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RECRYSTALLIZATION AS A MEASUREMENT OF RELATIVE SHOT PEENING INTENSITIES

BY K. B. VALENTINE

Abstract

The phenomena of recrystallization and grain growth of a critically strained, low carbon steel at subcritical temperatures were used as a means of determining the depth to which the cold work introduced by shot peening penetrated.

Data from tests utilizing this method indicate that depth of penetration is increased: (a) by increase of shot size; (b) by increase of shot velocity; (c) by increase of time of peening.

Penetration depths up to 0.025 inch were observed.

SHOT peening involves a number of variable factors including the size and shape of the part to be peened, shot size, velocity of shot, and the duration of peening. It is generally agreed that all of these variables enter into the effectiveness of a shot peening operation. The specific extent to which such variables affect the depth to which the cold work penetrates has not, however, received detailed consideration in reports concerning shot peening.

J. T. Norton (1),[1] by use of X-ray diffraction methods, determined that the thickness of cold-worked metal resulting from shot peening is about 0.006 inch. However, no data are presented concerning size of shot used, time of peening, and shot velocity.

Zimmerli (2) presented a photomicrograph showing structural differences at a depth of 0.004 inch below the surface of a shot-peened part, but he implied that the influence of shot peening penetrates to a greater depth than this.

Horger (3) states that much of the fatigue data already available loses some of its significance because of the absence of specifications concerning shot size, time of peening, and other factors.

It is the purpose of this paper to (a) describe a method of

[1]The figures appearing in parentheses pertain to the references appended to this paper.

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determining the effect of shot size, shot velocity, and duration of peening on the depth to which the cold work penetrates, and (b) present results of tests run to determine the effect of these variables on the depth of penetration of the cold work.

Metallurgists are familiar with the coarse grain structures in low carbon sheets which are insufficiently cold-reduced prior to commercial annealing. Sprankle and Hughes (4) have shown that 5 to 15% cold reduction of a 0.17% carbon steel results in a coarse grain structure after annealing at 1320 °F (715 °C). Sauveur (5) presents photomicrographs showing that 40,000 psi on low carbon steel tensile bars produced a coarse grain structure upon subcritical annealing, whereas 42,000 and 38,000 psi did not.

The method herein described for determining the effect of shot size, shot velocity, and duration of peening on the depth of cold work penetration was based on these phenomena of recrystallization and grain growth of critically strained, low carbon steel at subcritical temperatures. Low carbon steel test pieces were subjected to shot peening under controlled conditions and, after subcritically annealing, were microscopically examined, measuring the depth of recrystallization and grain growth.

Test strips 1½ x ¾ x 0.117 inch were cut from a hot-rolled, low carbon steel sheet. The chemical and physical properties of the steel from which they were cut are as follows:

C	Mn	P	S	Si	Ni	Mo
0.06	0.33	0.013	0.033	0.02	0.05	0.03

Ultimate Strength	46,800 psi
Yield Strength	35,400 psi
Elongation in 8 Inches	30.3%
Hardness	Rockwell B-74

These test strips were subjected to shot peening, utilizing conventional, manually-operated air blast equipment. Air pressures of 25, 35, 50, 70, and 90 psi and shot sizes of 0.023-0.033 and 0.047-0.055 inch were used. The shot was screened through U. S. standard sieves before tests were run to insure accurate sizes. Test strips were peened ½ minute, 1 minute, and 2 minutes with the air pressures and shot sizes mentioned. The shot peening nozzle was held 3½ inches from the test piece and perpendicular to the surface peened.

These peened test pieces were annealed at 1250 °F (675 °C) for 2½ hours in a neutral salt bath. Under these conditions the cold-worked metal was subjected to recrystallization and grain growth,

