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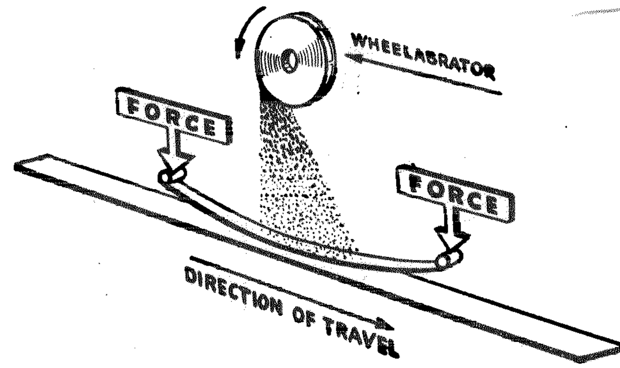
STRESS PEENING



• Schematic illustration of application of stress to spring while Wheelapeening.

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SHOT peening has been used extensively for increasing fatigue strength of machine parts. Since the beginning of the application of this process in production, a great deal of investigation has been devoted to determining the influence of factors responsible for the increase in fatigue strength. Some of these investigations have led to the development of methods of shot peening that further increase the effectiveness of the process.

The method of shot peening with which this discussion deals is one in which the increase in fatigue strength is striking even when compared with the fatigue strength of conventionally peened parts. Investigations at the American Wheelabrator & Equipment Corp. have verified the results of initial tests that demonstrated that this particular process of shot peening goes far beyond the results obtained by conventional peening.

This process has been referred to as *Stress Peening* because it consists of shot peening while the part is statically stressed in the same direction as the stress to be sustained in service. The same technique is used as in conventional peening, except for the application of static stress during the process. Fig. 1 shows the method of application of the static load during the peening of specimens for tests described herein. A coil spring would be subjected to a load to compress

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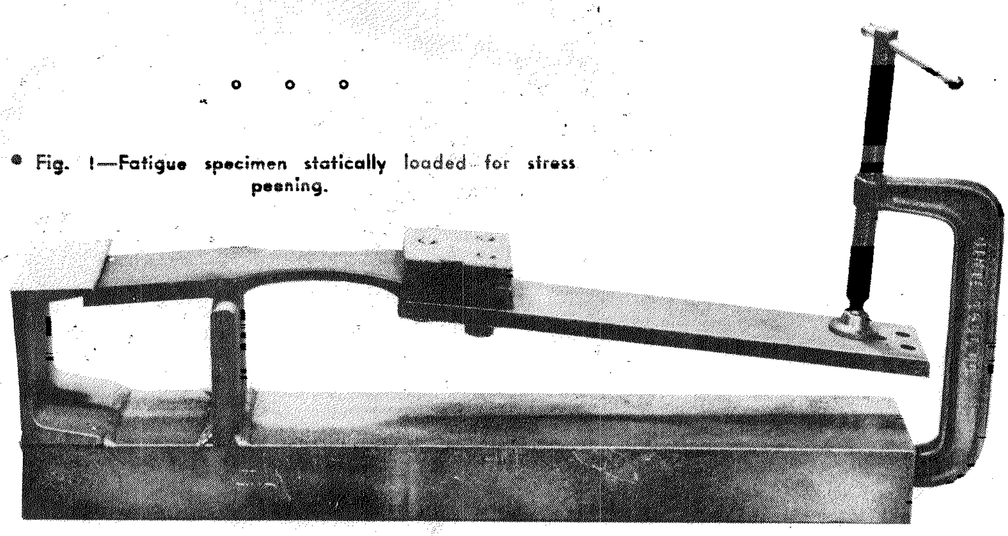
• Fig. 1—Fatigue specimen statically loaded for stress peening.



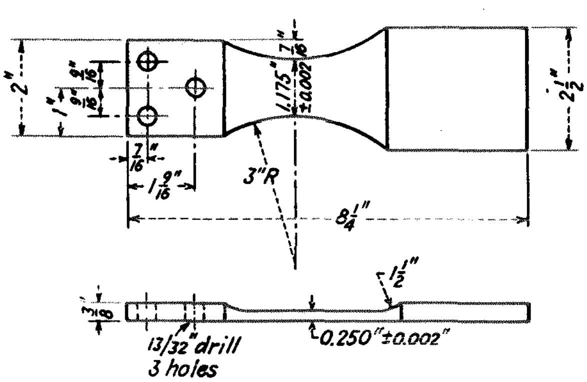
Stress peening, a process of shot peening while the part is statically stressed in the same direction as the stress to be sustained in service, gives some substantial improvement in fatigue strength. Results of investigations of stress peening, as well as the theory of the process, are discussed by the authors.

it during peening. The release of the external load after peening adds further residual stresses to those already imparted by the impact of the shot.

