#1962005

SHOT PEENING - THEORY

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What is Shot Peening?

Shot peening differs from blast cleaning, mainly in its purpose. The most common purpose of peening is to accomplish an increase in fatigue strength. The question is often asked, "how much increase can be expected?"

It is easy to cite examples of increased fatigue life in specific cases because there are so many case histories to refer to.

Increases of 600% in the life of leaf springs, 1370% in the life of coil springs, 1500% in the life of gears have been recorded, to mention only a few. But large variations in results of different tests are immediately apparent. Such variations are not necessarily peculiar to particular parts, but are influenced by a number of factors.

Assuming the same peening procedure, the increase in life will not always be the same for a given part, but will vary depending upon the stress to which the part is subjected.

In many cases, it is very difficult to determine the true stress to which a part is subjected in service. But in cases where the stress can be determined, a definite relationship can be shown between average life and applied stress for a given part. This is usually shown as an S-N diagram. (Stress vs. number of cycles.) When plotted on log paper, it is a straight line in the finite life region. Now if the same part is peened, the line of stress vs. life changes. Fig. 1 shows SN diagrams for flat specimens, non-peened and peened with a given set of conditions. The specimens were tested in simple bending, that is, with a cycle from zero to maximum bending stress. The peening, of course, was done on the side of specimen subjected to tension during each cycle. Note that the peened line is higher than the non-peened line. The life is greater for a given stress, or the stress is greater for a given life.

Note also that the slope of the line has changed due to peening. The lines are farther apart at lower stress. This means that the increase in life is considerably greater when the non-peened life is greater, and less when the non-peened life is less. Quite often, an SN diagram has a "knee" at a large number of cycles and the line becomes horizontal from there on. The stress at this knee is usually referred to as the endurance limit stress for indefinite life. If the stress is below that value, failure is not likely to occur at all.

It is apparent from these lines that if the non-peened life to failure is say 800,000 cycles, then the peened part would never fail at the same stress, and the increase in life would be indefinitely large. This is what actually happens in such a case. On the same part, peened under the same conditions, if the non-peened life is only 50,000 cycles, then the life is increased to about 275,000 cycles or 550%.

Fig. 1 deals with one peening condition only. With a more effective peening job on the same part, the life will increase even more, and the SN line will be even higher as shown in Fig. 2 for a different part.

From these charts, it is easy to see how futile it would be to quote even an approximate increase in life without knowing something about the conditions under which the part is to run.

It is important to note the distinction between increased life for a given stress on the one hand, and increased stress for a given life on the other. The percentage increase is very much different. For example, referring to Fig. 1, at a stress of 125,000 P.S.I., peening increases the life from 100,000 cycles to 600,000 cycles, or an increase of 600%. For the same conditions, using a life of 100,000 cycles, the allowable stress is increased from 120,000 to 160,000 P.S.I. or only 33.3%.

How Does Peening Accomplish These Results?

For the most part, unless the parts being shot peened are of a work hardenable material, there is very little change in the metallurgical structure of the material after peening, and therefore, little change in hardness.

The data available on fatigue as influenced by shot peening provides a great deal of evidence that the major reason for the increase in fatigue strength lies in the layer of compressive stress at the surface of the part.

In general, fatigue failures are due to repeated change of stress in which the maximum stress is tension or involves a tension componenet. Rarely, if ever, do fatigue failures occur as the result of compressive stress. This means that the compressive stress at the surface is all to the good.

The most common type of load causing fatigue failure is bending or torsion. In both cases, the maximum stress, due to the applied load, occurs at the surface of the material, and decreases in direct proportion to the distance from the neutral axis. In a symmetrical cross section, the neutral axis is at the center of the cross section.

Fig. 3 shows the bending stress in a simple beam resulting from the external forces shown at right angles to the thickness. The maximum tension stress is at the bottom of the beam. The stress at the top of the beam is of the same magnitude, but is in compression. These stresses occur in the plane of the load P.

