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New Studies May Help Prevent An Old Problem

Shot Peening: an answer to hydrogen embrittlement?

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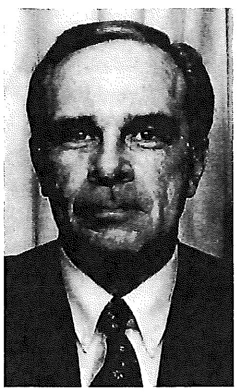


Jim Wandell has more than 20 years' experience in the metalworking industry at both the mill and service center levels. Author of several papers, he has presented shot peening seminars to OEMs, both large and small, and has been a featured speaker at several industry functions.

Historically, shot peening of coiled springs has been viewed as an economical means of significantly improving their safe operating stress range.

Springs, with wire diameters as small as .005 inch, as well as very large ones made from 3.0 inch diameter rod, have been successfully shot peened to increase their fatigue resistance. Peening is also used on a production basis on leaf springs, Belleville springs, and torsion bars.

The peening process is also viewed as a cost effective method of increasing a spring's operating life by five to ten times or more when compared to unpeened springs. The performance and life requirements of automobile engine valve springs is a typical example. Because of these demands, valve springs have been shot peened for more than 45 years.

Today, in addition to giving the end user, or customer, a highly engineered reliable spring, many requirements include the parts to be plated. In most cases, the plating is required for added corrosion resistance. For some parts, it may be just for cosmetic values. Whatever the reason, the plating process may be the chief cause of hydrogen embrittlement. When this occurs, the spring's performance as designed will be greatly curtailed. Controlled shot peening may be a preventative method and a solution to hydrogen embrittlement problems.

Through controlled shot peening, the surface of metal is pre-stressed in compression. This involves the bombardment of a metal's surface with small spherical cast steel, stainless steel, glass or ceramic beads. The peening causes the surface fibers to yield in tension and residually compressing the sub-surface fibers (Fig. 1). The action of the sub-surface fibers in trying to restore the surface to its original condition leave the surface in residual compressive stress. The magnitude of this compressive stress is equal to 50 to 60 percent of the ultimate tensile strength of the material being peened.

Residual compressive stress offsets the effects of the applied load and prevents fatigue crack initiation or crack propagation.

Because of shot peening, excellent improvements in fatigue characteristics are achieved. Fig. 2A is a Goodman diagram that shows fatigue strength increases of peened versus nonpeened round wire helical compression springs which were not preset. Of note are the various materials used including music wire SAE J178, hard drawn valve spring quality wire - SAE J172, oil tempered chromium-vanadium valve spring quality wire - SAE J132. Fig. 2B is a Goodman diagram showing fatigue strength improvements of the same springs which were preset.

One of the more common applications of shot peening has been its use prior to nickel or chrome electrodeposit. Any time a hard amorphous surface is applied to metal, it becomes very susceptible to fatigue cracking. Over time, in cyclical loading, these cracks will propagate into the base material reducing the fatigue life of the part. However, if that surface is shot peened prior to plating, leaving the surface in a uniform layer of compressive stress, then cracks in the hard plate surface cannot propagate. The life of the part is extended greatly (Fig.3).

The plating and subsequent baking of metal parts act as a fatigue debit lowering their overall strength. Fig. 4 shows the rotating beam bending test results of peened and unpeened 4340 steel plated with .001 inch