Stress peening is applicable to any part that is subjected to repeated stresses of high magnitude in simple bending or torsion, provided the part can be stressed during peening in the same sense as the stress to be sustained in service. Simple bending or torsion involves repeated stresses not completely reversed. Such parts might include leaf springs, coil springs, torsion bars, propeller shafts and belleville springs.

Stress peening can be used as a means for further reducing the size of parts that are being conventionally peened. In cases where shot peening is not being applied to production parts, a very substantial reduction in size could be accomplished by stress peening.

An example of the increase in fatigue strength by stress peening is illustrated by a comparison of the fatigue life of specimens shown in table I. The material was SAE 9260 steel, quenched and drawn to 40 to 45 Rc. The surface on the tension side where failure occurred was as-rolled, for the purpose of simulating many production parts. These tests were run in simple bending on a Krouse fatigue machine. It will be observed in the fatigue data in table I that there is a wide spread in life in some cases for presumably the same conditions. This is probably the result of the as-rolled condition in which surface imperfections can be expected. These imperfections would be expected to produce a wider spread in



● Fig. 2—Fatigue specimen reported in table I.

TABLE I

Specimens Wheelapeened at 0.014 A-2 Arc Height*
Test Stress 0 to 137,000 Psi

	Cycles to Failure: Minimum of Group	Cycles to Failure: Average of Group	Number of Specimens
Not Peened	27,000	53,000	9
Peened Conventionally	95,000	162,000	9
Stress Peened, Static Stress, 137,000 Psi	201,000	4,000,000†	10

† Two specimens of this group were run to 10,000,000 cycles without failures.

* Refers to test made on No. 2 Aimen Specimen Gage for measuring arc height of Aimen test specimens.

TABLE II

Specimens Wheelapeened at 0.014 A-2 Arc Height
Test Stress 0 to 137,000 Psi

	Cycles to Failure		Number of Specimens
	Minimum of Group	Average of Group	
Not Peened	38,000	55,000	10
Peened Conventionally	131,000	1,132,000	9
Stress Peened, Static Stress, 137,000 Psi	923,000	7,264,000†	8

† Five specimens of this group were run to 10,000,000 cycles without failure.

tests approaching the endurance limit stress for indefinite life. All tests were run in simple bending, that is, from substantially zero to a maximum stress during each cycle.

Table I is a brief summary of one of the earlier series of fatigue tests on laboratory specimens shown in fig. 2.

In these tests the stress peened specimens were subjected to the same peening conditions as those specimens peened conventionally, except for the applied stress during peening. That is, the peening was done with P-23 chilled iron shot at 1775 rpm using a 15 in. diam wheel; a conveyer speed of 12 fpm; and a shot flow rate of 150 lb per min. This produced an arc height of 0.014, A-2 on the standard Almen gage.[1]

From these data it will be seen that with conventional peening the average life of these specimens was increased better than 300 pct at a stress that resulted in a very short life on non-peened specimens. With conventional peening all specimens showed a finite life. A comparison of life shows a marked increase for stress peened specimens, but this comparison is somewhat indeterminate because of the fact that some of the stress peened specimens appear to have indefinite life. A comparison of the minimum life of the specimens in table I shows an increase of 350 pct for the conventionally peened group and almost 750 pct for the stress peened group. An examination of the stress peened specimens that failed suggested that the failure started 1/64 to 3/64 in. below the surface.

