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Increasing Endurance of Magnesium Castings by Surface Work

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COLD WORKING the surface of metals to improve fatigue strength has been an intriguing subject of study for 25 years, and in the last ten, such treatments have become a common manufacturing operation among steel users. They have extended the life and usefulness of many parts. Automobile springs and gears, railroad axles, and other steel articles highly stressed by alternating loads, are shot-peened or surface rolled as a common practice. Typical results for peening S.A.E. 1020 steel are quoted by H. F. Moore which show that shot peening increased the life of test specimens in reversed bending by as much as 100-fold for stress levels above 37,000 psi. Increase in the allowable working stress, due to the shot peening, was found to be of the order of 33% for the steel studied.

Until recently such strengthening treatments have not been practiced successfully on light metals to any significant extent. A possible exception to this may be the experience of George Sachs who applied a surface-rolling treatment to the hubs of magnesium propellers in Germany in the 1930's. According to his description in *Metals and Alloys* for January 1939, a cluster of three small rolls with $\frac{1}{16}$-in. working faces were forced against the rotating part at a pressure of about 150 lb. It appears that Sachs partially counteracted erosion and high stress concentration effects in the propeller hubs and, thereby, improved the fatigue life of the hubs 80 to 200%.

Other experience with magnesium has included shot-peening treatments of the type used for steel in a collaborative project between J. O. Almen of General Motors Corp. and The Dow Chemical Co.* Treated test pieces were tested in rotating-beam fatigue machines. The results are shown in Fig. 1. In these experiments the peened test pieces have fatigue strengths as much as 60% below the polished pieces, which is in great contrast to the beneficial effects on steel.

Machined, as well as machined-and-polished, test pieces were surface rolled in the General Motors laboratories and tested in the Dow laboratories. These showed that fatigue properties of the machined, polished, and rolled pieces were 10 to 15% higher than for the machined and polished specimens. Surface-rolling the machined (unpolished) pieces gave results practically identical to those from machined and polished surfaces.

From the foregoing experiments, it is evident that magnesium does not respond to conventional shot peening in the same way as steel. Consequently efforts were made to determine why, and to evolve treatments suitable for magnesium. These have been described very briefly in an article by the present author in *Metal Progress* for December 1949, p. 838.

Theory — There are three conceivable ways by which mechanical surface treatments can improve fatigue properties, acting singly or in combination. One is by inducing residual compressive stresses which counteract the tensile stresses applied in service, thereby lowering the net stress in the vulnerable surface regions. The second is by favorably altering the surface layers so that sources of stress concentration on and near the surface are rendered less effective. The third is by work hardening (and thereby strengthening) the cold worked surface layers.

Irrespective of the relative importance of each of these factors, there are certain requirements in the metallographic structure that must be met if the fatigue properties of magnesium are to be improved: The surface layers must be free of incipient cracks and flaws; they must be continuous, metallurgically, without intersecting porosity or other voids.

A photomicrograph is shown in Fig. 2, normal to the surface of a cast magnesium test piece which was shot-peened according to steel

*R. L. Mattson and J. O. Almen, "Effect of Shot Peening on the Physical Properties of Steel", Final Report, Part II, O.S.R.D. No. 4820, National Defense Committee of O.S.R.D., War Metallurgy Division, 1945.

