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SHOT

Effect of Shot Type On Spring Fatigue Life

These articles are based on papers presented by Zimmerli and Straub at a recent meeting of the Shot Peening Division of the SAE Iron and Steel Technical Committee. The test results here interpreted are helping the SAE group in its quest for knowledge to get more out

THIS investigation was undertaken to find out how various shot hardness will affect the endurance life. As a matter of interest, attempts were made to determine the possibility of overpeening springs even using shot known to be large for the wire size in the spring.

On all tests Almen strips were included with the springs. If correlation of the Almen arc height and spring life were possible, the tests run would establish this fact.

Six different lots of shot were used. These included one lot of P-46, one of P-28, and four of P-16. Of the P-16, one was steel, two were heat treated white cast iron, and one was white cast iron as were the P-46 and P-28. Physical and chemical tests were run on all of these types of shot.

The springs were all from one coil of oil tempered valve spring wire. They were coiled, heated, ground and processed at the same time so as to insure a consistently uniform test specimen.

From the test results we drew the following conclusions:

1. Throughout the range of hardness tested in the shot there was no significant effect on the ultimate endurance limit of the springs.
2. The size of shot did not affect the endurance limits within certain limitations; for instance, P-16 or P-28 shot gave comparable results. Shot P-46 on the 0.148 in. wire employed in the springs lowered the endurance limit.
3. These springs can be overpeened with the coarse P-46 shot. This was impossible under the same conditions with P-16 shot.
4. There is no relationship between arc height and endurance limit.
5. From breakdown tests it appears that shot life is inversely proportional to the hardness of the shot.
6. The smooth nonpeened appearance of samples using steel or soft shot will cause a departure from the usual inspection methods for peening.

Fatigue Tests

After shot peening all fatigue machine springs were heated to 450 F for one-half hour. Then they were placed in the fatigue machine in sets of eight at such stress ranges that we could determine

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Table 1—Endurance Limits of Springs for Various Periods of Shot Peening

Shot	Material	Hardness	Time of Shot Peening 15 min	15 min	30 min	120 min
P-46	White Cast Iron	Rockwell 65 C	less than 20,000-115,000	16,750-106,200	11,700-110,500	11,700-110,500
P-28	White Cast Iron	Rockwell 63 C	14,200-123,600	3,300-110,000	12,600-120,000	10,930-113,750
P-16 Lot 100	Steel	Rockwell 34 C	13,500-116,000	10,750-118,200	16,000-115,000	over 12,750-120,500
P-16 Lot 101	Heat-treated White Cast Iron	Rockwell 62 C	11,500-122,500	10,000-117,500	10,000-127,500	11,100-120,250
P-16 Lot 102	Heat-treated White Cast Iron	Rockwell 48 C	12,300-123,750	10,750-125,800	13,000-120,500	11,000-119,200
P-16 Lot 103	Heat-treated White Cast Iron	Rockwell 26 C	16,000-122,500	12,200-120,000	10,750-118,000	11,000-121,000

Note: Endurance limit not shot peened 20,000-95,000.

By John Straub
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PEENING

Why Peening Calls For Uniform Shot

of shot peening.
Based on his test results, Zimmerli sees variation in shot hardness influencing very little the endurance life of a peened part. Straub strongly urges uniformity of shot size and weight and shows how it makes for more economical production peening.

I have long been enthusiastic about the importance of uniformity of shot size in a peening operation, particularly from the standpoint of removing broken shot from a peening machine as quickly as possible.

One of the most striking fatigue test comparisons is that in which specimens were peened with and without a high percentage of broken shot in the peening machine. This series of tests was run for the purpose of simulating the conditions which existed in a production peening machine. The production machine involved contained approximately 86% broken shot in the working material.

The following fatigue tests were made on flat specimens of 9260 steel, 40–45 RC with a thickness of $\frac{1}{4}$ in. and a width of $1\frac{1}{8}$ in. in the region of maximum stress. The tests were in simple bending, with a stress range of substantially zero to a maximum of 137,000 psi. The surface of the specimens was as-rolled on the side subected to tension stress.