A second series of tests was made on specimens that had been chamfered on the edges as shown in fig. 3, which would be more representative of actual machine parts. It should be mentioned that the chamfered specimen shown in fig. 3 was adopted for all subsequent fatigue testing. The results of this second series of tests are shown

TABLE III

Specimens Wheelapeened at 0.010 A-2 Arc Height
Test Stress 0 to 137,000 Psi

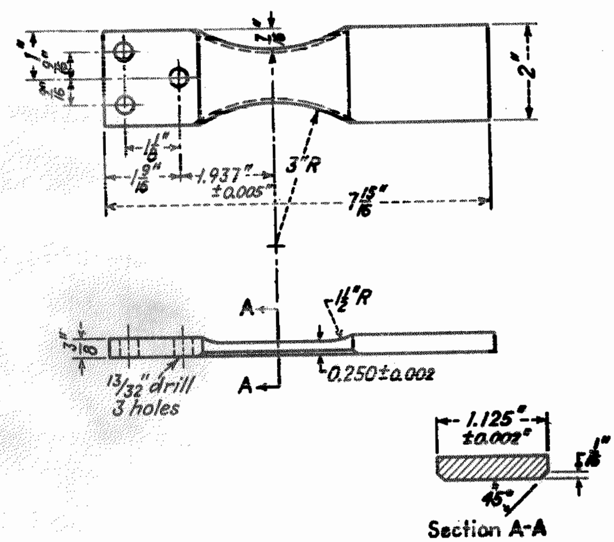
	Cycles 'e Failure		Number of Specimens
	Minimum of Group	Average of Group	
Peened Conventionally	161,000	255,000	10
Stress Peened, Static Stress, 137,000 Psi	137,000*	7,600,000†	8

† Six specimens of this group were run to 10,000,000 cycles without failure.
*Next lowest life 739,000 cycles

in table II. The peening conditions were the same as used in the tests reported in table I.

The minimum life of stress peened specimens in table II was more than seven times as great as that for the conventionally peened specimens. The average life of the conventionally peened group was very strongly influenced by one specimen that failed at an exceptionally long life of 8,700,000 cycles, compared with the other specimens of that group. The next longest life was 257,000 cycles, or less than one-third of the shortest life obtained in the stress peened group. Subsequent testing under the same conditions has indicated that the average life of identical specimens conventionally peened is on the order of 275,000 cycles. The static stress used in stress peening the specimens reported in tables I and II was the same as the applied stress in the fatigue tests, namely, 137,000 psi.

Table III represents tests in which the peening was done at a reduced wheel speed, thus resulting in a reduced arc height of 0.010, A2. Other in-



● Fig. 3—Fatigue specimen reported in tables II, III, IV and V.

vestigations on the same type of specimens have indicated that for conventional peening, 0.014, A-2 is the optimum for this thickness.

The minimum life of the stress peened group was exceptionally short as compared to the others of that group, which would suggest that there may have been an invisible defect in the steel. The only other failure in this group occurred at 739,000 cycles, which is considerably greater than the maximum life of the conventionally peened group (484,000 cycles).

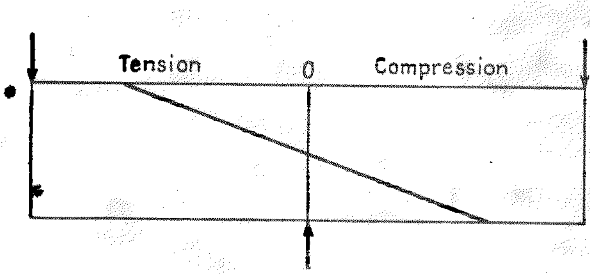
Additional tests have been run with a materially decreased static stress during stress peening with similar results. The lowest static stress used to date is 90,000 psi. Inasmuch as the specimens peened while subjected to this stress indicate an endurance limit stress substantially the same as those with a greater static stress during peening, it is reasonable to believe that a substantial increase in fatigue strength could be obtained with even lower static stress; but would approach that of conventional peening as the static stress approaches zero.

Another series of tests was made at an applied stress of 157,000 psi. In this case, the stress peened specimens were subjected to a static stress of 137,000 psi during peening. The results are shown in table IV.

It should be mentioned that only one stress peened specimen indicated in table IV had a shorter life than the maximum life of conventionally peened specimens. Stress peening should be distinguished from the process commonly known as presetting, scragging, or bulldozing. Presetting consists of loading a machine part in the same direction as the applied service load to a sufficient stress to exceed the yield stress thereby causing permanent deformation or *set*. When the external load is released, the surface fibers in which the yield stress was exceeded (in torsion or bending) will be in a state of stress in the opposite sense to that applied on those particular fibers during the presetting operation.

