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Understanding the Beneficial Effects of Shot Peening

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THE high level of performance of the jet plane and the modern automobile would be impossible without beneficial residual stresses. Such stresses could be used to a much greater extent in the manufacture of industrial and domestic machinery, leading to savings in weight and greater serviceability along with lowering over-all cost.

This discussion is directed toward a physical understanding of shot peening, a commonly used method for inducing beneficial residual stresses. Mechanical parts of ductile material (such as low-carbon steel) which are subjected to static loads in service usually fail by slow yielding along regions of maximum shearing stress. Moderate stress concentrations are not serious because such concentrations are relieved by localized yielding of the adjacent material. In repeated loading, however, both ductile and brittle materials fail by sudden fracture (without plastic flow) in regions of maximum tensile stress. The stress at fracture in repeated loads, termed the endurance limit, is considerably less than the static tensile stress. If stress concentration exists, progressive fracture may lead to earlier failure[1] due to the inherent weakness of surface material.

A layer of residual compressive stress on the surface of a ductile material will greatly increase its fatigue strength. This layer, which need be only a few thousandths of an inch thick, is commonly produced by shot peening.

In shot peening, pellets (shot) of steel or chilled cast iron are entrained in an air jet, and blown toward the part area to be peened. The intensity of peening depends on three variables: the size of shot, its velocity as imparted by the air stream, and the duration (seconds) of peening. The mechanics of the process is as follows:

When a shot strikes the surface being peened, an indentation will be formed, Fig. 1, in which the region adjacent to the shot will be deformed plastically in tension, while the underlying layer will be deformed elastically in tension. (The stress is within the elastic limit because the strain is distributed over a thicker layer.)[2]

When the shot rebounds, Fig. 1(*b*), the elastically stressed subsurface material recovers, inducing a layer of residual compressive surface stress in the plastically stressed layer. A low tensile stress remains in the subsurface layer, and a small "dimple" is left on the surface.

As peening is continued over adjacent surface areas, the surface becomes residually stressed in compression in a covering layer about a few thousandths of an inch in thickness. Underlying this layer, the tensile stress will be of lower intensity because it is distributed across a comparatively thick layer. Thus, forces in the peened surface are in equilibrium.

If the intensity of peening is excessive, however, the compressive layer will be thicker. Then, the tensile stress in the underlying region can be so high that it may lead to a fatigue fracture, originating in this subsurface layer. Thus, there is an optimum intensity of peening.

Fig. 2 can be used to explain why metallic surface layers are weaker than sound subsurface layers. A sound subsurface element, as shown in the figure, offers restraint to elongation by the force. This restraint is due, first, to its internal cohesive strength (atomic attraction), and second, to its restraint to elongation provided by the four faces of adjoining material: top, bottom, front, and back. The surface element at (*b*) has the same cohesive strength as at (*a*), but has only three restraining faces: front, bottom, and back. Thus, a surface element is weaker than a sound subsurface element.

A layer of compressive residual stress on the surface will thereby strengthen surface elements by providing additional resistance to the tensile load, P.

The fatigue strength of a metallic member to be subjected in service to one-directional (not reversed) bending can be further increased if the member is externally loaded to induce, during peening, a tensile stress on the surface within the elastic limit, and maintaining it during peening.

To show the effect of presetting without peening, consider the leaf springs in Fig. 3. At (*a*) is shown a multiple-leaf spring. At (*b*) is a single-leaf spring that was prestressed by supporting the midpoint and forcing the ends down where the spring shackles are

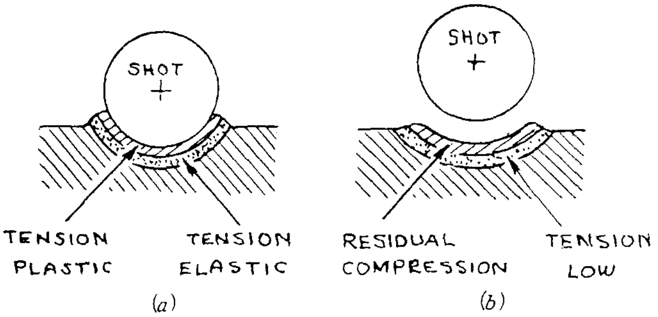

Fig. 1—Shot peening mechanisms: (*a*) Impact.; (*b*) Rebound.