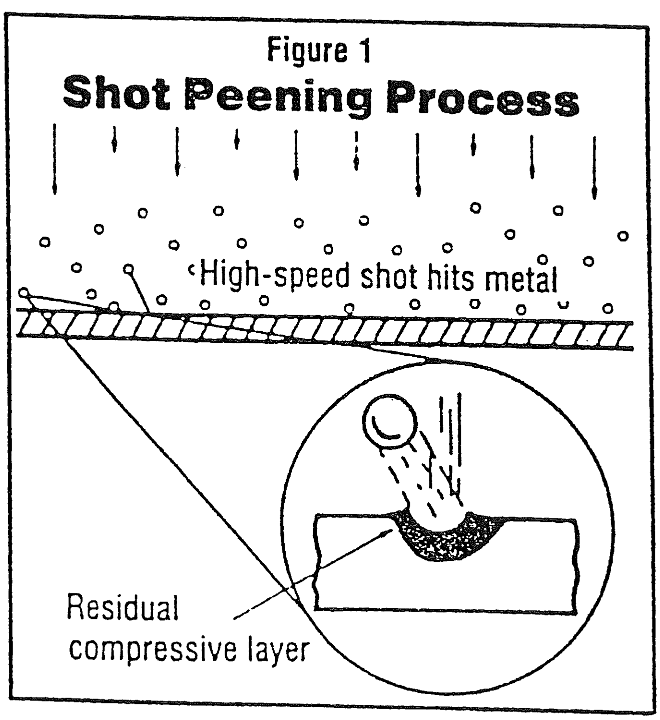


Fig. 1: Peening compacts surface layer, stressing it in compression

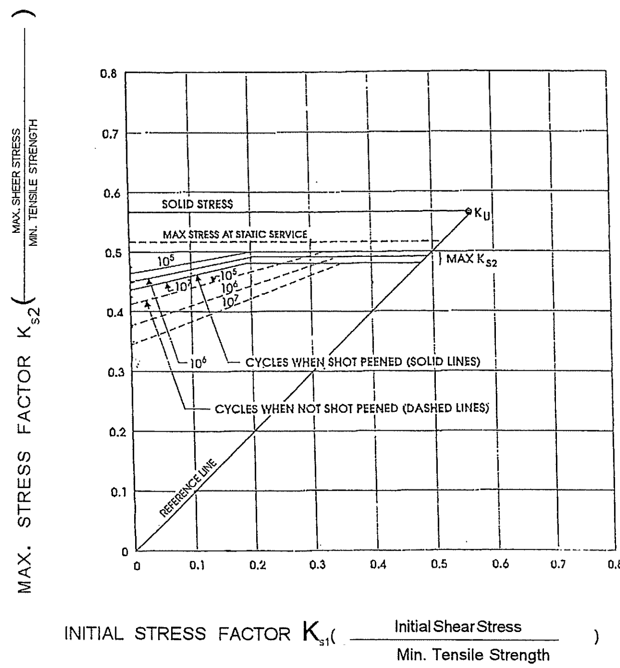
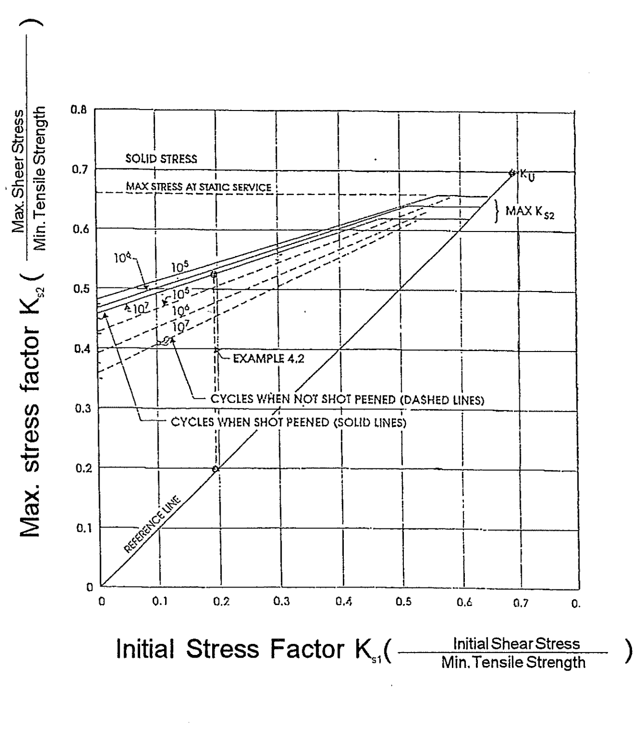


