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ABSTRACT

Advances in chemistry and parts design have extended the useful life of many engine, structural and landing gear components. Sufficient data has been collected and summarized to estimate length of service periods between inspection and overhaul, and even the number of times that components can be reconditioned and reused. Shot-peening has become an important element in obtaining improvements in fatigue life and as a preparatory process for many coatings.

The purpose of this paper is to discuss typical applications of shot-peening used in the overhaul process. We will also identify process controls necessary to retain or restore the shot-peening benefit designed into parts by the original manufacturer.

UNDERSTANDING FATIGUE FAILURES

Fatigue cracks occur at the surface of parts during dynamic or stress reversal loading. Surface crack initiation usually occurs in the presence of residual or applied tensile stresses. When external bending or load stresses are applied to a part, the resultant stress at any depth will be the algebraic sum of the residual stress and the stress due to the applied load at that depth. Consequently, if the surface stresses are in tension before loading, the resultant stress will be pure tension.

Once crack initiation has begun, these resultant stresses are concentrated in the cracks and at some point these cracks will reduce the cross sectional area of the part until it can no longer support its load, and premature failure will occur.

Fatigue cracks originate at stress concentration areas such as machine marks, scratches, sharp radii of holes, fillets, keyways and other changes of section. By shot-peening these areas, fatigue life can be greatly improved.

SHOT-PEENING - THE MECHANISM

The shot-peening process is based on sound engineering principles. It is not a form of surface stress relieving, but utilizes the concept of modulus to achieve its benefits.

By bombarding the surface of a part or work piece with spherical, relatively hard media (i.e. chilled cast steel RC45-55), the surface of the part is dented, causing local plastic deformation. The sub-surface material resists movement and compressively strains against the surface. This interaction between elastically strained sub-surface and plastic deformation on the surface results in a surface residually stressed in compression.

Figure 1 shows the result of a single impact, its affected area, and a stress distribution diagram. Since the part is in equilibrium with no external forces applied, the area under the stress distribution curve in the regions of compressive stress must be equal to the corresponding area under the curve in the region of tensile stress. Further, the sum of the movements of these areas must be equal to zero.

(FIG. 1)

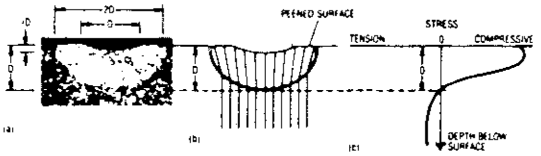

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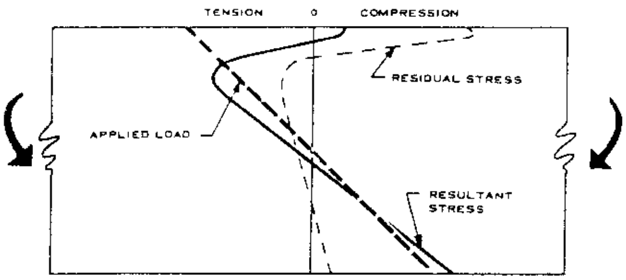
Figure 2 illustrates a beam with an external bending moment applied after shot-peening. The resultant stress at any depth will be equal to the algebraic sum of the residual stress and the stress due to the applied load at that depth. The resultant curve of the stress distribution is shown as a solid line and the individual components are shown as dotted lines.(1)*

Note that even after loading, the peened surface still retains a compressive stress. This can be depended upon to prevent formation of surface cracks.

(FIG. 2)



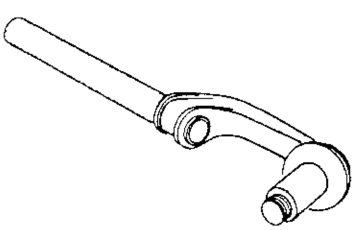
RESULTANT DISTRIBUTION OF STRESS IN A SHOT-PEENED BEAM WITH EXTERNAL LOAD APPLIED. SOLID LINE IS THE RESULTANT

As the surface of the part is being placed in compression, two other benefits occur. First, any residual tensile stress that may have been present as a result of manufacturing or processing has now been removed. This benefit is the basis for the concept that shot-peening is a stress relieving process.

Second, as the part's surface is being cold worked, scratches, machine marks and other potential stress-risers are being removed from the surface of the part.

