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The Effects of Shot Size on the Residual Stresses Resulting from Shot Peening

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In the shot peening of automotive parts, it is desirable to obtain the best possible stress distribution for a particular application without creating an undesirable surface condition which would be deleterious to the life of the part. It is therefore important to understand the effects of the various shot peening variables, such as shot hardness, shot size, peening intensity etc., on the residual stress distribution and how the stress distribution relates to the fatigue strength of the part.

This can be accomplished by isolating the shot peening variables and then determining the effect of each variable upon the fatigue strength when the part is subjected to various types of loading.

This investigation was limited to obtaining information on the influence of shot size upon the residual stress and to gain an understanding of how this shot peening variable affects torsional fatigue strength.

Abstract

This report describes the influence of shot size upon the residual stress curves. It was found that these curves could be represented by a Gaussian type function which clearly illustrated the effect of changing shot size. The results showed that the maximum compression is located increasingly further subsurface and the total in depth influence of the shot peening becomes greater as the shot size is increased.

Material and Procedure

As shown in Figure 1, the specimens examined were 0.61" test diameter fatigue bars fabricated from a single heat of SAE 5160 material, machined, quenched and tempered to 50 R"C" and finished ground as a single lot. All fatigue tested specimens were shot peened, prestressed in torsion to 175 ksi and then tested in torsion from zero to maximum stress in the direction of prestressing. The shot type and hardness as well as the method of peening, the shot peening machine and exposure time were the same for all samples.

All x-ray diffraction measurements were made at the maximum diameter of the fatigue bars. A General Electric XRD-6 Diffractometer was used with Cr k radiation, V filter and a proportional counter. A 1 degree collimated beam slit was used which resulted in an exposed area of about 1/8 in. square on the curved surface. The three point parabola fitting technique was used.

The residual stress was measured on three samples from each of four shot size groups. It was measured in three directions on each sample—the tangential direction and two 45 degree directions. These two 45 degree directions were the ones that received the maximum tensile and compressive loading during the preset operation.

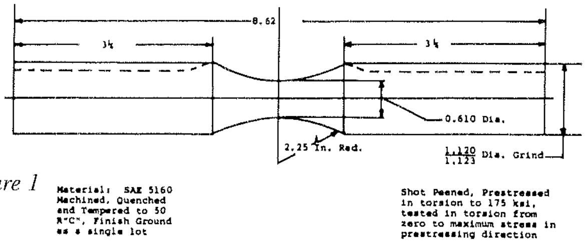

Figure 1

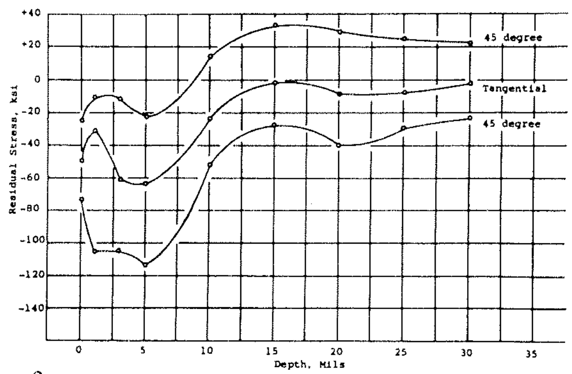

Figure 2

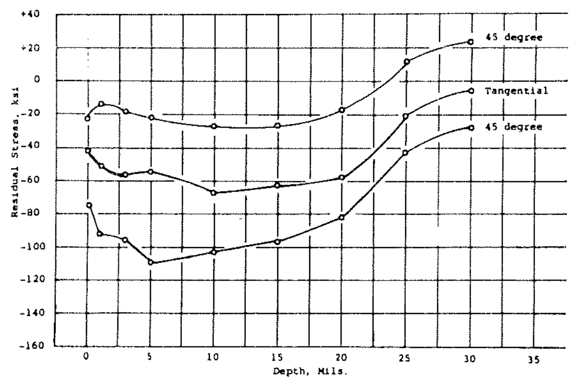

Figure 3

Figure 1. Fatigue specimen
Figure 2. Residual stress versus depth; single sample, 230 shot size
Figure 3. Residual stress versus depth; single sample 660 shot size

Results

The residual stress results on a representative sample from the smallest and largest shot size groups are shown in Figures 2 and 3. Figure 2 shows the residual stress as a function of depth below the surface of the specimen. The three curves represent the stresses found in the three directions on the sample. The data plotted on the lower curve was measured in the 45 degree direction which received the maximum tensile loading during the preset operation. The middle curve represents the tangential direction and the top curve is a plot of the results in the 45 degree direction which received the maximum compressive loading during the preset operation. This sample was shot peened with a well-conditioned operating mixture of CS 230 which was the smallest shot used. As can be seen, the shot peening influence extends to about 15 mils, or 15 thousandths of an inch below the surface of the specimen. Below this depth, we have only the residual stresses resulting from the preset operation.