If the bottom side of the beam is peened at a given intensity, residual stresses will be set up as illustrated in Fig. 4. Note there are three regions of residual stress: compression at the peened side, tension in the sub-surface material, and compression at the non-peened side. Since, with no external load, forces and moments must balance, this is inevitable. Each cross hatched area in Fig. 4 represents a force: tension in one direction and compression in the opposite direction. If the external loads of Fig. 3 are now applied to the beam, the bending stress will be as shown in the dotted line of Fig. 5. The resultant stress at any depth will then be the algebraic sum of the stresses (residual and applied) at that depth. That is, if the stresses are in the same direction, the resultant stress is their sum. If they are in opposite directions, the resultant stress is their difference. The solid line in Fig. 5 shows the resultant stress. Note that at the bottom surface where the applied tension stress is maximum, the resultant stress is very low; so low that failure is not likely to occur at the surface. Note also that the maximum resultant tension stress (at point A) is lower than the maximum applied tension stress. In addition, the maximum resultant tension stress now occurs in material below the surface, which inherently has greater fatigue strength than surface material. Even the slightest roughness on the surface will decrease fatigue strength if the maximum tension stress occurs at the surface.

Even if the maximum stess in the sub-surface material of the peened beam were equal to that in a non-peened beam, we would expect an increase in life by virtue of the fact that the maximum stress is not subject to stress concentrations. Even in a polished surface, a machine part is not entirely free of stress concentrations.

Now, consider a higher intensity of peening, which would result in a deeper stress, using the same beam. Fig 6 shows such a condition. Note that the magnitude of the maximum compressive stress at the peened surface is not much different. This is related to the yield strength of the material. But the depth of compression stress is greater, which results in an increase in area under the compression curve at the peened side. Furthermore, the compression stress on the opposite side will increase due to the higher intensity. In consequence, the increased area in compression must be balanced by a corresponding increase of area in tension. But the portion of the beam thickness which is available to absorb the increased tension stress has been diminished. The result is that the internal tension stress must increase in magnitude. To a degree, the influence of this increase in internal tension stress is reduced by the fact that its maximum is at a greater depth, at which the external bending stress is less. But if the intensity of peening is excessive in relation to the thickness of the beam, the resultant stress may be greater than that with a lower intensity.

In Fig. 6 the same external load is applied as in the previous case. Note that the maximum resultant stress is no less than at the lower intensity. As a matter of fact, in this particular case, it is slightly greater.

This suggests that any further increase in arc height would result in a condition of diminishing returns. The peak resultant stress will be minimum when the depth of residual compression stress is in keeping with the thickness of the part peened. Fatigue tests at different intensities are in agreement with this trend.

Stress Peening

The foregoing discussion deals with peening parts in their free state. If a part is peened while subjected to a static stress in the same sense as the applied stress in service, the gain in fatigue strength far exceeds that resulting from peening in its free position. This is in excellent agreement with the above theory of residual stresses due to peening.

Referring again to the condition of Fig. 4, if a constant bending stress is applied to the beam during peening, the compressive stress at the peened side (bending stress still applied) will be similar to that of Fig. 4 at the peened side. However, the remaining part of the stress curve will contain the bending moment due to the external load. When the static bending stress is released after peening, the result is equivalent to the addition of a bending stress in the opposite direction. Hence, the maximum residual stress is placed at a much greater depth, and this occurs without a sudden increase in tension.

Furthermore, due to the release of the externally applied bending stress, the residual tension stress is distributed in such a way that the increase in tension stress is very gradual. Finally, when the service load is applied, the resultant tension stress is of a much lower magnitude than in the case of peening in the free state.

Establishing Arc Height

On the basis of fatigue tests on various thicknesses peened at various arc heights, Table I has been used for determining peening intensities in relation to thickness.