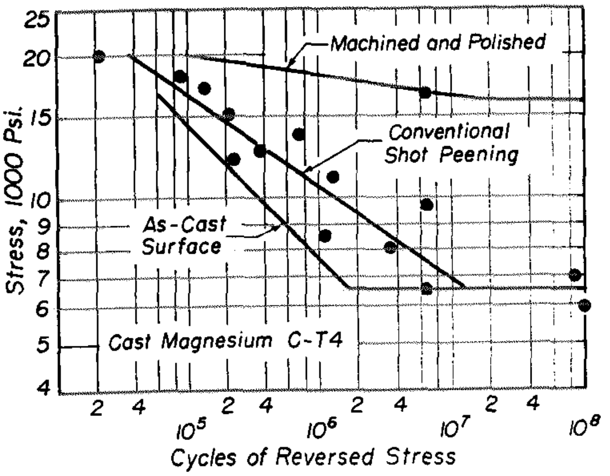


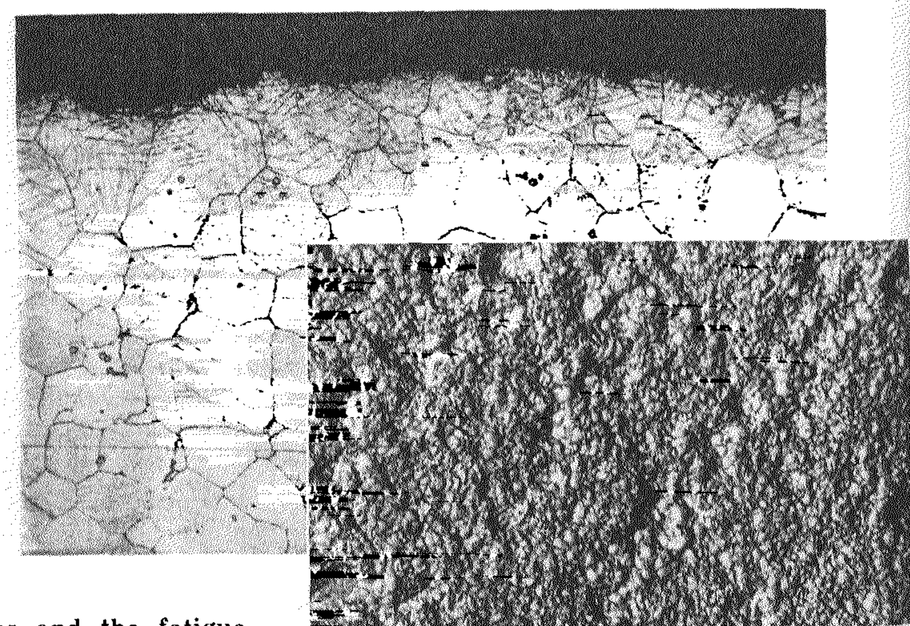
Fig. 1 — Fatigue Tests in R. R. Moore Machine of Cast C-T4 Magnesium Alloy Test Pieces in Three Different Surface Conditions. (Mattson and Almen.) Plotted points are for peened specimens only. *Peening conditions*: 0.011-in. arc height, 0.018-in. shot. Nominal composition of alloy is 9% Al, 2% Zn, 0.1% Mn, balance Mg

gravity while dropping 24 to 48 ft., were found to work the surface layers intensely to depths of 0.030 in. and more. The surface layers were not cracked. Results are shown in Fig. 3. The shot used are over 12 times the diameter and 1600 times the mass of the shot used for steel. The basic nature of the cast surface is eradicated, yet it is not pitted.

Plate-bending fatigue tests have been performed on specimens of the type shown in Fig. 3e on p. 120 of "Metals Handbook" (1948 Edition). (Plate-bending fatigue tests show the closest correspondence of all the standard laboratory tests to service results of magnesium.) Results are assembled in Fig. 4.

Various surface finishes for cast H-T4 alloy are represented. Peening with large shot strengthens the metal to a superior degree. Of particular note is the similarity of fatigue curves

Fig. 2 (below) — Section at 50 ×, Normal to Cast H-T4 Alloy Panel, and Surface at 6 ×, Shot Blasted With 0.016-In. Shot. Intense cold worked layer only 0.003 to 0.005 in. deep, associated with cracks and flakes. Nominal composition of alloy: 6% Al, 3% Zn, 0.2% Mn, balance Mg



