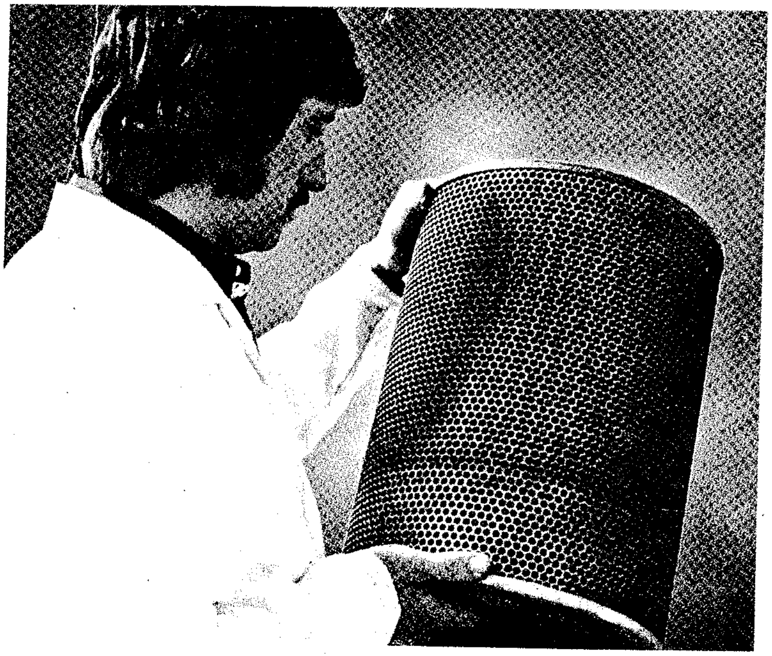

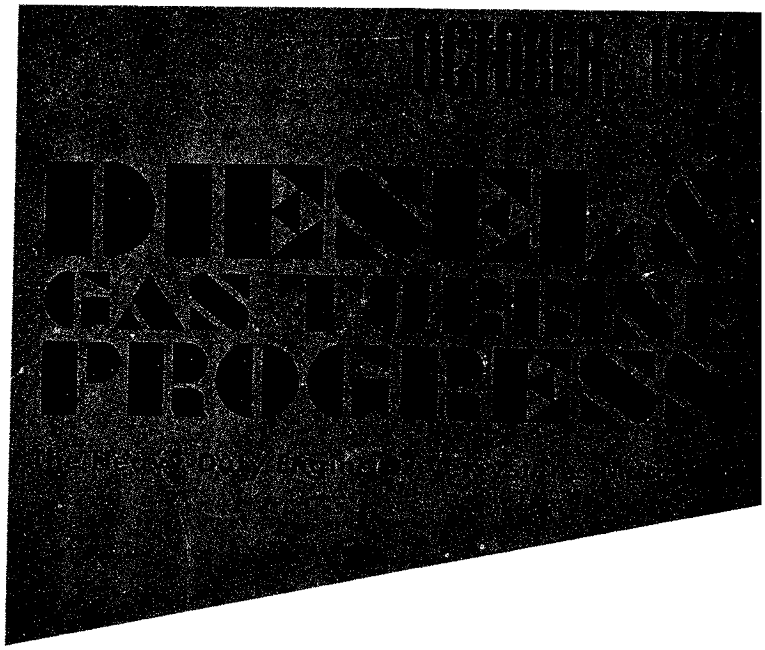

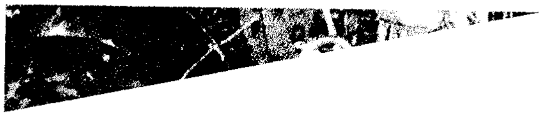

SHOT PEENING GIVES PARTS HIGHER FATIGUE LIFE

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For Diesel And Gas Turbine Components

Shot Peening Gives Parts Higher Fatigue Life

By Gerald Nachman*

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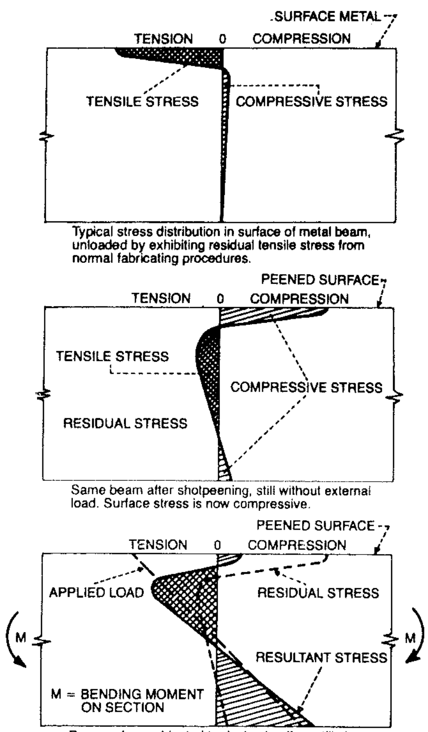


Typical stress distribution in surface of metal beam, unloaded by exhibiting residual tensile stress from normal fabricating procedures.