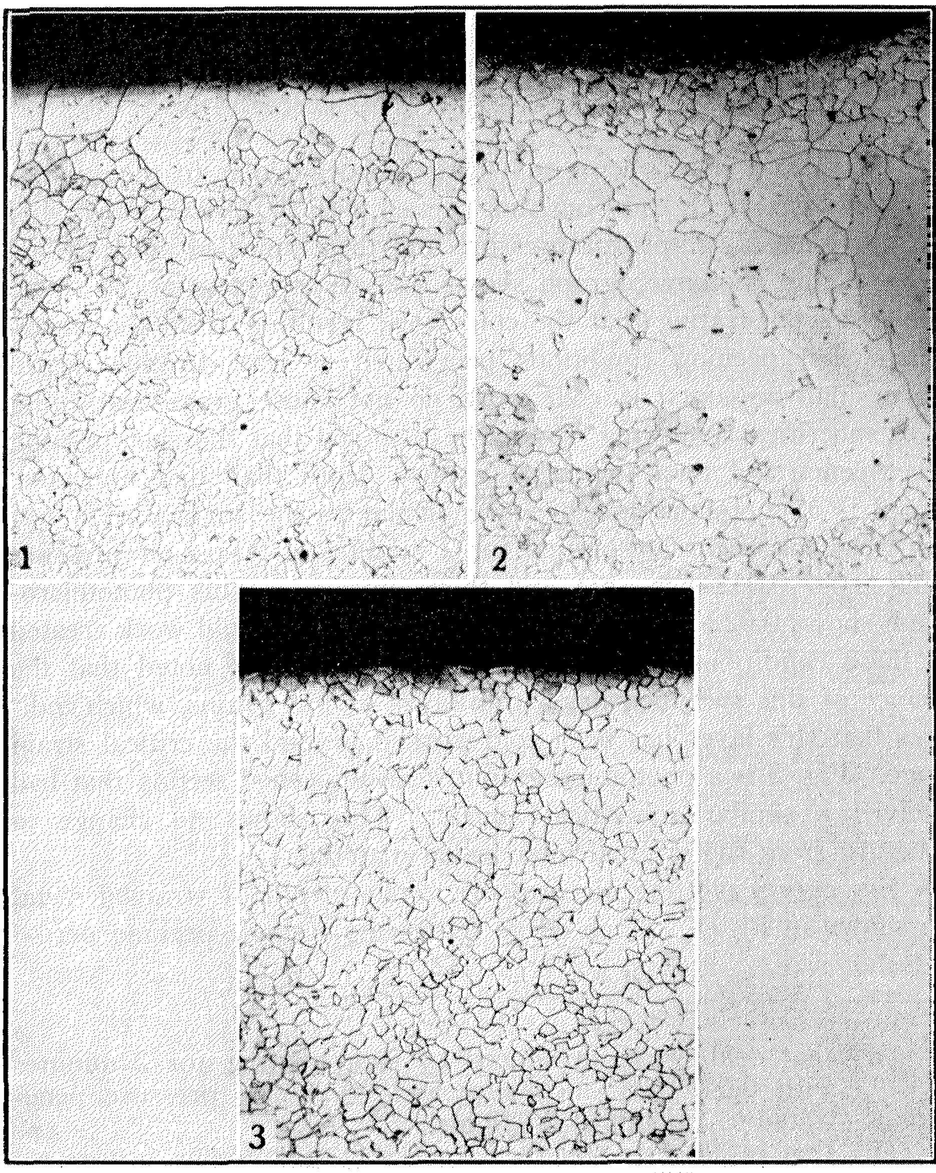

Fig. 1—Photomicrograph Taken Perpendicular to the Surface of the Test Strip Shot-Peened ½ Minute at 25-psi Air Pressure. Shot size 0.023-0.033 inch. × 100. 3% nital etch.

Fig. 2—Photomicrograph Taken Perpendicular to the Surface of the Test Strip Shot-Peened 2 Minutes at 90-psi Air Pressure. Shot size 0.047-0.055 inch. × 100. 3% nital etch.

Fig. 3—Photomicrograph of an Unpeened Section of the Surface of the Test Strip That Had Received a Subcritical Anneal. × 100. 3% nital etch.

and the structural difference from the original was distinctly discernible by microscopic examination. Measurement of the layer of changed structure afforded a method of determining the depth of critical strain. (An annealing temperature of 1050 °F (565 °C) was tried, but at this temperature the resultant grains were smaller than the original and not as easy to measure.) The microsections for observation were cross sections taken from the center of each test strip.

Fig. 1 is a photomicrograph taken perpendicular to the surface of a test strip which had been shot-peened with 0.023-0.033-inch shot for ½ minute at 25-psi air pressure and then annealed as described above. This photomicrograph shows a layer of coarse grains 0.005 inch deep, illustrating that the cold work resulting from these particular shot peening conditions penetrated at least to this depth. Since small amounts of cold work do not cause grain coarsening upon subcritical annealing, it may be assumed that the shot peening effect penetrated to a somewhat greater depth than that indicated. Fig. 2 is a photomicrograph perpendicular to the surface of a test strip that had been shot-peened for 2 minutes at 90-psi air pressure using 0.047-0.055-inch shot and then annealed. This photomicrograph shows 0.022-inch recrystallization due to the cold work created by these conditions of shot peening. It should be noted that the surface of this specimen has a thin layer of fine grains, which indicates that this layer has been cold-worked beyond the critical strain range. Fig. 3 is a photomicrograph of an unpeened section that had received a similar subcritical anneal. This shows no change in structure from the original unannealed material.