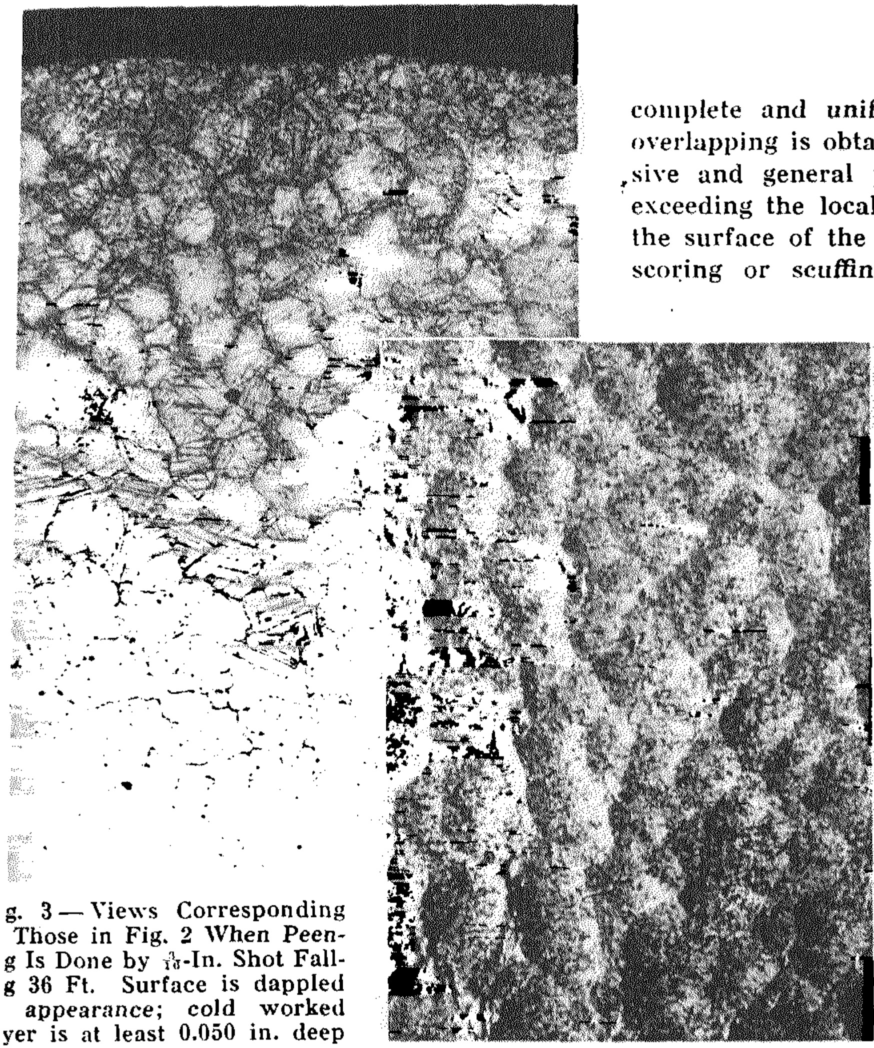
practice — that is, with high-velocity, small-diameter shot. The depth of visible surface working is 0.003 in. The surface exhibits irregular contours, surface cracking and spalling. Figure 2 also shows the pock-marked or pitted condition. The surface has deteriorated instead of strengthened; the surface layers have been overworked or deformed beyond their ability to absorb energy (as evidenced by the local incipient failures), and yet the amount of energy applied to the surface is small, as indicated by the shallow surface working.

From these observations and the fatigue tests plotted in Fig. 1, it was concluded that beneficial treatments must prevent surface deterioration and yet retain relatively high applied-impact or surface-working forces. Experiments were therefore conducted to determine if the *conventional* peening treatments could be altered.

Various kinds of shot were tried, including glass and plastic, but without avail. Heating the shot and warming the surfaces of the metal also gave no success. A practical solution was obtained by a technique involving high forces but without the high-velocity impacts: Hardened steel shot, large in diameter, accelerated by

after $\frac{3}{16}$-in. shot peening, whether the surface was previously machined or as-cast. This suggests that a saturation is reached for this *type* of surface-working beyond which it is difficult to improve without basic change in method. Also of interest is the finding that polishing does not improve fatigue properties.

Other methods for inducing the same beneficial surface by techniques which might be more suitable for certain production operations were also studied. A rubbing or burnishing technique was evolved which complements the



g. 3 — Views Corresponding Those in Fig. 2 When Peening Is Done by $\frac{1}{16}$-In. Shot Falling 36 Ft. Surface is dappled appearance; cold worked yer is at least 0.050 in. deep

ɜening treatment; it seems quite suited to ıachined surfaces, while shot peening can be sed on unfinished or as-cast surfaces.

Surface rubbing cold works or induces nergy into the surface of the metal. Surface racks and other flaws are not formed under roper treatment. Cold work of metal at the urface is deep and intense.