Fig 2A: Fatigue strength diagram for round wire helical compression springs which are not preset. All stresses are Wahl corrected. Diagram applicable to springs which are not preset and to the following materials: music steel spring wire and springs -SAEJ178; hard drawn carbon steel valve spring quality wire and springs -- SAEJ172; oil tempered carbon steel valve spring quality wire and spring -- SAE J351; oil tempered chromium-vanadium spring quality wire and springs --SAE J132. (Ref. 1)

Fig. 2B: Fatigue strength diagram for round wire helical compression springs which are preset. Diagram applicable to moderately preset springs and to materials mentioned in Fig. 2A. (Ref. 1)



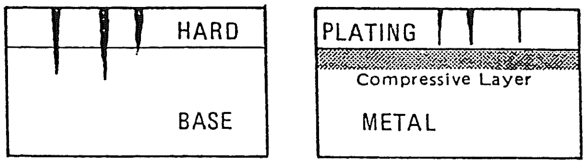


Fig 3: Plating cracks will not propagate into prestressed base

of electroless nickel. Because of test results such as this, shot peening prior to plating is recommended on cyclically loaded parts to enhance fatigue properties. Federal Specification QQC-320 and MIL-C26074A call for shot peening of steel parts prior to chrome or electroless nickel plating where service requires unlimited life under dynamic loads. More recently, the American Society For Testing and Materials (ASTM) has published Standard Specification B851 covering shot peening prior to plating.

In addition to conditions just reviewed, hydrogen embrittlement of the base metal can occur in the plating bath. By making the part cathodic in a plating solution containing water and acid, hydrogen forming on the part's surface frequently enters the material and embrittles it. This condition may be further enhanced if the surface of the material is in residual tensile stress.

Atomic hydrogen is extremely mobile and easily

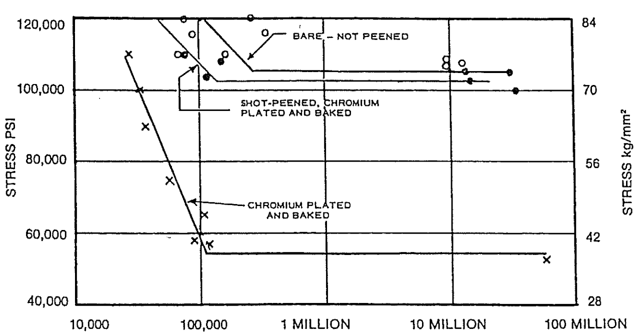


Fig 4: Cycles to failure 4340 steel, 52-53Rc rotating beam fatigue. (Ref.2)

penetrates and interacts with a metal. It greatly reduces its ductility and ability to withstand cyclic loads. One of the best preventative methods is to not allow hydrogen to enter the metal or vastly slow down its ability to migrate into a metals' surface.

In 1986, a study conducted at Ohio State University shows that shot peening not only retards the time for hydrogen to migrate through a metal's surface, but also lowers the steady state permeation rate of the hydrogen by as much as 24%.

Fig. 5 is a summation of the study comparing a non-peened, annealed membrane versus a shot peened membrane with hydrogen being introduced to one side. It is important to note that on the non-peened membrane, hydrogen permeated it within 20 minutes. On the peened membrane, it took 80 minutes for hydrogen to permeate, or a 400% increase in time. Of further significance was the reduction in the steady state value of the hydrogen -- up to 24%.

Hydrogen embrittlement is often the result of the acid clean and/or the electroplating of high carbon steels that have residual tensile stress on the surface during treatment. By shot peening, surface residual

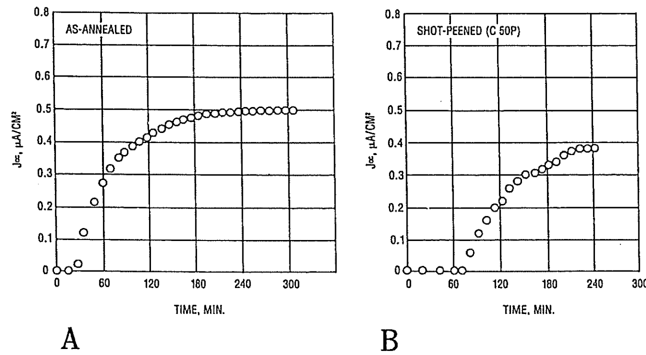


Fig 5: Effect of shot peening on hydrogen migration. J^8, A/CM^2 hydrogen permeation rate. (A) non-treated surface (B) shot-peened surface. (Ref.3)