Six curves plotting air pressure versus depth of strained metal are shown in Fig. 4. Each curve represents a single peening period and shot size.

These data show:

(a) that cold work introduced by shot peening for 2 minutes with 0.047-0.055-inch shot and 90-psi air pressure penetrated to a depth of 0.022 inch
(b) that in all tests run the larger shot size (other factors remaining constant) caused a deeper penetration of strained metal than the smaller shot size
(c) that as the air pressure (velocity of shot) was increased, the depth of strained metal increased
(d) that, in general, the depth of penetration of the cold work was increased with increased peening time.

Another series of tests was run to determine the effect of extended peening time on the depth of cold-worked layer. Using 70-psi air pressure and 0.023-0.033-inch shot, test pieces were peened 1, 2, 5, and 10 minutes. The thickness of these specimens was measured before and after peening and found to remain constant for 1, 2, and 5 minutes of peening time; but after 10 minutes of peening 0.004 inch had been removed from the surface of the test piece. Consequently, the depth of penetration for the 10-minute peening time test was not considered entirely valid. These test pieces were

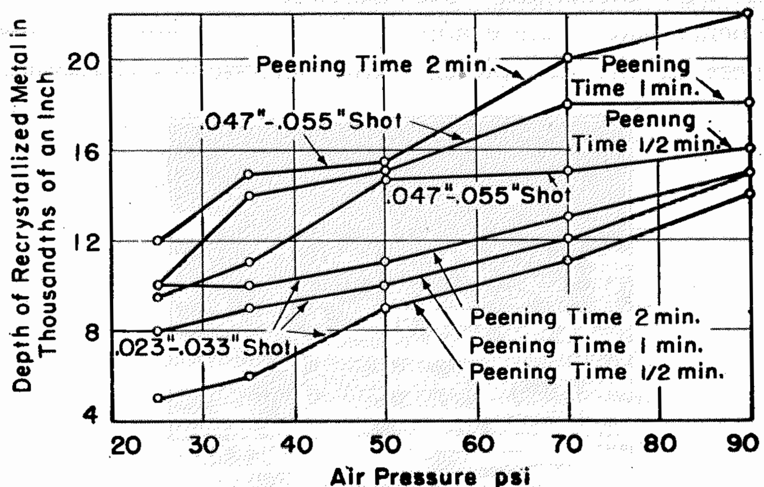

Fig. 4—Air Pressure Versus Depth of Recrystallized Metal for Shot Sizes and Peening Times Indicated.

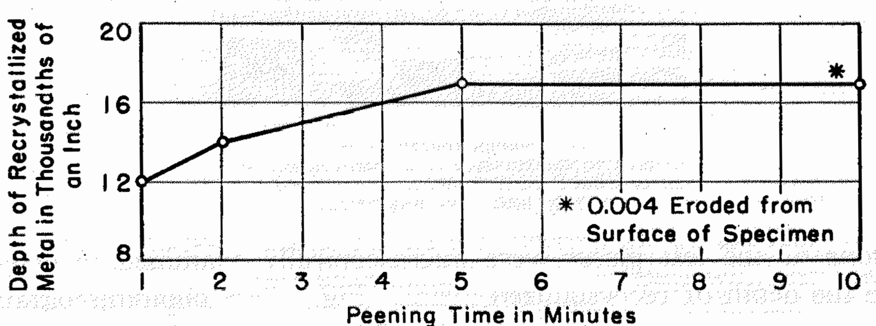

Fig. 5—Air Pressure Versus Depth of Recrystallized Metal. Air pressure 70 psi. Shot size 0.023-0.033 inch.

annealed as previously described and cross sections microscopically examined to determine the depth of recrystallized metal. Results obtained from this series of tests are plotted in Fig. 5. These data show that for this set of peening conditions the depth of penetration of the cold-worked layer increased with peening time up to 5 minutes.