Same beam after shotpeening, still without external load. Surface stress is now compressive.

Beam, when subjected to design loading, still shows some residual compressive stress at surface.

Figure 1.

ONE of the prerequisites of early fatigue failure of turbine blades, crankshafts, connecting rods, leaf springs, piston rings and pins, to cite a few examples, is present from the moment these components are manufactured. This is residual surface tensile stress, unavoidably induced in most metal and alloy parts by machining, grinding and, to an extent, by plating and other finishing and forming operations. Residual surface tensile stress creates microscopic surface fissures or "stress risers" between the metal grain boundaries. As the components undergo cyclic loading during operation of the equipment, the risers enlarge and propagate inward until premature fatigue failure results.

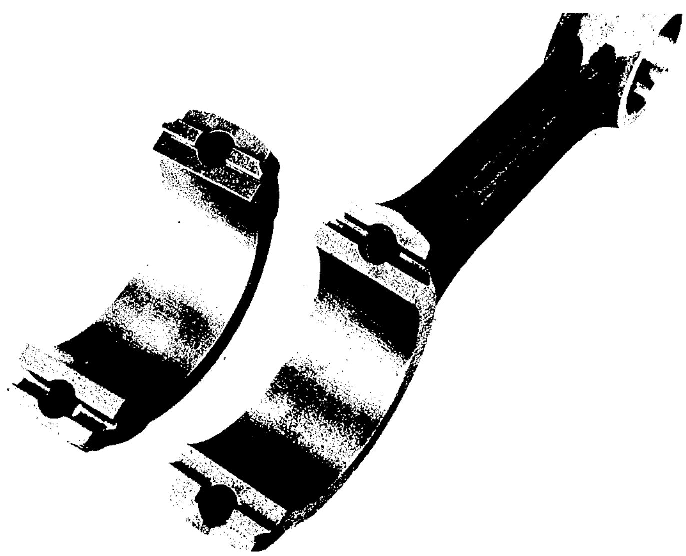
The phenomenon of stress corrosion which also originates at the stress risers, requires a more or less corrosive environment. It proceeds whether or not the untreated part is in actual use. Never-before-used parts held in inventory are subject to continuous stress corrosion. Most typically, in the case of gas turbines and diesels, unprotected parts are being cyclically loaded in a mildly corrosive atmosphere. Premature failure is caused by fatigue, the continual progression of an intial stress riser, aggravated to greater or less extent by corrosion. Coating or plating the surfaces covers over the stress risers preventing atmosphere contact and corrosion, but does not hinder fissure progression and fatigue. Controlled shot peening, especially of those areas most likely to be affected, is a means of preventing both fatigue and corrosion failure.

Controlled shot peening includes those carefully monitored procedures involving uniform impacting of a metal surface with spherical steel shot and/or glass beads, thereby producing a result not unlike that of hundreds of thousands of minute peening hammers impacting with blows of precisely equal intensity. What controlled shot peening does is to convert the tensile stressed surface layer into a compressively stressed one, one which will remain compressively stressed after loading. This is illustrated by the three diagrams in figure 1. The resulting compacted layer of metal, several thousandths of an inch deep, prevents origination and/or propagation of stress risers.

Chrome plated piston rings of 9254 alloy steel, hardness 45 Rc, for example, used to present a fatigue problem found to be caused by the plating process itself. Controlled shot peening prior to plating increased fatigue strength from 85,000 to 150,000 psi or 76%. Peened sub-surfaces of plated components also prevent propagation, to the base metal, of minute cracks which originate in the plating, as a fatigue crack will not propagate into the compressively stressed zone. On forged steel crankshafts for six cylinder diesel engines used in heavy-equipment, shot peening, by one manufacturer, of the journal fillets (hardness 24-27 Rc) increased the fatigue limit from 51,000 to 63,400 psi, or 24%. In testing the effect of shot peening on nodular iron cast shafts of the same design (hardness 255 Bu), the fatigue limit was found to be increased from 38,000 to 50,000 psi or to about the same value as that of unpeened forged shafts. One particular manufacturer of gas turbine systems specifies controlled shot peening on the dovetail portion of hot gas pass buckets, fillets on compressor blades in the platform-to-airfoil areas and of certain key rotating elements subject to vibratory and other high cycle fatigue stresses. Shot peened foils and roots of turbine blades as well as discs are standard with a number of leading turbine producers. A British engine company uses shot peened detuner leaf springs on their large marine couplings. Another's power system incorporates controlled shot peening of such gearbox parts as planet gears, pinions, idler gears, output wheels and mainshafts.