One group of 10 fatigue specimens was peened to a very scant coverage as measured on a quantitative basis.

A second group of ten specimens was peened identically to the first group and was then peened under the same conditions with respect to wheel speed and conveyor speed, but with a blast which consisted of broken shot to the same size analysis as that found in the production machine. Since the working shot in the production machine consisted of one part whole shot and five parts broken shot, the fatigue specimens which had been peened with whole shot were then peened with five times as much broken shot.

The results of these tests are shown in Fig. 1, in which the fatigue life of each specimen is shown. The first group of specimens shown on the extreme left, represents non-peened specimens. The next group to the right represents those specimens peened with whole shot only, and the third group represents those specimens peened with whole and broken shot. Note that the fatigue life is practically unchanged by the addition of the blast with broken shot, despite the fact that the blast of

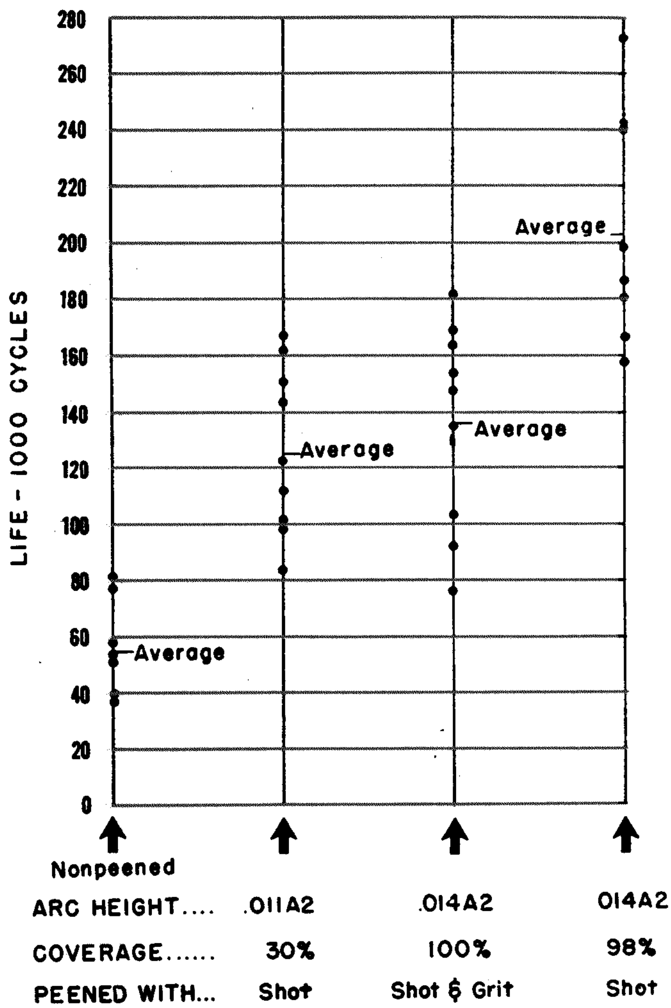

Fig. 1—Influence of broken shot on fatigue life

broken shot had increased the arc height from 0.011 A-2 to 0.014 A-2 and had increased the coverage from only 30% to well over 100%.

This work was done after an extensive series of tests had indicated that under similar conditions, with respect to blast uniformity, the fatigue life increases with increasing arc height up to 0.014 A-2 or greater. It had also been shown, previous to these tests, that under the same conditions with respect to blast uniformity, increased coverage resulted in increased life up to 100%.

Another group of specimens was then peened with whole shot to an arc height of 0.014 A-2 and 98% coverage. Note that the arc height and coverage in the last mentioned group are the same as those obtained with the mixture of whole and broken shot. The results of this group are plotted in Fig. 1, at the extreme right. Note that in this case, the fatigue life is definitely greater than that of the group peened with whole and broken shot, even though the arc height and coverage are the same.

Referring again to groups 2 and 3 in Fig. 1, it is apparent that the broken shot adds nothing to the fatigue life which was obtained with a relatively small quantity of whole shot.