SHOT-PEENING BEFORE PLATING

(FIG. 3)

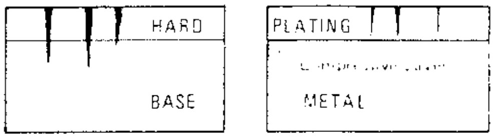


The landing gear component shown is one of the many parts shot-peened before chrome plating to counteract the harmful effects of plating on the fatigue life of metal parts. This is due to the fine cracks which develop in the plating and propagate into the base metal.

*NOTE: Numbers in parenthesis denote references listed in the summary.

If the surface of the base metal can be residually stressed in compression before plating, the cracks in the plate will not propogate into the part. For this reason, it is always recommended to shot-peen highly stressed parts which are to be plated.

(FIG. 4)

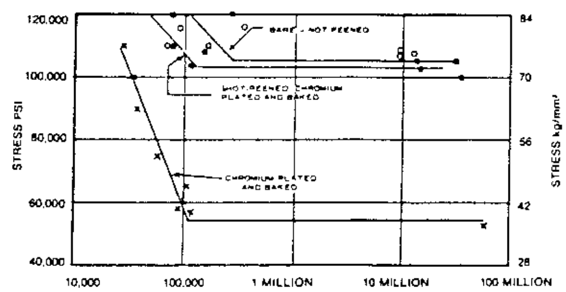


PLATING CRACKS WILL NOT PROPAGATE INTO PRE-STRESSED BASE.

Shot-peening before chrome plating and electroless nickle plating is called out in federal specification QQ-C-320 and MIL C-26074A, respectively, for all steel parts designed for unlimited life under dynamic loads. Some of the softer plates, such as cadmium, can also lower the fatigue strength unless they are preceded by shot-peening. Many tests show that the bond of the plate on a shot-peened surface is at least as good as on a ground surface.

Recent data indicate that peening after chrome plating is also very beneficial, to increase both fatigue and corrosion resistance.

(FIG. 5)(2)

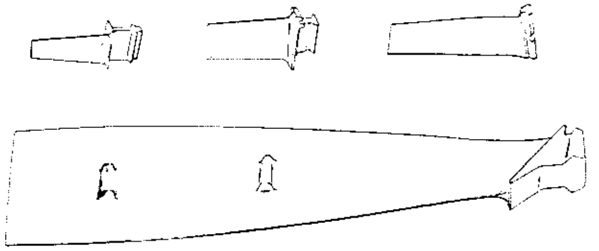


4340 STEEL, 52-53R_C ROTATING BEAM FATIGUE

COHEN WADC TN 57-178, FIGURES 1, 3 & 5

BLADES

(FIG. 6)



Blades and buckets for aircraft jet engines, stationary gas turbines, steam turbines and compressors are standard applications for shot-peening

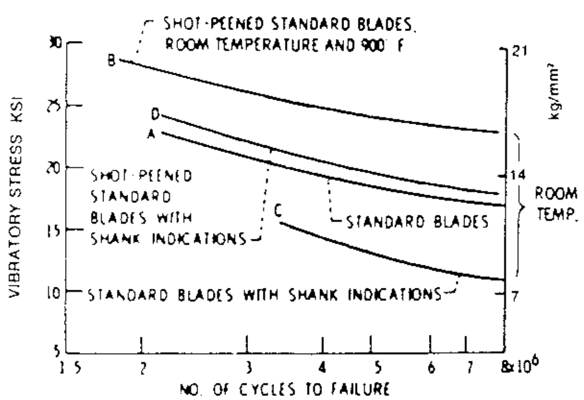
Blade roots(steel and titanium) are peened to prevent fretting, galling and fatigue. Broaching of the fir tree can leave tears, pits or scores which are stress-raisers. Shot-peening to a depth below these surfaces discontinuities will correct this detrimental effect.

The air foils of blades are commonly shot-peened to retard the harmful fatigue effect caused by pitting, prevent stress corrosion cracking, retard fretting in the tie wire holes, and to increase fatigue life in general.

Many coating and plating processes used on airfoils tend to decrease the fatigue life. Shot-peening is used to offset this detrimental effect.

It is recommended to repeen the blades on overhaul of the unit, as the compressive stress induced by shot-peening will encompass any surface fatigue damage, thereby negating the initiation or propagation of fatigue cracks. The discs or wheels which support the blades are also peened, especially in the slots and tie rod bores.

