Shotpeening experiments show that this treatment increases stress corrosion of some nonferrous metals such as brass, aluminum and magnesium, in some cases showing an increase in life up to 40 times.

Shotpeening of Nonferrous Metals

by HAROLD A. KNIGHT, News Editor, MATERIALS & METHODS

MOST OF THE EXPERIMENTS and experience with shotpeening have involved ferrous metals, such peening proving effective where the part or component in service has to stand one or more of some half dozen kinds of stresses, such as fatigue. The effect of peening on nonferrous metals is perhaps less known and not so far advanced. In antiquity, however, the hand peening with a rounded hammer involved both types of metals—ferrous for making swords and hammered brass, and bronze for ornamental and utilitarian items.

During the war considerable experimental work with peening was organized by governmental technical services. Thus, in one cooperative project 135 separate industrial and research organizations worked. Probably about 10% of the materials experimented on were nonferrous metals.

In these studies consideration was given to material, hardness, intensity of peening, shot size, shot type and nature of the surface before peening. Besides peening, other pre-stressing processes were used such as surface rolling, hammer peening and pre-setting. Studies were also made of high temperature effects on pre-stressed specimens of certain super alloys.

Among the nonferrous metals, studies were chiefly in two categories: (1) effect of shotpeening on fatigue strength, and (2) on stress corrosion cracking. Other tests dealt with peening's effect on season cracking, crushing strength and static strength. In the first category experiments were conducted on aluminum, magnesium, nickel and various nickel alloys and on bronze. The loads applied involved one of the following: reverse bending, bending, rotating beam and service. On stress corrosion cracking, materials studied were magnesium and brass.

It is interesting to note that the "father" of modern shotpeening, H. F. Moore, research professor of engineering materials, emeritus, University of Illinois, started off his experiments as a boy with nonferrous metals. During high school days he spent spare time in electrical experiments in his attic. He needed some "spring brass." His friend, the local telegraph operator, advised him: "Take the brass back from a discarded thermometer, hammer it all over with a round nose hammer and you will find that it becomes springy and holds its shape no matter how much it vibrates."

Fatigue Durability Tests

Some fatigue durability tests gave the following results: Peening improved duralumin by 16%; mag-
Stress Corrosion Resistance

The photographs and typed-in captions are self-explanatory in showing the effect of peening on J-1H alloy in resisting stress corrosion.

The experimenters favor peen both inside and outside except the tapped hole at the top and clamping surface of the flange. Threads were cold-rolled with a special tool. Two domes were bolted together to form an assembled accumulator. Then cyclic hydraulic pressure was applied, 90 cycles per min. A non-peened dome failed at 89,200 cycles; a peened, at 121,000. The experimenters were evidently conservative when they said: "The limited data indicate that the component may be improved by peening."

An experiment with General Electric Co. reported that shotpeening was beneficially applied to a machine part (a phosphor bronze brake armature support diaphragm) as thin as 0.008 to 0.010 in. The shot used was commercial malleable iron, 0.016 to 0.019 in. dia. The shotpeening intensity was too low to measure with standard apparatus. Coverage was considered ample as judged by visual examination. The part, shaped somewhat like a quarter moon, but actually a strip ¼-in. wide, was peened all over. Under the blast it was manipulated by hand. A compressed air type of machine was used. The test or load consisted of laboratory bending fatigue. The part was assembled in its normal brake mechanism. A.c. current was passed through the brake coil giving a magnetically applied oscillating load at the rate of 60 cycles per sec.

These tests are particularly interesting because of the relatively large number of cycles to failure. Durability of the phosphor bronze diaphragms is increased by peening. Also, in the non-peened condition diaphragms of beryllium bronze are shown to be superior to those of phosphor bronze.

Actual results were expressed by the experimenter in graph form. Four specimens of phosphor bronze, non-peened, were found failed at the first examination. Three other non-peened samples had undergone around 150 million cycles before failure. However, six specimens of peened samples were still going strong at 500 million cycles. (Six non-peened beryllium bronze specimens did equally well.)

Another case history involves a nose wheel torque collar of aluminum alloy. Critical areas and fillets were peened (the internal bearing surfaces and tapped holes being masked). The test or load was a laboratory fatigue similar to that given in service, applied pneumatically. The average durability of two shot-peened collars was 150% greater than those not peened.

Stress Corrosion Resistance

An important purpose of shotpeening nonferrous materials is to extend stress corrosion resistance. Thus, in cold drawn brass (copper 68.6; zinc 31.3) cups, 1/32 in. thick, and exposed after peening to an ammonia atmosphere, the time before cracking was extended to 23 hr. from 2 1/2 hr. for non-peened brass, for one specimen and to 100 hr. for another. It might seem that in the case of a formed or semi-formed part it is best to shotpeen both inside and outside. This observation was made with a 70-30 cartridge brass cup, 0.040 in. thick wall, 1 7/8 in. dia. and 1 3/8 in. high, tested for stress corrosion cracking. The test piece was a drawn, unannealed cup. It was treated for testing with a 1% mercurous nitrate solution containing 1% concentrated nitric acid.

