 2T would not increase the height by more than 10%. Arc height can be termed Almen intensity only when saturation has been achieved.

"Coverage," in this study, is defined as the ratio of peening time relative to that required to attain a given intensity. Thus, the time required for saturation is termed 100% coverage. Peening for one-half this time is termed 50% coverage; peening for twice as long is termed 200% coverage, etc. Note, however, that in another convention sometimes used, coverage is defined as the percentage of the surface that has been indented.

Table I — Shot Sizes and Almen Intensities Used for Fatigue Study

Steel Shot and Diameter, mm (in.)	Almen Intensity, mm (in.)
S-110, 0.28 (0.011)	0.08 (0.003) A 0.20 (0.008) A
S-230, 0.58 (0.023)	0.18 (0.007) A
S-330, 0.84 (0.033)	0.08 (0.003) A 0.28 (0.011) A
S-550, 1.40 (0.055)	0.18 (0.007) C[1] or 0.54 (0.021) A[2]
Glass shot, 0.51 (0.020)	0.38 (0.015) N[3] or 0.13 (0.005) A[2]

1. "C" scale values are about one-third those of "A" scale. 2. Converted to "A" scale. 3. "N" scale values are about three times those of "A" scale.