(FIG. 7)(3)



SUPPRESSION OF FATIGUE DAMAGE OF INCONEL 713C TURBINE BLADES BY SHOT PEENING

PEENING OF HOLES

In production, holes as small of .096-inch diameter can be shot-peened under controlled conditions.

The bores of long tubes, oil well drill pipes, helicopter spars, propeller blades, piston pins, hydraulic cylinders, turbine blade tie wire holes, etc. are commonly peened to obtain the same benefits outlined in the previous pages.

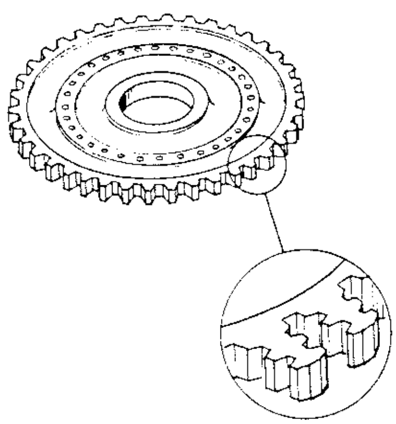
POROSITY

Shot-peening will frequently eliminate porosity on castings and similar parts, particularly in high pressure applications. In many cases, shot-peening is more reliable and economical than impregnation or welding.

CONTROLLED TANGENTIAL GLASS BEAD CLEANING

Recent developments in overhaul of gas and steam turbine units in the field on disc serrations have caused problems in highly critical areas due to the smearing over and covering up of the fine hairline cracks through the aluminum oxide cleaning process. Controlled tangential glass bead cleaning is now being used to overcome this problem as the glass beads are propelled tangential to the surface with the effectiveness of removing the surface oxides and other foreign deposits in the critical areas of the disc serrations without the harmful effect of covering or smearing over the fine hairline cracks that should and must show up through the required nondestructive testing to be performed on each part. This process of tangenial glass bead cleaning also does not in any way affect the dimensional limits of the part.

(FIG. 8)



SHOT-PEENING CONTROL

The object of controlled shot-peening is to produce a compressively stressed surface layer in which the amount of stress, the uniformity of the stress, and the depth of the layer can be held constant from piece to piece. As it is practically impossible to inspect the stress distribution on a finished part, the full control of all aspects of the process become imperative. The basic variables of stress, depth and coverage are obtained in practice by the use of the right combinations of shot, exposure time, choice of air pressure or wheel speed, nozzle size, distance of nozzle from part and angle between shot stream and peened surface. It is extremely important that the relative motion between shot stream and part be mechanized for uniformity and reproducibility.

The general specifications used to establish controls for proper shot-peening results are the SAE Specification(AMS2430) and Military Specification(Mil-S-13165).

SHOT-PEENING MEDIA - Since the peening cycle requires striking a workpiece with enough energy to cause local plastic deformation, it is apparent that spherical shapes are essential. Irregular or broken shapes or shot that has evidence of surface porosity are not acceptable (see Figure 9).

(FIG. 9)(4)

1. Acceptable Shapes

2. Unacceptable Shapes

3. Unacceptable Shapes

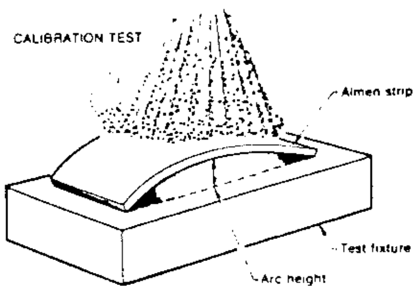
Visual inspection of shot upon receipt, before and after the peening cycle and during extended peening operations is necessary to determine if surface damage is occuring instead of the compression desired.

When shot doesn't meet standards of size and shape, it must be removed from the peening equipment and discarded or reclaimed.

One method of separating acceptable from unacceptable shot uses a machine called a classifier. This unit has an airwash system for dust/dirt removal, and a multi-screen sorting system to size shot. Dust free and properly sized shot is metered into a double fluted spiral. Shot that is spherical rolls freely to an outer spiral and is collected and stored as clean, properly sized media ready for re-use. Shot that is broken or otherwise not properly shaped will tumble slowly, remaining in the first spiral. It is rejected and discarded.