Thickness of Part	Arc Height
1/16"	.012N
1/8"	.008A
1/4"	.014A
3/8"	.018A
1/2"	.021A
5/8"	.007C
3/4"	.008C
7/8" or greater	.010C or greater

With a thickness greater than 7/8", there appears to be no optimum. The life continues to increase with higher arc height within the limits of arc height obtainable.

The tabulation can be used for simple sections. For tubular or other hollow sections, much greater arc heights can be used than that indicated by the wall thickness.

The selection of arc height should be made according to the economics of the particular application. For example, if the only problem is to eliminate infrequent failures, it may be more practical to use an arc height well below the optimum for lower cost of operation.

The above tabulation cannot, by any means, be taken as an indication that a good peening job is accomplished if the suggested arc height is obtained. This is further discussed in a later paragraph.

Establishing Coverage

The degree of coverage most desirable in a peening operation is, in many cases, dependent upon economics. A high degree of coverage may result in a further increase in life. This may occur even beyond a coverage of 98%, provided the arc height is not excessive for the thickness of the part in the area subject to failure. If the arc height is excessive, no additional gain in life is likely to occur with coverage beyond 98%. Coverage beyond 98% can be quite effective for further increased life particularly in parts of changing contour such as gear teeth, etc.

For very high stresses, coverage beyond 98% may offer no additional gain in life. For example, if the non-peened life to failure is as low as 10,000 or 15,000 cycles, the increase in life may be as great with 98% coverage as with a higher degree of coverage.

Coverage should be considered in the light of the economics of the particular application. Since coverage approaches 100% as a limit as the exposure time is increased indefinitely, the time required for greater coverage increases appreciably. This is illustrated in Fig. 7 which shows % coverage vs. exposure time. Note that the exposure time required to obtain 98% coverage is approximately 2.5 times as great as that for 80% coverage. Fatigue tests have consistently indicated greater life at 98%, but not in proportion to the required exposure time.

The proper balance of gain in fatigue strength and economics may be illustrated by two examples:

1. Assume large precision gears are to be peened for an application in which indefinitely long life is required at maximum load. The cost of such gears is such that the cost of peening is not significant, even with very high degree of coverage. (Several times the exposure required for 98%.) In this case the added fatigue strength justifies high coverage.

2. At the other extreme, assume small leaf or coil springs are to be peened in volume production. The unit cost of the spring is very low and peening is required to prevent fatigue failures at a fixed stress level. In this case it is quite likely that a coverage of 98%, or even less, would provide adequate protection, and therefore, the cost of peening, with good practice, would be very low.

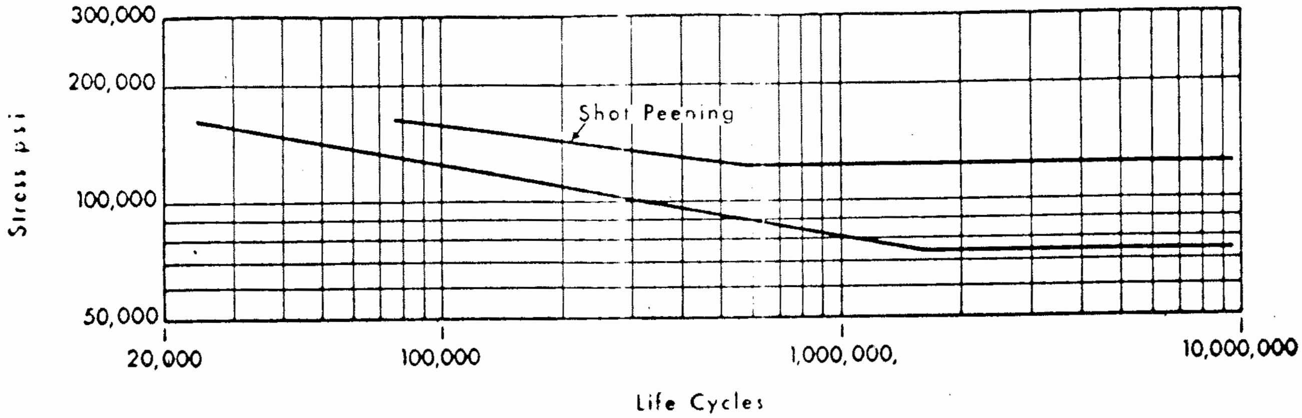
Shortcomings of Arc Height and Coverage

If the specified arc height is achieved in a peening operation, it is no guarantee of a good peening job. The same applies to coverage. If, for any reason, the intensity of the blast striking the work is very non-uniform, pellet to pellet, the specified arc height can be obtained at full coverage, and yet the results can be disappointing.