Experience shows that controlled shot peening of blades already fatigue-damaged through loading will extend their life, at the same stress level, over

On forged steel crankshafts for diesel engines used in heavy duty equipment, shot peening, by one manufacturer, of the journal fillets increased the fatigue limit by 24%.



The most critical areas of connecting rods are the fillets next to the bores, but the rods are usually shot peened all over except in the bores. Figure 5 provides more data on peened and unpeened connecting rods.

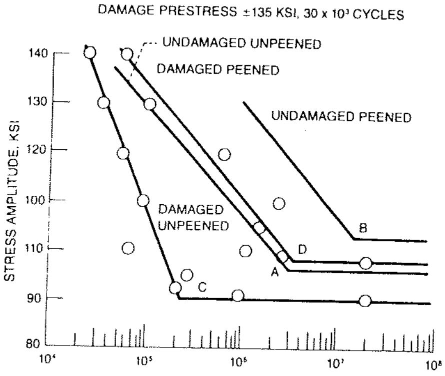
those of unpeened new blades, or will permit operation at higher stress levels. If the fatigue damage has not progressed too far, that is, if the minute cracks representing fatigue damage have not penetrated too deeply, controlled shot peening will, in effect, eliminate them and place the surface layer under compression. Surface stress riser formation will be prevented just as in the case of a peened new blade. At just what point should shot peening be undertaken in the case of operating components which already exhibit fatigue damage? Since shot peening inhibits the possibility of surface fissure initiation and/or progression, the earlier in the life span that it is done, the better. The danger in waiting too long is that crack progression might extend so far as to make shot peening ineffective in extending fatigue life. The curves in figure 2 illustrate the value of controlled shot peening in so rejuvenating fatigue-damaged 4340 steel components that they can be operated at considerably higher stress levels than can (no fatigue damage) unpeened items.

Curve A represents the stress levels accommodated by new, unpeened specimens without fatigue damage while curve D that of the same, but fatigue-damaged specimens which were not shot peened. The latter could be operated at approximately 2% higher stress level. In other words, shot peening more than compensated for the loss due to fatigue damage. Even more dramatic is the difference peening makes in fatigue-damaged blades, amounting to about 10% increase in allowable operational stress level.

Inconel 713C turbine blades with grinding indications on their shanks have considerably lower fatigue resistance than the same blades without such indications, as shown in curves W and X, figure 3. However, if the former are shot peened prior to going into service, their allowable stress level, as represented by Y, is higher than that of the unpeened blades without grinding indications.

In grinding hard steel, the high surface tensile stresses induced by this operation may approach the ultimate strength of the material. The condition is often disregarded by manufacturers as long as grinding cracks do not appear in the finished product. However, the excessive surface stress sharply reduces fatigue life. Controlled shot peening is an effective means of correcting the situation, as the curves in figure 4 show.

DAMAGE PRESTRESS ±135 KSI, 30 x 10³ CYCLES



Shot peening as a means of overcoming prior fatigue damage with 4340 steel tested in rotating bending.

Figure 2.

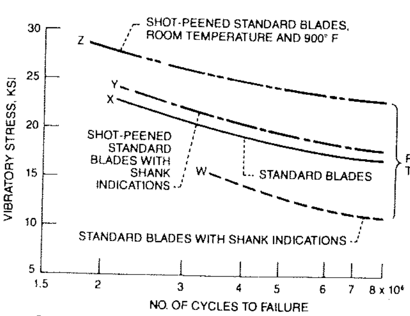
Shot peened surfaces help resist fatigue failure to a considerably greater degree than will unpeened, smooth, polished surfaces. Though the appearance of the shot peened surface is far from displeasing (it is actually desirable, in many cases) a shinier surface but with the desirable effects of shot peening is sometimes required. In those cases, shot peening is accomplished *first*, followed by lapping, honing or polishing up to a carefully predetermined degree of metal removal. The most critical areas of connecting rods are the fillets next to the bores, but the rods are usually shot peened all over except in the bores. The bar graph in figure 5 shows that peened rods whose surfaces were subsequently scratched had 40% higher stress endurance limit than unscratched, but unpeened samples.