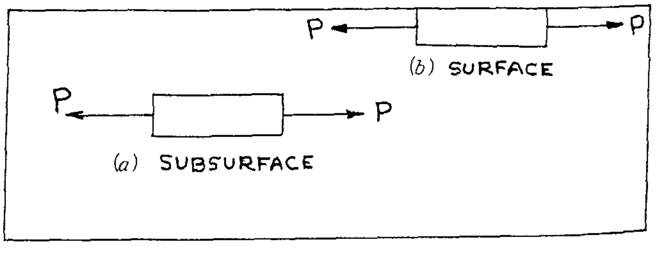

Fig. 2—Strength of surface and subsurface elements.

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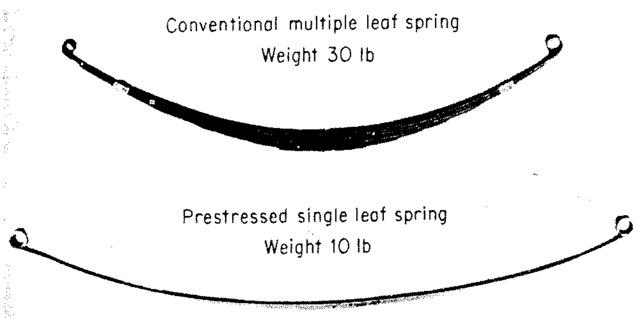

Fig. 3—Springs designed for same service. Comparison shows material is more efficiently used when prestressed properly.

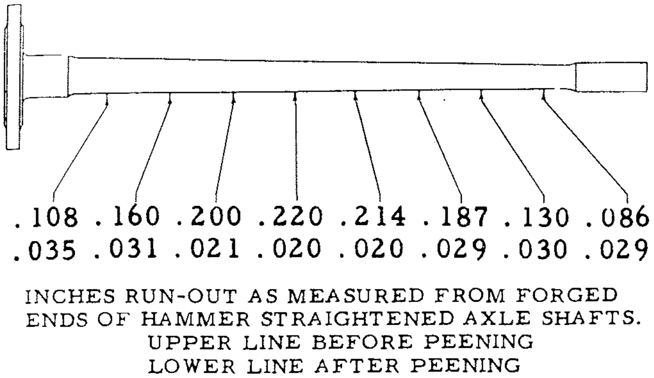

Fig. 4—Inches run-out as measured from forged ends of hammer-straightened axle shafts. Upper line, before peening; lower line, after peening.

attached. (Such loading deflects the spring in the same direction as in vehicle service.) End loads were then increased, stressing the top of the spring plastically (beyond the elastic limit) in tension. When the external load was released, the recovery of the elastically stressed part of the spring induced a layer of residual compressive stress in the plastically stressed part. Then, when the spring was installed in service, the tensile stress on the top layer of the leaf was decreased, acting to raise the endurance limit. Therefore, the single leaf spring has the same maximum stress as the multiple leaf spring, saving in weight as indicated.[2]

The magnitude of forces involved in the use of residual stresses in metal parts can be appreciated by the following case history. It was necessary to straighten a group of axle shafts due to "run-out" resulting from heat-treating. The run-out is indicated by the upper line of values in Fig. 4.

Initially, the shafts were intended to be straightened by hammering on the concave side to introduce a layer of residual compressive stresses, which should correct the "run-out". However, through error, they were hammered on the convex side. Though this procedure straightened the shafts, it left high residual tensile stresses on sides that were originally convex.

A pneumatic air hammer was constructed, Fig. 5, to straighten these shafts. Each was placed in a grooved anvil so that it was peened on the concave side as it moved longitudinally until being straightened by the compressive stress introduced on the concave side. Lower values in Fig. 4 show the inches run-out after peening.