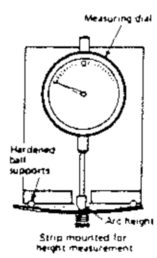
INTENSITY - In an effort to standardize shot-peening callouts, Mr. J. O. Almen of General Motors Research Laboratories Division developed a method of measuring, specifying and duplicating the amount of energy required to provide a desired depth of compression. When a spring steel specimen strip is placed into a holding fixture and peened on one side only, the strip will curve when removed from the fixture (see Figures 10, 11 and 12).

(FIG. 10)(5)



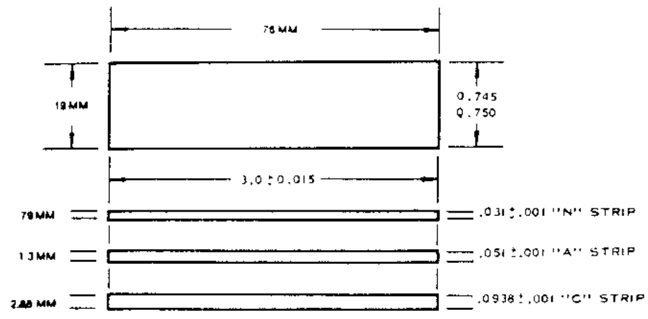
The amount of curvature is measured by a modified dial indicator gauge called an Almen gauge (designed by J. O. Almen). Curvature readings are in .001 inches and are specified in thousandths of inches of curvature and also specify the thickness of specimen strip used. The strip used for most applications is the "A" strip 3/4" by 3" by .051". For intensities of less than .004", a thinner strip should be used, an "N" strip with a thickness of .031". Readings will be three times higher than those of an "A" strip. If the reading on an "A" strip is above .020", a "C" strip with a thickness of .093" should be used. Readings on a "C" strip will be 0.3 times those of the "A" strip(see Figures 11 and 12).

(FIG. 11)



Almen gauge

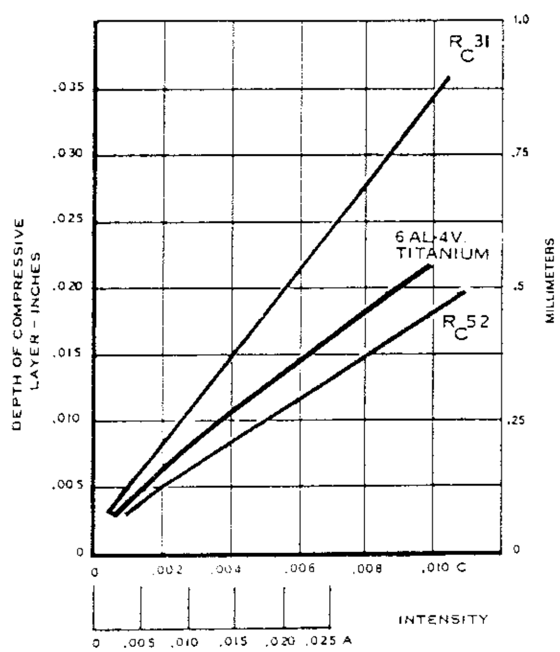
(FIG. 12)



TEST STRIP SPECIFICATIONS

A summary of work done by Wright Patterson AFB and independently by Dr. Henry Fuchs resulted in the summary chart (Figure 13) which correlates intensity to depth of compressive layer for two different hardnesses of steel and a 6-4 titanium alloy. These charts can be of significant value in designing shot-peening specifications for the materials or hardness values noted. Estimated depths of compression for other hardnesses can be interpolated from this chart. NOTE: The rule of sines applies to intensity. If a .010"A intensity is verified at a 90° angle between shot stream and workpiece, changing the angle to 45° would reduce the intensity to .007"A. Further reducing the angle of impingement to 30° would result in an intensity of .005"A(following the sines of 90°-45°-30° angles.)

(FIG. 13)



DEPTH OF COMPRESSIVE STRESS VS ALMEN INTENSITY FOR STEEL & TITANIUM

COVERAGE(per Mil-S-13165B) - Complete visual coverage is defined as uniform denting or obliterating of the original surface of the part or workpiece as determined by either of the following methods:

(a) - Visual examination using a 10X magnifyng glass.

(b) - Dyescan tracer liquid used in the Peenscan process described as follows:

"Prepare a control specimen of the same material as the actual workpiece. Coat this control specimen with tracer liquid called Dyescan #220 and/or #226 by dipping, spraying, or painting and allow the Dyescan liquid to dry. Check coating under a black light to insure complete coverage of the coated area to be shot peened has been accomplished. Shot peen control specimen under proper shot peening conditions for the required intensity and coverage as prescribed. Re-examine under the black light in order to determine if the Dyescan liquid has been completely removed. Full coverage is indicated by complete removal of the Dyescan liquid.