Shafts and axles of all sizes are shot peened to improve their fatigue life. One particular shaft, in order to provide protection for the equipment it drove, was designed with a groove which caused the shaft to fail at a certain overload point. The groove, however, caused premature fatigue failure.

Since shot peening was instituted, the part no longer fails in fatigue, yet provides the proper overload protection. Pioneered by the automotive industry, shot peened coil springs have been in use for long periods of time. Springs with wire diameters as large as three inches have been successfully peened. The Goodman diagram in figure 6 shows the additional stress permissible on the peened springs.

Control is the byword of shot peening, to insure uniformity over every portion of a surface configuration, to insure quality uniformity in terms of steel shot and glass beads. Also, shot peening is a specialized, precision process for which conventional peening and blasting equipment is largely unsuitable. A test program is required to establish peening parameters and the cost of the operation for a given component. One company whose only business is shot peening for others, both on individual job and contract bases, is Metal Improvement Company of Teaneck, New Jersey, a subsidiary of Curtiss-Wright Corp. They are qualified and equipped to undertake the necessary engineering recommendations as well as to process parts at their ten U.S. and two European locations. Metal Improvement also has trained crews for assignments in the field.

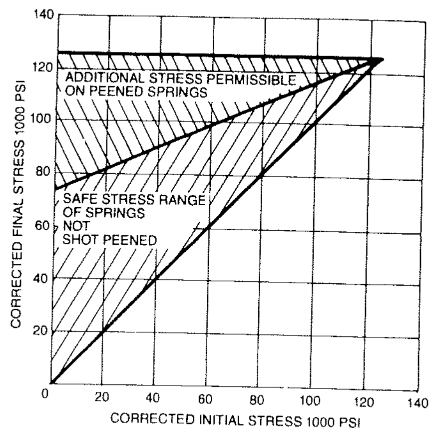
Since surface tensile stress is largely unpredictable, and, for all practical purposes, immeasurable by the design engineer, it is seldom taken into account. The classic approach to the problem of premature fatigue failure is an often costly redesign involving changes in material, configuration and dimensions. If the cause of the trouble is surface tensile stress, as it is often found to be after elimination of other physical factors as well as after careful testing, controlled shot peening can save the high cost of redesigning the part. Peening, itself, costs comparatively little, frequently amounting to less than 1% of the total cost of the item.



Suppression of fatigue of Inconel 713C turbine blades by shot peening.

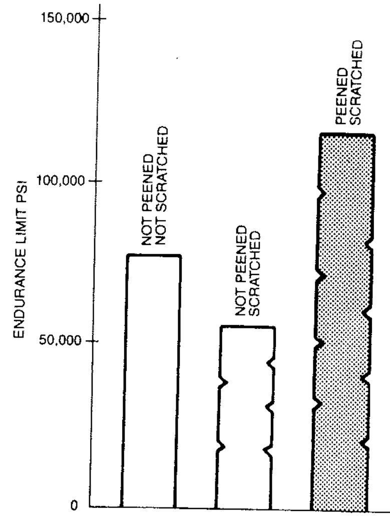
Figure 3.

In this same regard, the added fatigue strength derived from peening could well allow thinner sections, less costly materials, and a less costly design.



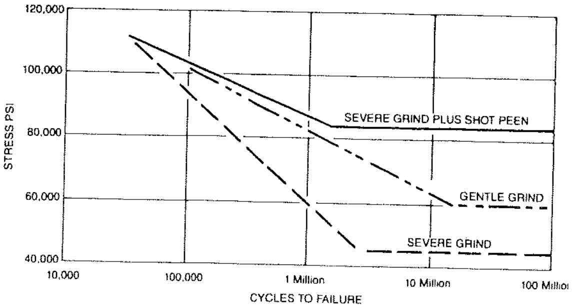
SAFE STRESS RANGES FOR COIL SPRINGS (.207 DIAMETER STEEL)

Figure 6.



EFFECT OF PEENING AND SCRATCHES ON ENDURANCE LIMIT OF 4340 STEEL AT R_c51

Figure 5.



REVERSED BENDING FATIGUE OF FLAT BARS OF ROCKWELL HARDNESS C45

Figure 4.

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