It has been found[9] that presetting after shot peening is more effective in increasing fatigue strength than presetting alone or presetting followed by shot peening. Although the increase in fatigue strength by shot peening can be augmented by presetting, the results do not approach those obtained by stress peening.

In order to investigate the relative fatigue strength in a stress peened part in comparison with one which has been shot peened and preset, a group of test specimens, identical to those



● **Fig. 4**—Distribution of stress in a beam with external bending load only.

shown in fig 3, was tested after having been shot peened and preset. The results of this comparison are shown in table V. The data of table II are repeated in table V for ease of comparison.

The first row of preset figures in table V shows the results of tests on specimens which, after peening, had been preset to the extent that the permanent deformation was 1/8 in. at a distance of 11 7/64 in. from the critical section. The second row of figures of table V shows the results of one test in which an excessive preset of 1/4 in. was accidentally obtained, at the same distance from the critical section. The presetting was performed on the fixture shown in fig. 1.

It will be observed by comparing the results of presetting with those of stress peening in table V that a substantial improvement in fatigue strength can be obtained by presetting after peening, but even these results do not approach those obtained by stress peening. It appears that another advantage in stress peening lies in the fact that the magnitude of the static stress during the peening operation is not a critical factor, whereas in a presetting operation the applied load in presetting must be carefully controlled.

TABLE IV

Specimens Wheelapeened at 0.014 A-2 Arc Height
Test Stress 0 to 157,000 Psi

	Cycles to Failure		
	Minimum of Group	Average of Group	Number of Specimens
Not Peened	23,000	26,000	2
Peened Conventionally	94,000	117,600	10
Stress Peened, Static Stress, 137,000 Psi	116,000*	4,290,000	9

* One specimen in this group failed at 72,000 cycles but showed a very deep pit at the origin of failure, and, therefore, the specimen was considered defective.

It has been known that shot peening, when properly applied, greatly increases the fatigue strength of machine parts provided the impact of the shot is not excessive for the particular cross-section involved. It has also been known that *over-peening*, or peening to an excessive degree of impact, can be responsible in extreme cases for an actual decrease in fatigue strength. Further, in cases where such excessive peening occurs, the failure is subsurface because of the excessive tension stresses that necessarily exist in order to balance the forces within the part.

To illustrate this, fig. 4 represents the stress distribution in an externally loaded beam, assuming no residual stresses in the beam, according to the conventional formula. Fig. 5 represents the residual stress in a similar beam that was shot peened on the upper surface; no external load. It should be mentioned that fig. 5 is shown for the purpose of illustration, and the depth of the compressively stressed layer at the peened surface is greatly exaggerated for that purpose. Actually in conventional peening the depth of this layer is relatively shallow in relation to the thickness of the part.

Since such a beam is in equilibrium with no external forces, the shape of the residual stress curve must be such that the forces resulting from tension stresses are equal to those resulting

TABLE V

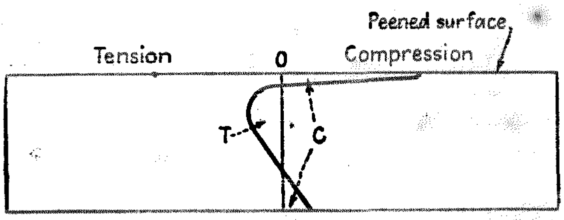
Specimens Wheelapeened to 0.014 A-2 Arc Height
Test Stress 0 to 137,000 Psi

	Cycles to Failure		
	Minimum of Group	Average of Group	Number of Specimens
Not Peened	38,000	55,000	10
Peened Conventionally	131,000	1,123,000	9
Preset, 1/8 in. Set	232,000	2,265,000*	9
Preset, 1/4 in. Set	70,000	76,000	1
Stress Peened, Static Stress, 137,000 Psi	923,000	7,284,000†	8

* One of this group ran to 10,000,000 cycles without failure.
† Five of this group ran to 10,000,000 cycles without failure.

from compressive stresses. In other words, the area T in fig. 5 must be equal to the areas C. Further, the summation of the moments of forces represented by these areas must be equal to zero.