For example, assume that the production peening machine, containing five parts of broken shot and one part whole shot, is operated with a flow rate of 300 lb per min to the wheel. Now assume that the broken shot is removed from the machine and that the flow rate to the wheel is decreased so that the amount of whole shot flowing through the wheel is the same as it was with the mixture, all other conditions being the same. This would mean that flow rate would be one-sixth of 300 lb per min, or 50 lb per min.

Under these conditions, the parts passing through the machine would represent an ideal case for rejection because of the fact that the coverage is only 30% and the arc height is less than 80% of the specified requirements. But in actual fact, those parts are just as good as those which were peened with the mixture, in spite of the vast differences in coverage and arc height. It requires very little imagination to realize the difference in cost between flowing 50 lb per min of whole shot versus 300 lb per min of whole and broken shot through the wheel.

I believe that these results show rather conclusively that broken shot in a peening machine is of utterly no value relative to the whole shot, even though the cost of the operation with a large proportion of broken shot is decidedly higher.

This does not imply that grit or broken shot of itself cannot be used to increase fatigue life. Increased fatigue life can be obtained by blasting with grit or broken shot. It does imply, however, that the broken shot is totally ineffective relative to the full-sized shot by virture of its reduced weight. In other words, the effect of broken shot is definitely not additive to the effect of whole shot in its relation to increased fatigue life.

Unfortunately, the influence of these factors on fatigue life and cost cannot be recognized without a comprehensive series of fatigue tests. It is a foregone conclusion that the end goal of shot peening is increased fatigue life at low cost. No matter how effective peening may be in increasing fatigue life, it will not be generally accepted unless the cost of the operation is sufficiently low that it will more than pay its own way.

I am more confident now than I ever was that peening can far more than pay its own way, provided the requirements of low cost are recognized. To my knowledge, the largest single factor controlling the ultimate costs of peening is uniformity of the intensity of the blast.

In analysis of what constitutes intensity of the blast, there are three major elements involved:

1—Velocity of the shot. This does not represent a serious problem from a uniformity standpoint. It is unlikely that in a peening operation the shot velocity, in a given blast, would be subject to much more than 10% variation.

2—Hardness of the shot. Uniformity in this case is not a serious problem. If the shot is harder than the work, any variation in shot hardness would have no more than a slight influence, if any, on results; if the elastic limit is not exceeded in peening, it makes little difference how nearly the elastic limit is approached.

3—Size and weight of the individual particle. Uniformity in this case, appears to be the greatest problem of the three. Actually, the present specifications for peening shot allow a variation in size of almost 20%. This does not include the allowance for oversized and undersized shot relative to the nominal size.

For equivalent fatigue life, peening with whole shot of uniform size is unquestionably more economical than peening with shot having a wide range of size. As mentioned, this is not always easy to demonstrate without comprehensive fatigue testing; but in cases where such tests can be made, the result is always the same.

To stabilize a peening machine, (to obtain a high percentage of whole shot in continuous operation), it is necessary to remove the broken shot continuously. If, in replacing the broken shot, the new shot which is added has a wide range of size, then in removing broken shot, the smaller size of the new shot will be removed from the machine without actually having been used in the peening operation.

Approaching the problem from another standpoint, assume that a shot is broken in half. The weight of each broken particle will then be half of that of the original pellet. This half would be equivalent in weight to a whole pellet whose diameter is the cube root of 0.5, or approximately 80% of the diameter of the original pellet. Therefore, it follows that whole shot, whose diameter is less than 80% of that of the large pellets, would be equivalent to broken shot and, would be of no value relative to the larger size.

On this basis, it appears that for peening, the range of shot size should be as close as practical to a range of from 100% to 80%. It is interesting to note that this tolerance is quite close to the present SAE specifications for peening shot.

Since uniformity of shot size appears to be such a vital factor in blast uniformity, I believe that every effort should be made to obtain peening shot with the minimum practicable variation in size.

Spring Fatigue Life

. . . . **Zimmerli**

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the highest range that the springs would withstand ten million loadings.