Areas which do not produce full coverage will show a white color under the black light whereas full coverage will give off a dark color.

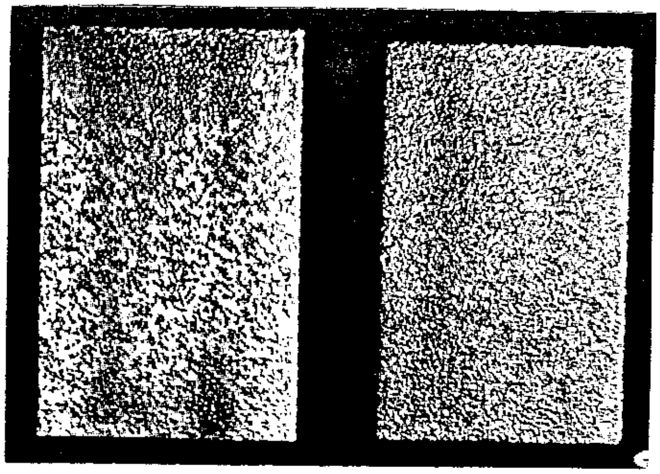
Coverage of actual production pieces can be established by using the same procedure used for control specimens. This can be done by utilizing the Dyescan liquid for each part or on a statistical sampling basis."

Incomplete coverage is evidence that the surface of the part has not been placed in a residually compressive condition, and the desired improvements in fatigue life that shot-peening provides will not be there. In addition, incomplete coverage may actually set up stress differentials between peened and unpeened surfaces that could lower fatigue life. (See Figures 14, 15 and 16.)

MICROPROCESSORS - The ultimate control. Shot-peening as a process has entered the microprocessor age. Reproducibility of fatigue life improvement has been the goal of the shot-peening industry for the past forty years. Automated machines, the numerical controlled machines, have helped to define the dynamic parameters we must monitor to obtain the same improvement in production parts that have been achieved in engineering development peening.

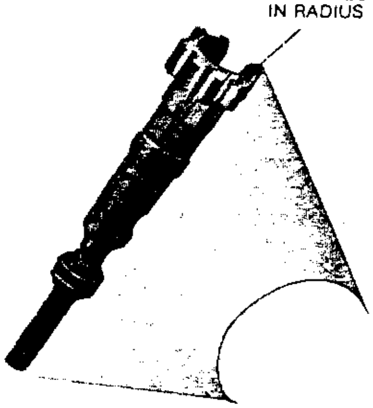
With microprocessors, we have the ability to selectively activate peening nozzles, vary velocity, monitor shot flow, parts rotation and translation within the equipment and produce printed records of these events at the time of processing.

(FIG. 14)

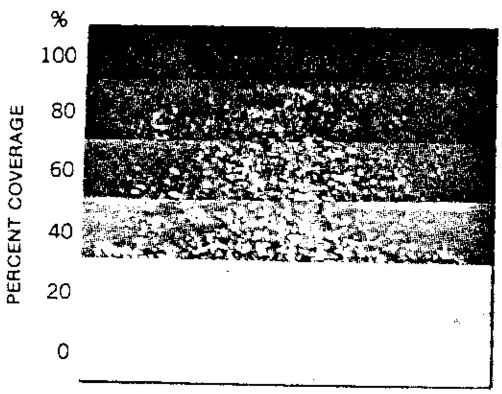


Partial Peen Complete Peen

(FIG. 15)



(FIG. 16)



SUMMARY

Shot-peening can extend the fatigue life of parts that are dynamically loaded, even those made from high strength-super alloys.

It is effective as a pre-plating and/or coating process. It minimizes the effects of embrittlement during plating and retards crack propagation due to changes in surface finish and hardness caused by processing.

Since there is no production method available to measure the induced compressive stress, positive process controls are essential to ensure repeatability in the shot-peening process. These controls must include the quality of media used (size, shape and condition), maintaining the level of kinetic energy necessary to achieve depths of compression required, (monitoring peening intensity) especially at areas of section change and on surfaces where stress-risers may exist and, finally, the application equipment should be automated to the extent that air pressure, shot flow and movement of the part through the shot stream are controlled and monitored.

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