When a bending moment is applied to the beam of fig. 5, the resultant stresses at any depth will be the algebraic sum of the bending stress in fig. 4 and the residual stress of fig. 5, as shown in fig. 6 (solid line). The dotted lines of fig. 6 show the individual stresses of figs. 4 and 5.



● Fig. 5—Distribution of stress in a shot peened beam with no external load.

Almen[3] has stated that the surfaces of repeatedly stressed specimens are much more vulnerable to fatigue than the deeper layers.

It can be seen from fig. 6 that the resultant tension stress at the surface is materially reduced by the residual stresses caused by peening, and, therefore, a substantial increase in fatigue strength would be expected. However, if the part is peened to an excessive degree, in relation to its thickness, the area of the compressive stress curve adjacent to the peened surface increases, thereby increasing the tension stresses

[1] *"Shot Peening," American Wheelabrator & Equipment Corp.,* 1947.

[2] *"Report on the Effect of Shot Blasting on the Mechanical Properties of Steel," by R. L. Mattson and J. O. Almen, Part II, p.* 23, *War Metallurgy Div., of the National Defense Research Committee of the OSRD.*

[3] *"Improving Fatigue Strength of Machine Parts," by J. O. Almen,* THE IRON AGE, *June* 10, 1943, *p.* 65.

in the region T. Thus, as peening becomes excessive, the resultant tension stress below the surface becomes greater until, in extreme cases, it may exceed the maximum stress caused by external load, even considering the surface vulnerability.

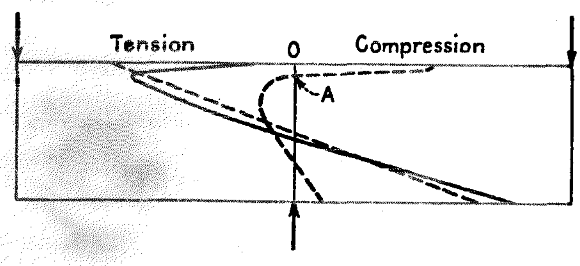
Referring again to fig. 6, it will be noted that even in the residual stress curve, which has been exaggerated for the purpose of illustration, the residual compressive stress is rapidly decreasing with depth, crossing over into the tension stress region at point A. For convenience, the point A has been referred to as the *crossing point*.

Since the resultant stress is the algebraic sum of the residual and bending moment stresses, the resultant stress at the depth of the crossing point is equal to the bending stress at that depth. Beyond that depth, the residual stress is additive to the bending stress, and it is expected that the maximum resultant tension stress is somewhat deeper than the crossing point. If this crossing point could be placed at a greater depth, then the two stresses (residual and bending moment) would become additive at a greater depth, where the bending stress is smaller. However, if, at that point, the rate of increase in residual tension stress is excessive, the maximum resultant tension stress may still be relatively high.

With conventional peening, increased impact of the blast tends to increase the depth of the crossing point, but it also tends to produce a more rapidly increasing residual tension stress in the region adjacent to the crossing point. The final effect may be an actual increase in the maximum resultant tension stress, as evidenced by overpeening that, when carried to extremes, can actually reduce the fatigue strength.

Stress peening, on the other hand, increases the depth of the crossing point and produces a more moderately increasing tension stress in the region adjacent to the crossing point. This is accomplished by the release of the external bending moment after peening, which is equivalent to adding a bending stress in the opposite direction. Since this bending stress adds compressive stresses, increasing linearly from the center of the beam toward the peened surface, the result is a definite increase in the depth of the crossing point, as well as a more gradual increase in the residual tension stress adjacent to the crossing point.

The fact that those stress peened specimens



● Fig. 6—Resultant distribution of stress in a shot peened beam with external load applied. (Solid line is the resultant.)

that did fail indicated subsurface failures supports the theory that the maximum stress is placed at a greater depth by stress peening.

These sub-surface failures are contrasted to those resulting from overpeening in that the life of the stress peened specimens was so much greater than that of conventionally peened specimens, that it indicates a distinctly different character of residual stresses.

As the test results appear to agree with this theory, it has been concluded that the superior results obtained by stress peening are due to the increased depth of the crossing point and a more desirable slope of the residual stress curve adjacent to that point. The results obtained to date on stress peening indicate that the potentialities of shot peening are much greater than has been realized.

Acknowledgment

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