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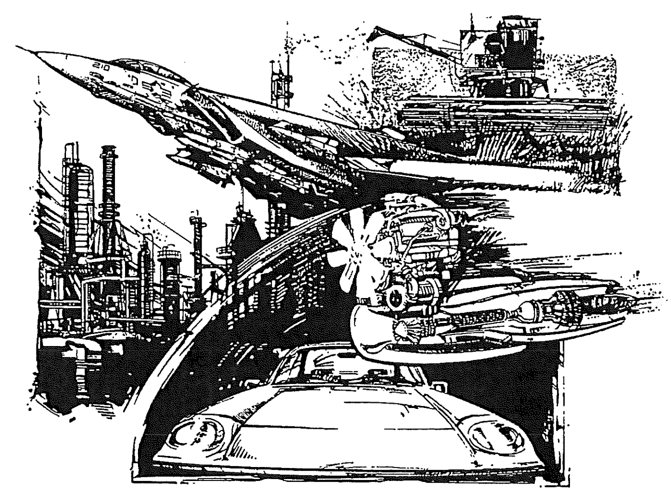

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stress is changed to compressive thus eliminating tensile stress. By peening prior to plating process, hydrogen embrittlement can be prevented.

Recently, a new study was conducted to see what effect increased peening intensities would have on hydrogen's steady state permeation rate. By increasing the intensity of the peening process, or how hard the material is being hit, on the same hardness of material you'll drive the compressive layer deeper. Fig. 6 points out this relationship with the depth of the compressive layer on the horizontal axis and the peening intensity on the vertical axis as noted by "C" and "A" scale. This refers to the Almen "C" or Almen "A" arc heights which are a function of shot hardness, shot mass, shot velocity, angle of impingement, and exposure time. Looking at the graph, on either scale by going from point "0" (zero) to the right, means the part is being hit harder. As you can see, by going from .002C to .004C, whether peening a Rockwell C-31 hard part or a Rockwell C-52 hard part, the depth of the compressive layer is deeper.

The new study did indicate that the steady state permeation value decreased as the peening intensities increased. Fig. 7 is a summation of the study as done on 4130 steels. These favorable findings were strictly attributed to an increase in the depth of the compressive layer induced by shot peening.

A word of caution should be sounded regarding higher shot peening intensities. This approach may not always be practical; as placing the cross-sectional area of a part into too much compression could lead to distortion of the material. A rule of thumb is that a compressive layer should not exceed 10% of the cross sectional area of the material.

Another phenomena may be happening in the plating bath which may be of concern to springmakers. Stress corrosion cracking (SCC) of the metal used for the spring could occur.

For SCC to occur, there has to be an interaction of three things: 1) a specific environment
2) a susceptible alloy
3) tensile stress.

Fig.8 illustrates the "Stress Corrosion Triangle." If all three of these conditions interact with one another, the possibility of SCC to occur is greatly enhanced.

The specific environment possibilities for various alloys are virtually unlimited. To name a few: chlorides, fluorides, polythionic acids, and sulfides with austenitic stainless steels; Amines, anhydrous ammonia, carbonates, cyanides, hydroxides, and nitrates with carbon steels; chlorides and hot water with aluminum. If static tensile stress is added to any of these combinations, then SCC may be the failure mechanism.