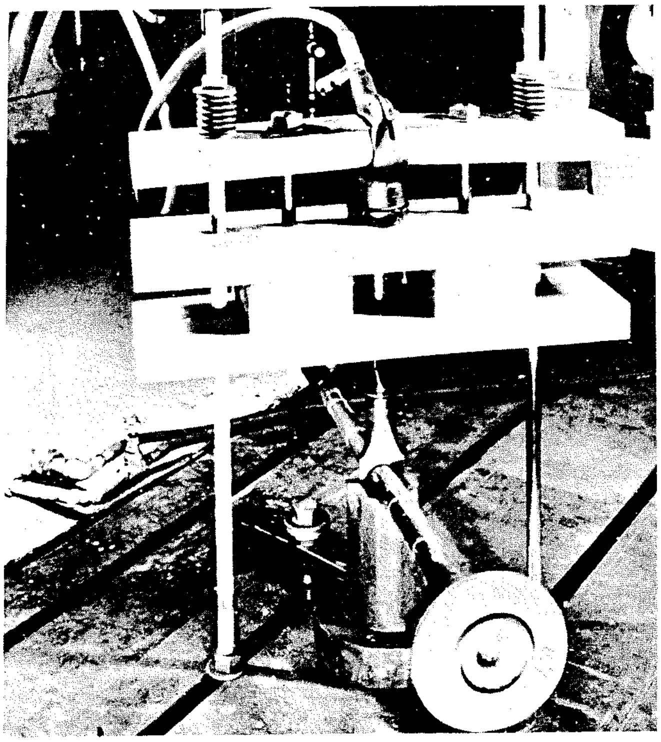

Fig. 5—Setup for hammer straightening of axle shafts after heat treatment.

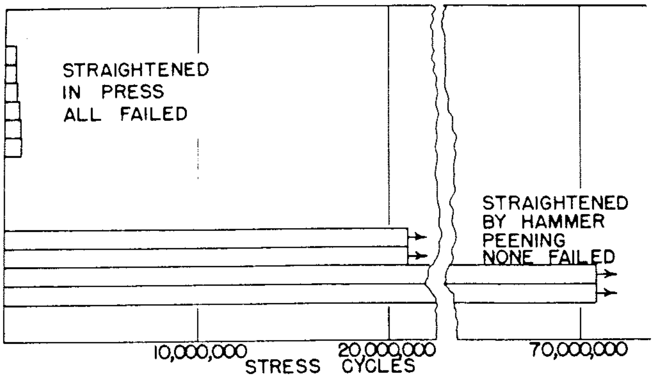

Fig. 6—Straightened axle shafts. The straightening method determines the residual stress and the resulting fatigue strength.

In Fig. 6, the "number of cycles" to failure are shown for the two instances described above.

In the case history cited above, the axle shaft was heat treated to increase its strength, thus meeting service requirements. Heat treatment, however, caused lateral deflection, as indicated by the run-out shown by the upper line of values in Fig. 4. Run-out was then materially reduced by shot peening on the concave side.

As an alternate method to meet strength and straightness requirement for the shaft, the manufacturer may find it profitable to avoid heat treatment by shot peening the shaft uniformly over its entire area. This procedure could meet, in one operation, the strength requirement and avoid run-out.

To sum up, the author feels that the effectiveness of beneficial residual stresses, amply demonstrated in the automotive and aircraft industries, could well be used by many other industries in the manufacture of critical parts to increase serviceability and, in most instances, decrease production cost.

REFERENCES

1. J. O. Almen: Peened Surfaces Improve Endurance of Machine Parts, *Metal Progress*, Feb. 1943, p. 212.
2. J. O. Almen and P. H. Black: *Residual Stresses and Fatigue in Metals*, p. 68, McGraw-Hill Book Co., Inc., New York, 1963.
3. See J. O. Almen and P. H. Black: *Residual Stresses and Fatigue in Metals*, p. 68, McGraw-Hill Book Co., Inc., New York, 1963.