It was found when samples which had been shot peened only were compared to those which had been both shot peened and prestressed, that there was no substantial difference in the residual stress curves in the direction of the maximum applied tensile loading, until a depth below the surface was reached at which the stress curve was not influenced by the shot peening process.

Also, as expected, it was found that the tangential residual stress was one half the sum of the two 45 degree residual stresses. This result was established with a linear correlation coefficient of 0.97, and holds throughout the shot peened-prestressed layer examined.

Figure 3 is also a plot of the residual stress as a function of the depth below the surface of the specimen. These three curves again represent the three directions in which the residual stress was measured. This bar was shot peened with a well-conditioned operating mixture of CS 660 which was the largest shot size used. These curves have a shape similar to the ones shown in Figure 3; however, here the shot peening influence extends much deeper—to about 30 mils, or thirty thousandths of an inch below the surface for the larger shot size. Because of this difference in the curves, it was decided to establish some parameters which would describe these changes in the total stress curve.

The residual stress results on the three specimens from each of the four shot peening groups were averaged. I then established a functional relationship between the average residual stress for a group and the depth below the surface. This was done only for the 45 degree direction receiving maximum tensile loading during the preset operation since the residual stress in this direction is of greatest interest in relation to the life of the specimen. It was found that the data could be represented quite well by an equation of the form

$$Y = A \,\mathrm{Exp}\, [-2(x - \underline{x})^2/W^2] + B$$

Y = Residual Stress (ksi)

X = Depth below the surface (mils)

$A + B$ = Maximum residual stress (ksi)

B = Preset residual stress level (ksi)

W = A measure of the width of the stress curve (mils)

$\underline{X}$ = Depth to maximum residual stress (mils)

The values of the correlation coefficients, W and $\underline{X}$ for the four groups are listed in the following table:

Group	Correlation Coefficient	W	$\underline{X}$
2	0.98	7.8	4
3	0.99	14.9	7
5	0.95	18.3	9
6	0.92	20.0	10

The correlation coefficients show that in all four cases there is a very good fit between the curve and the experimental data.

Figure 4 shows a plot of the residual stress as a function of depth for both the smallest and largest shot sizes. Each data point is an average of three specimens. Each curve is a plot of the equation shown above with appropriate values for the parameters $\underline{X}$ and W. These calculated curves fit the data points with correlation coefficients of 0.98 for the smallest shot size and 0.92 for the largest shot size. The two graphs clearly show the resulting differences which occur when the shot size is changed.

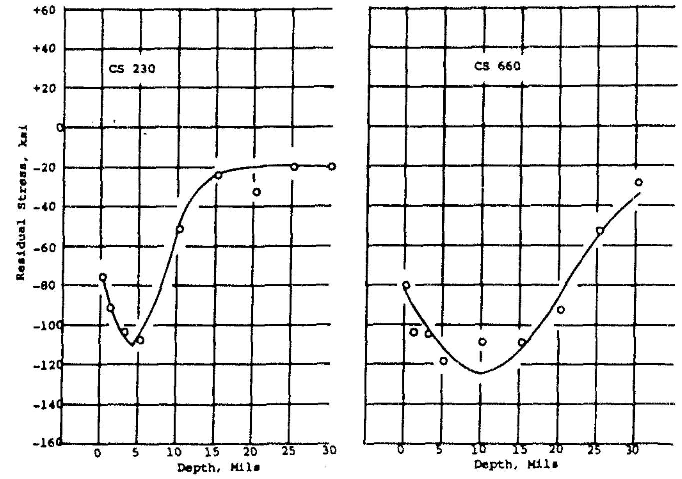

Figure 4. Residual stress versus depth

$\underline{X}$, the depth to the maximum compression, is plotted in Figure 5 as a function of shot size. This plot shows that the maximum compression is located increasingly further subsurface as the shot size is increased. (Figures 5, 6, amd 7 are on page 48.)

In Figure 6 we see a plot of W, the width of the stress curve, as a function of shot size. It is similar to the curve in Figure 5 and shows that the stress curve becomes increasingly wider with increasing shot size. Thus, not only does the maximum stress occur further subsurface as the shot size is increased but also the total in depth influence of the shot peening becomes greater.

The last Figure, 7, is a plot of the average surface residual stress as a function of shot size. Again, each data point is the average of three specimens per group. Each line represents the results in the three directions in which the residual stress was measured. As can be seen, the surface residual stresses resulting from these wildly different shot sizes are not greatly different.

Discussion

The information gained in this study can be applied to specific situations. For example, if a part receives torsional loading during service and is free of surface defects like pits, laps or seams, then it would be advisable to use a small shot size. This is true for two reasons. First, under such conditions the failure origin under torsional loading is at the surface and the surface residual stress is substantially independent of shot size, and second the larger shot size would create an undesirable surface roughness which would be detrimental to the life of the part. On the other hand, if the part tends to have severe surface defects prior to shot peening, such as seams and pits, then a larger shot size would be advisable since the deeper stress pattern would override the stress riser affect caused by these defects. Our experience has indicated this would be of greater benefit than the deleterious effect of increased surface roughness resulting from the larger shot size. ❍