TOOLS FOR THE OPERATION

A spherically tipped tool is used, designed or mounting either in a fixed or in a spring-oaded position in a tool stock. Dimensions of he tool tip are determined within limits by the :ontour of the work, and are between 1/8 and 1 in. diameter. If the tool is in a fixed or spring mounting, it is loaded enough to depress it into the work between 0.004 and 0.015 in. beyond touch contact. The tool is then traversed across the work in a shaper or lathe. The speed of translation of the tool, within the limits of recommended machining practice for magnesium alloys, seems to have an undetectable effect on the results. Traverse of the tool across the work is maintained around 0.006 in. per stroke, so complete and uniform coverage and a slight overlapping is obtained. In order to get intensive and general plastic deformation without exceeding the local yield or shear strengths at the surface of the metal, thus causing tearing, scoring or scuffing, a relatively heavy-grade machine oil lubricates the working surface. A hardened steel ball, obtained from a bearing manufacturer, mounted in a tool shank as shown in Fig. 6 (page 54) has been found most suitable. Flats worn on the rubbing surface of the ball can be easily rotated away from the point of contact at periodic intervals.

Close visual inspection of the resulting surface is one way to control the variables involved in this treatment. The surface must finish bright without laps, tears, or discontinuities. Furthermore, there must be complete and uniform working without grossly defined ridges. A typical example is shown in Fig. 5, on the next page, representing one of the cast panels tested for bending fatigue.

A photomicrograph through a section after this treatment had been applied is also shown in Fig. 5. It will be noted that the surface is flawless and that a zone of intense working

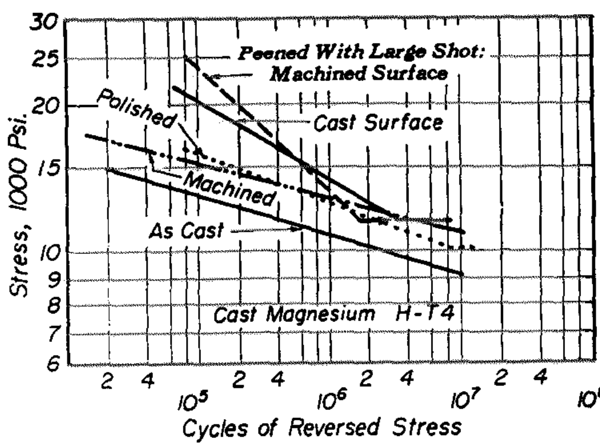
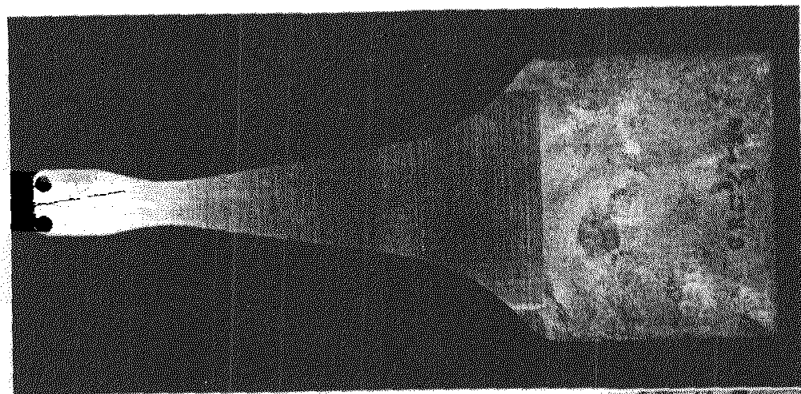


Fig. 4 — Endurance Limit of As-Cast H-T4 Panels Is 8000 Psi. but After Machining and Polishing It Is 10,000. If cast or machined surface is peened with $\frac{1}{16}$-in. shot falling 36 ft. the endurance limit is 12,000 psi. (top two lines)