The experimenters reported that cup life, when peened with shot or grit on both inside and outside, is "much greater" than for non-peened cups. Peening outside only or inside only usually made for some increased life. In such cases of outside-inside peening, the degree of peening is important. Thus, where too high intensity was given on outside-only peening, conditions made for early failure at an inner surface because of high residual tension stress in the inside.
face layers imparted by peening. Where lower intensity was observed in the peening there was a slight gain in life because of more favorable distribution of internal stresses.

In another case where the brass cup was subjected to ammonia atmosphere, generated by 100 cc. of 75% ammonia hydroxide solution (by volume), the stress corrosion cracking life increased many times by peening both outside and inside surfaces.

In the case of a large brass cartridge case the experimenter observed that stress corrosion cracking was more effectively decreased by large shot at high intensity than by small shot at lower intensity.

As an antidote to stress corrosion cracking 52 SH magnesium alloy, peened with glass beads, showed no cracking at the end of 12 days, though unpeened it lasted 2½ min. Magnesium alloy (AMC-57 SH) test strips, when stressed and exposed to potassium chromate and sodium chloride, failed in 120 sec.; when peened, they lasted 10 days with no cracking or corrosion. J-7H magnesium alloy sheet failed in 9½ min.; when peened it lasted 430 hr.

Another interesting series of experiments was conducted on Dow J-1H magnesium alloy sheet since this material is highly susceptible to stress corrosion in the as-received condition. Specimens were prepared from sheet, 0.064 in. thick. Strips 1 by 10 in. and 1 by 9 in. were stressed by bending into arcs with 8½-in. chords and held in this position during testing. The different length of specimens provided 2 deg. of stress for observation of the effect produced by this variable.

Stress corrosion was applied in the following manner. An 8-hr. cycle was used in which samples were immersed for 4 hr. in tap water, then dried for 4 hr., the duration of the corrosion test being 30 days.

In Group A, six samples each of 10-in. and 9-in. strips were bent into arcs, then peened full length on the outside surface. After 30 days all samples were intact, with neither failures nor cracks.

In Group B three samples each of 10-in. and 9-in. strips were peened one-half their length on both surfaces, then bent into arcs. All failed in the unpeened portion after one day of the test.

In Group C three samples each of 10- and 9-in. strips were peened one-half their length on the outside surface only, then bent into arcs. The 10-in. strips failed after one day of test; the 9-in. strips failed after four days—all in the unpeened sections.

In Group D, six samples each of 10- and 9-in. strips were not peened and bent into arcs, forming 8½-in. chords. As to the 10-in. specimens, one failed after one day, the remaining, after four days. Of the 9-in. strips, one failed in 4 days, the rest failing at intervals, all being broken after 13 days.

The conclusion of the experimenters with this J-1H magnesium alloy sheet is, that shot peening, especially following forming, decreases to a marked degree the tendency of this alloy to corrode under stress.

Other experiments involved the influence of shot peening on season cracking of brass. A non-peened brass cup failed in 2½ hr. in an ammonia atmosphere, whereas a lightly peened specimen was undamaged after 10 hr. exposure.

Other Applications for Peening

An interesting application has been to cure porosity in aluminum die castings subjected to pneumatic or hydraulic pressures. In the case of one part leakage was reduced from 50% of all parts made to 20%; in another case from 16% formerly to 4% after peening. One maker of such die castings shotpeened both sides of the casting in a rotary-type, multi-table machine. As a result 90% of the castings had no leakage, while 10% had only slight seepage.

The International Nickel Co. is experimenting with shotpeening of various nickel alloys. A novel use of peening is testing the silver adhesion to silver plated steel bearings as practiced at Pratt & Whitney Aircraft. The hammering action of the shot produces deformation of the silver. If the silver is poorly bonded it will extend and flow and become blistered. Several makers of aluminum cooking utensils have shotpeened for decorative purposes and also to resist corrosion pitting.

Types of Shot Used

The most commonly used shot for peening is commercial chilled iron, with hardness of 800 to 900 Vickers, used chiefly on hardened work. A softer, but tougher, shot is heat-treated cast iron. Considerable progress has been made in developing steel shot, capable of withstanding the peening action more effectively than cast iron.

Pratt & Whitney Aircraft have found that the conventional chilled iron often becomes embedded in soft metals such as aluminum. Hence a softer shot, "Mall abrasive." Others have found that when shot, particles become embedded, one may immerse the peened metal in hydrofluoric, nitric or chromic, then hydrofluoric—thus effectively removing the particles.

In fact, some go as far as to advise against ferrous
Those Who Did Research

Prominent among the 135 organizations cooperating in war research on nonferrous metals were the following: Battelle Memorial Institute, Lockheed Aircraft, International Nickel Co., Douglas Aircraft, Consolidated Vultee Aircraft, Dow Chemical Co., Pratt & Whitney Aircraft, General Electric Co., Aluminum Co. of America, General Motors Research, Rensselaer Polytechnic Institute, the Navy Dept., and the Springfield Armory.