This machine consists of a double throw crankshaft to which, by means of connecting rods, a walking beam is attached. Upright rods to a header transmit the motion to springs mounted on a heavy beam which forms the top of the machine. The whole is driven by a variable speed electric motor. Magnetic relays stop the machine, should a spring break. A counter reduced 100 to 1 automatically records the number of spring compressions while the machine is running. The motor speed range of 1100 to 3300 rpm was carefully tested by means of a synchronized neon light to be sure no surge or other loading in the machine parts was present to change the calculated stress. For these tests a speed of 2000 rpm was used.

Our results to date are given in Table 1:

The stress ranges given as endurance limits are based on 10,000,000 cycles and have been corrected to allow for the set occurring in the springs during the test.

It will be noted that in one place we could only establish an endurance limit of less than a given figure while in another place we have given it as over a figure. In these instances we had insufficient springs to complete our tests.

The first thing to notice in Table 1 is that in every case the shot peening treatment has increased the endurance limit of the springs. For the lowest figures given we have increased the safe stress range 19.3%. For the highest endurance limit the increase in safe stress range is 56.7%.

It is at once apparent that the P-46 shot is too coarse for these springs. While it has increased the endurance limit over the springs which have not been shot peened, the values in the table are in almost every case lower than for any of the other shot. There would appear to be a tendency to over shot peen with this shot for long times of peening, but the differences are hardly more than the experimental error in our testing.

In the case of the P-28 shot we have a value for our 15 min run which appears low. Actually, for some reason we have not been able to determine, this was caused by the springs setting more than usual during the tests. The stress range is comparable to the other runs with the exception of the springs peened for two hours. The fact that this test is somewhat lower does not necessarily indicate much, because we have a ± 3000 psi possible machine and setup error. However, it might be well said that the springs are shot peened to the practical limit.

From our data on the various lots of P-16 shot, it does apear that we are obtaining endurance limits with it that are strictly comparable to P-28 shot. It would also indicate that there is practically no difference as far as the endurance limits obtained are concerned whether, within the limits of the hardness used, we use hard or soft shot.

If we refer to the arc heights (which we obtained during the various shot peening operations) and compare them with the endurance limits determined for the springs which were peened with the Almen strips, it is readily apparent that in an investigation of this type there is absolutely no correlation between arc height and endurance limit.

From our data there does not appear to be any tendency to over shot peen using the P-16 shot.

The depth of cold working with different size shot has not been completely worked out. If the larger shot does go deeper, then standards of shot size for various wire sizes should be considered. Also, peening hot wound springs with some ferrite the heavier shot then might be an advantage. It is hoped that this data by X-ray (or any other method) can be soon made available to all interested parties.

We know that the softer shot gives us lower maintenance of our equipment. Our tests here in 1939 and 1940, and reported to A.S.M. in 1941, showed equal fatigue life. These tests confirm the previous runs in that soft shot from an endurance point of view will produce results comparable with the hard shot. It is evident that an economy can be achieved using steel or a heat-treated cast-iron shot.

At present this will be hard to accomplish because (1) inspection departments and some metallurgists use visual means to say whether or not a part is properly shot peened, and (2) government and some company prints often carry an arc height as part of the peening outline. This will have no beneficial effect on the quality that will be received by these agencies but may well determine the kind of shot to be used.

Actually, such a specification could lower the quality of the peening. By adding a little oversize shot to the machine it is possible to raise the arc height quickly, but not the spring endurance limit which might go less than that anticipated.

After 60 days continuous running using soft shots on valve springs, we have some production figures which indicate to us:

(a) One lb of steel shot will equal 6 lb of white cast-iron shot.

(b) The steel shot cuts repairs to equipment by 50% minimum.

(c) Steel shot will not remove small burrs or similar grinding imperfections from springs. Springs appear bright and unpeened.

(d) So-called malleablized white cast iron carries enough white iron shot that breaks into grit to remove burrs in the samples tested.

(e) Routine fatigue tests on test springs run with valve springs over this period of time averaged slightly higher stress range with steel than when white cast iron shot was used on production work. Such springs were peened with P-28 shot 30 min with a 115-lb charge of automotive valve springs in the machine. This is average production data and should not be confused with the smaller number of springs in the machine when the experimental tests were run. It is simply given to show a trend.