Fatigue tests have indicated that insofar as fatigue strength is concerned, intensities "do not mix." That is, the effective part of peening blast is comprised of the largest, hardest pellets, striking the work at the highest velocity and at the maximum angle of impact. Any part of the blast which has appreciably less impact than the maximum is ineffective. This means that for efficient peening, uniformity of the blast should be maintained. The parts should be exposed to the blast in the most advantageous position and the shot should be maintained at a uniform size by the removal of broken or undersized shot. The standard S.A.E. tolerances for shot size provide adequate uniformity.

Influence of Types of Shot on Economy

A discussion of the economics would be incomplete without some mention of the requirements of shot. Since the advent of steel shot, fatigue tests have indicated that even when the work to be peened has a hardness of 60 Rc, the required gain in fatigue strength can be obtained most economically by the use of steel shot with a hardness of approximately 42-50 Rc. When the shot hardness greatly exceeds this range, its durability is likely to decrease materially, thereby increasing the cost of the peening oepration.



Influence of Conventional Shot Peening on Fatigue Strength of Spring Steel using Production Conditions

~~FIG B~~
Fig. 1

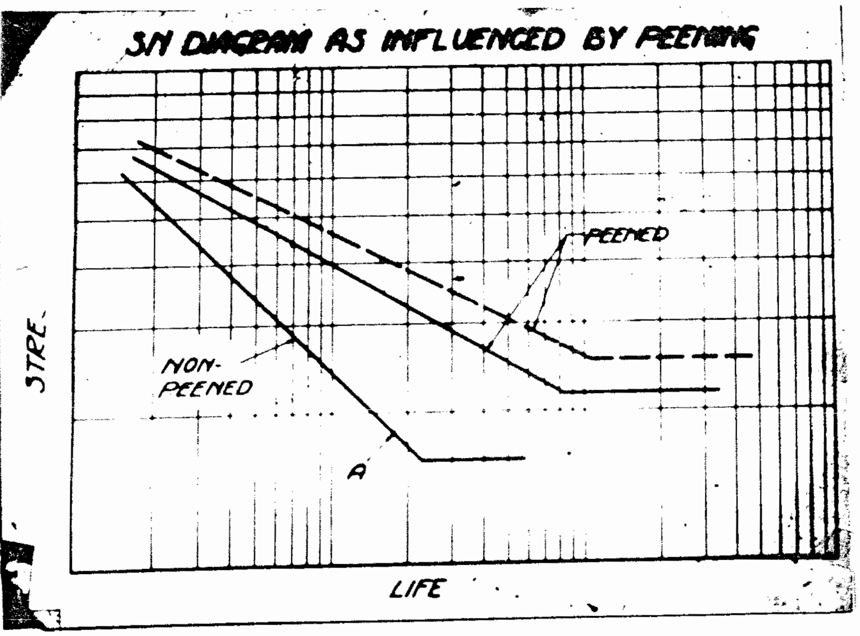


Fig. 2

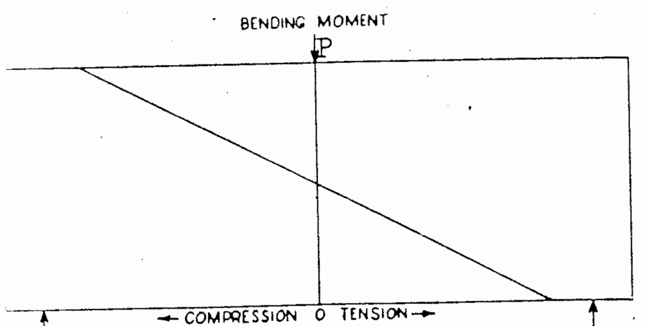


FIGURE 3

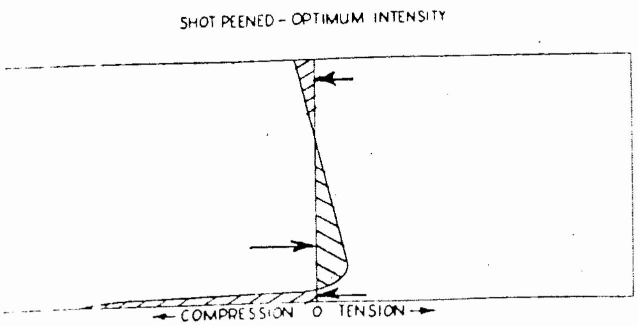


FIGURE 4

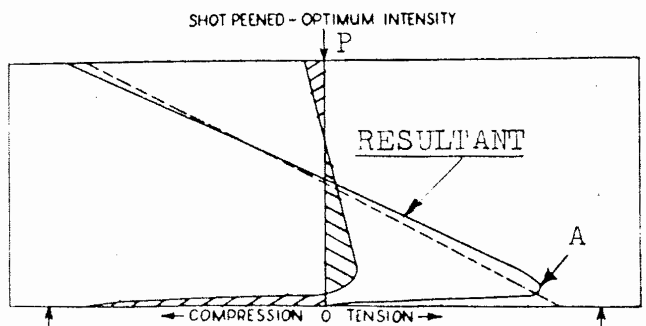


FIGURE 5

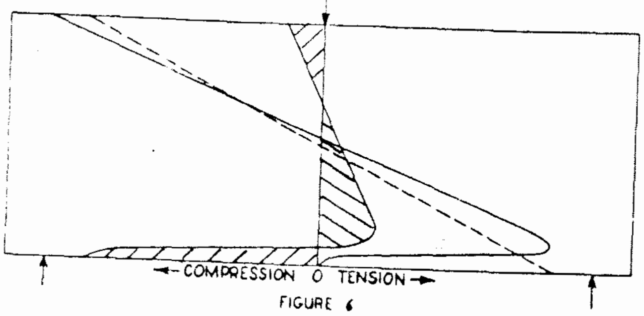


FIGURE 6

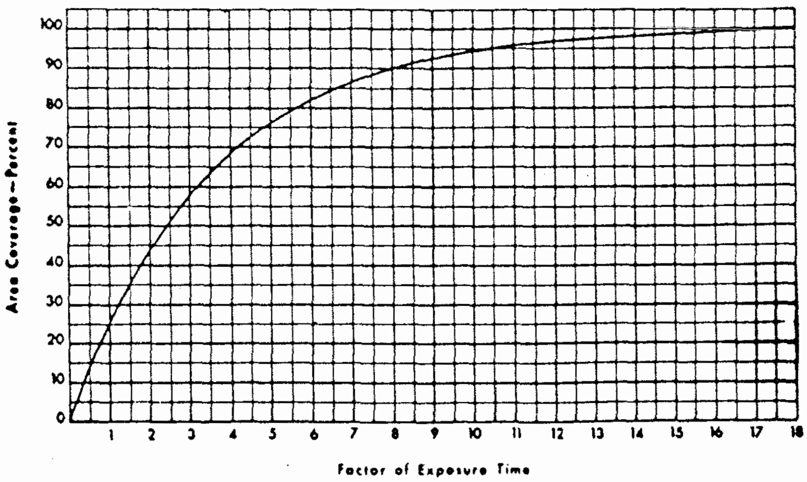


FIG. 7

Relationship between Area Coverage and Exposure Time