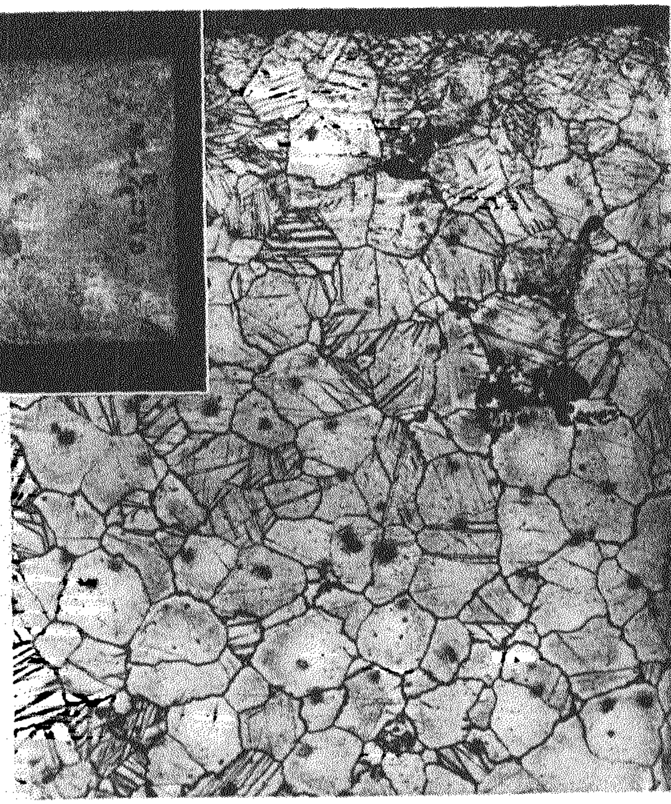


Fig. 5 — Cast H-T4 Which Has Been Ball Burnished, Cold Working 0.030-In. Surface Layer Heavily Without Causing Flaws. Acetic picral etch, magnified 50 ×. Panel is half size, being 7½ in. long

exists to a depth of 0.030 in. and fades out at about 0.080 in.

Panels of the type shown in Fig. 5 were tested in fatigue, with results shown in Fig. 7. For purposes of comparison, our best results from surface rolling are shown. (This selection is similar to that used by Sachs; confirming other comparisons we have made, the compression by surface rolling does not develop the fatigue properties induced by the combination of compression and rubbing or smearing by the hard steel ball.)

Summary — Fatigue tests run according to our best present methods of fatigue testing have shown that surface working as described improves fatigue properties quite significantly. Several hundred laboratory fatigue tests on standard commercial magnesium casting alloys have verified this statement.

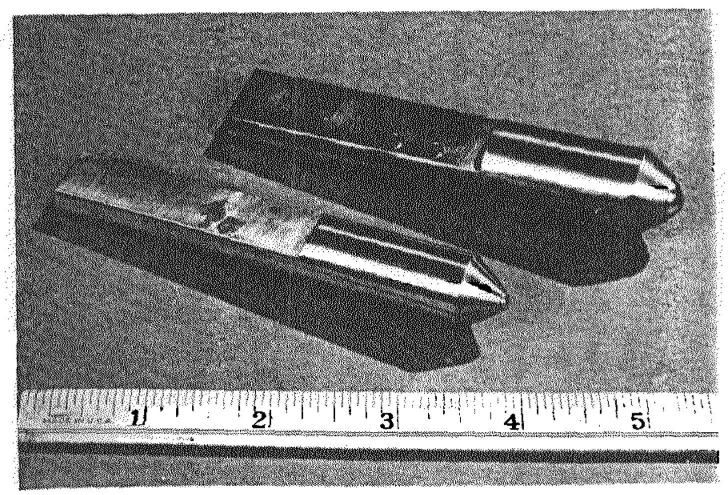


Fig. 6 — Basic Tool Design for Surface Rubbing

It is appreciated that the application of such treatments on a production basis frequently involves circumstances which are not included in the right degree in laboratory demonstrations. Such is undoubtedly true for the above treatments. Phenomenal improvements may be possible if optimum production methods can be developed. The experience of Bendix Aviation Corp. in applying these treatments, on a production basis, to aircraft wheels is a case in point, and will be described in a subsequent article by W. H. DuBois of that firm's staff.

Fig. 7 — S-N Fatigue Bands for Cast H-T4 Magnesium Alloy With Prepared Surfaces. Aggregated results from several hundred tests on a variety of commercial magnesium alloys and heat treatments indicate that alloy and heat treatment have no discernible influence on these tests