Further tests showed that erosion of the test pieces caused by shot peening at high air pressures for extended peening times could be eliminated by a shallow hardened carburized case. Test pieces were carburized at 1650 °F (900 °C), pot-cooled, reheated to 1425 °F (775 °C) and quenched in water. Microscopic examination showed 0.007-0.010 inch total case depth, 0.005 inch hardened case depth, and a core of equiaxed polyhedral grains. These test strips were shot-peened under the following conditions: air pressure—90 psi; shot size—0.047-0.055 inch; peening times—2, 5, and 10 minutes. Measurements taken before and after peening showed no decrease in thickness of the test piece. After subcritical annealing, cross

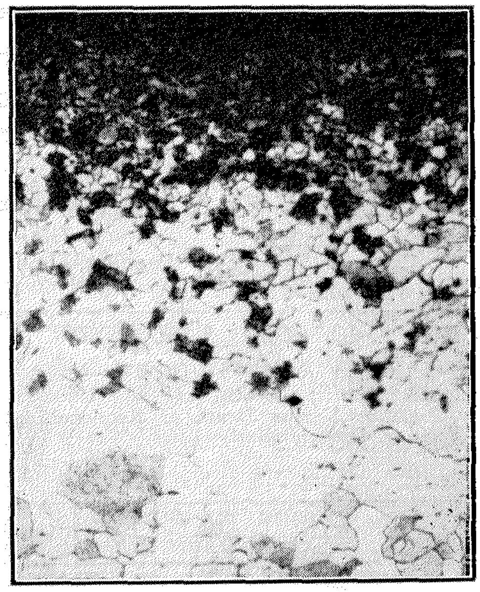

Fig. 6—Photomicrograph Taken Perpendicular to the Surface of a Carburized Test Strip Shot-Peened 5 Minutes at 90-psi Air Pressure. × 100. 3% nital etch.

sections of the test pieces were microscopically examined to determine the depth of recrystallized metal. Fig. 6 is a photomicrograph taken perpendicular to the surface of a test piece which had been shot-peened with 0.047-0.055-inch shot for 5 minutes at 90-psi air pressure. This photomicrograph shows that the cold work of peening penetrated to a depth of at least 0.023 inch. Results of this series of tests are plotted in Fig. 7. These data show that for this set of peening conditions the depth of penetration of the cold work increased with peening times up to 10 minutes.

The expedient of measuring the arc height of a hard, high carbon test strip as a control means for shot peening may not always be applicable. Conceivably, for example, on heat treated parts of medium hardness it might be desirable to use a peening intensity insufficient to affect such a strip. A low carbon test specimen treated and examined according to the method described herein would give the required information for these conditions.

Another obvious advantage inherent in low carbon steel test specimens is the possibility of closely simulating the parts to be peened in such features as radii, flanges, or other shape characteristics

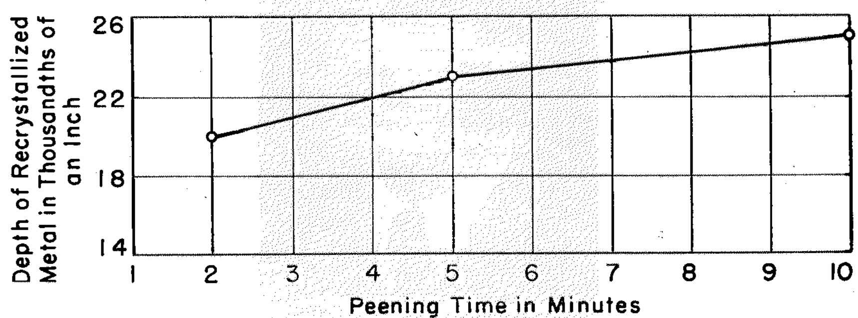

Fig. 7—Air Pressure Versus Depth of Recrystallized Metal. Air Pressure 90 psi. Shot size 0.047-0.055 inch.

as may affect the peening operation. These could then be advantageously used to determine satisfactory shot size, nozzle positioning, and angle of shot impingement, and as control pieces for maintaining the optimum shot peening conditions thus determined.

The shot peening of coil springs (such as valve springs) offers an illustration of where these could be helpful. A flat, hard test piece cannot give an indication of the efficacy of shot peening on the inside of the coils. However, a coil identical in dimensions to the springs to be shot-peened, made of low carbon wire and normalized to remove coiling stresses, can be put through the actual shot peening operation. Subsequent examination, in accordance with the method herein described, would then indicate the effectiveness of shot peening in any surface locations in the coil.

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