Most of the case histories mentioned in this article are from war time research under auspices of the Office of Scientific Research & Development (OSRD). Copies of these researches are now obtainable in form of photostats or microfilm from the Office of Technical Services, Department of Commerce, Washington 25. There are three reports identified: (1) (19515) OSRD 3274; (2) (31211) OSRD 6647, and (31211) OSRD 4825. These reports consist of text, photographs, tables and graphs.

Observations and Comments

J. O. Almen, head, mechanical engineering, Research Laboratories Div., General Motors Corp., told us recently that there are apparently no important additions to make to the data accumulated during the war on the gains in fatigue strength by prestressing insofar as nonferrous materials are concerned.

The theory of peening, of course, is that each shot acts as a tiny peen hammer, making a small dent in the surface of the metal and stretching the surface radially as it hits. There results a plastic flow of the surface fibers beyond their yield point in tension, in a layer that extends 0.005 to 0.010 in. below the surface. The fibers underneath are not stretched to their yield point and retain their elasticity. The two outer layers are subjected to a compressive stress, the outer ones to a shorter length than they would tend to remain. In the equilibrium which results, the surface fibers are in residual compression, while the inner ones are in tension.

Surface compression stress is several times greater than the tensile stress in the interior so that when working stresses are applied tending to impose a tension stress, that tension is offset by the residual stress in the surface layer. Fatigue failures generally result from tension stresses.

In applying this theory to certain nonferrous metals, Mr. Almen and his co-experimenters find that the gain in fatigue strength from peening is dependent on the ability of the specimens to retain the residual stresses that have been induced. When these pre-stresses are lost, shotpeening is usually harmful because all that remains is the roughened and fractured surface produced by peening.

It is for this reason that the rotating beam and similar reversed stress fatigue tests are not capable of indicating the gains that may be expected in machine elements that are to be loaded in one direction only, whether in bending or in torsion. Under reversed-loading, the residual compressive stresses are readily lost by creep, whereas in one direction loading this loss is not serious.

Mr. Almen states further that magnesium does not readily support a continuous load and tends to relax or creep with time. We would, therefore, not expect magnesium to be so greatly influenced by residual stresses, since such stresses would be lost by creep.

An experiment at Massachusetts Institute of Technology, in explaining failure of peening to improve fatigue durability, suggested that perhaps the specimens were already compressively stressed near the surface due to heat treatment, hence peening could not add additional compressive stress.

Here are more cold-drawn brass (36.5-31.3) cups exposed to stress corrosion influences, revealing details on peening intensity. Among details are inner and outer surfaces, at what part of the cup the peening was directed, exposure period before cracking, and location of the crack, if any. (As to intensity, 0.003 A2 means: Height of arc, resulting on test strip from peening one side, is 0.003 in. The "A2" specifies type of Almen test strip used, the alternate being left out.)

<table>
<thead>
<tr>
<th>SPECIMEN NO.</th>
<th>PEENING INTENSITY</th>
<th>EXPOSURE TIME BEFORE CRACKING</th>
<th>LOCATION OF CRACK</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.003 A2 all over</td>
<td>2 1/2 hours</td>
<td>SIDE</td>
</tr>
<tr>
<td>6</td>
<td>0.003 A2 all over</td>
<td>2 1/2 hours</td>
<td>SIDE</td>
</tr>
<tr>
<td>7</td>
<td>0.003 A2 all over</td>
<td>8 1/4 hours</td>
<td>SIDE</td>
</tr>
<tr>
<td>8</td>
<td>0.003 A2 all over</td>
<td>13 hours</td>
<td>SIDE</td>
</tr>
<tr>
<td>9</td>
<td>0.003 A2 all over</td>
<td>22 1/4 hours</td>
<td>SIDE</td>
</tr>
<tr>
<td>10</td>
<td>0.003 A2 all over</td>
<td>7 3/4 hours</td>
<td>BOTTOM</td>
</tr>
<tr>
<td>11</td>
<td>0.003 A2 all over</td>
<td>7 3/4 hours</td>
<td>BOTTOM, SIDE</td>
</tr>
<tr>
<td>12</td>
<td>0.003 A2 all over</td>
<td>13 hours</td>
<td>SIDE</td>
</tr>
<tr>
<td>13</td>
<td>0.003 A2 all over</td>
<td>50 hours, NO CRACK</td>
<td>NONE</td>
</tr>
<tr>
<td>14</td>
<td>0.003 A2 all over</td>
<td>50 hours, NO CRACK</td>
<td>NONE</td>
</tr>
<tr>
<td>15</td>
<td>0.003 A2 all over</td>
<td>23 hours</td>
<td>SIDE</td>
</tr>
<tr>
<td>16</td>
<td>0.003 A2 all over</td>
<td>48 hours, NO CRACK</td>
<td>NONE</td>
</tr>
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</table>

Note: Commercial malleable iron shot used on Specimens No. 5 through 14. Commercial chilled iron shot used on Specimens No. 15 through 18.