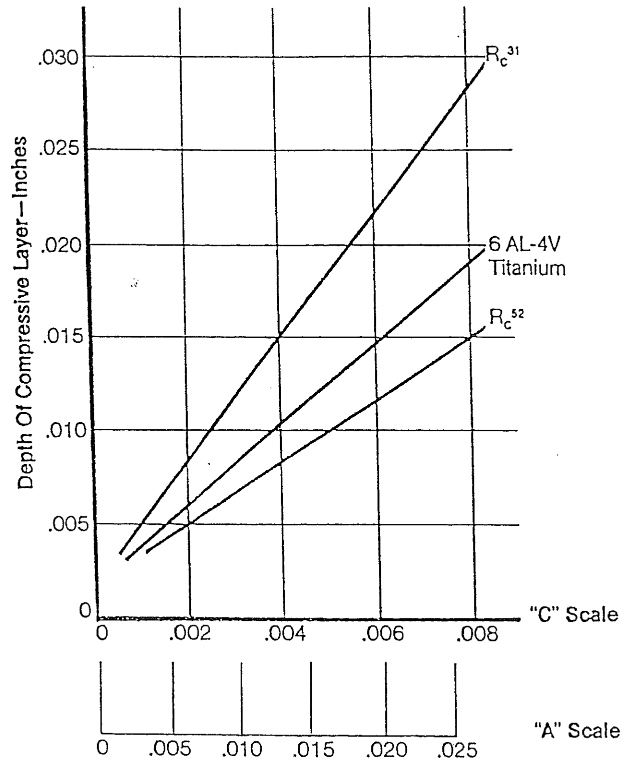

Fig. 6: The harder the material being peened, the shallower the depth of the compressive stress layer resulting from peening at a particular intensity (arc height). (Ref. 4)

Effect of Shot Peening Intensity on Hydrogen Permeation at an I_c of $2A/m^2$

Intensity	Diffusivity rise, cm^2s^{-1}	Diffusivity decay, cm^2s^{-1}	Fluz,J. A/m^2
zero	$4.10x10^{-7}$	$4.30x10^{-7}$	$10.05x10^{-3}$
7	$3.50x10^{-7}$	$4.38x10^{-7}$	$7.17x10^{-3}$
12*	$5.13x10^{-7}$	$3.83x10^{-7}$	$5.0x10^{-3}$
12**	$3.62x10^{-7}$	$3.80x10^{-7}$	$6.7x10^{-3}$
15	$3.87x10^{-7}$	$3.61x10^{-7}$	$6.7x10^{-3}$
22	$7.60x10^{-7}$		$4.25x10^{-3}$

0.1 N NaOH Specimen thickness = 0.19cm
* Peening bead diameter = 0.0343cm
** Peening bead diameter = 0.083cm

Fig. 7 Ref. 5

Of primary importance is the fact that inducement of residual compressive stresses in the surface of the metal, because of shot peening, can be an effective measure for preventing SCC, regardless of the dominant SCC mechanism, the material of construction, or the corrosive environment. If any leg of the triangle is broken, such as the absence of surface tensile stress because of shot peening, SCC will not occur.

Based on what has been presented, indications are that shot peening should have a very beneficial effect on the retardation of hydrogen embrittlement as well as the retardation of hydrogen assisted cracking. Certainly, it may be an answer to an age-old problem springmakers face when plating is required by their customers. ❖

The Stress Corrosion Trangle

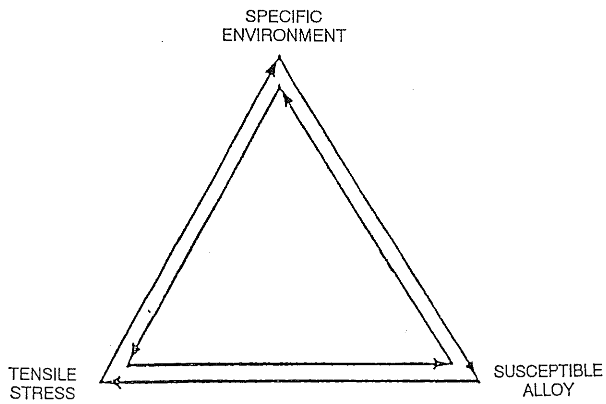

Fig 8: (Ref. 6)

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PEENSCAN®

PEENSCAN is a process used to measure shot peening coverage in terms of amount and uniformity, by either automatic or semi-automatic means of shot peening.

PEENSCAN process provides quality controlled peening.

PEENSCAN PROCESS tracer liquids dry into an elastic film which needs to break-up for removal. The objective of the PEENSCAN process is to provide a practical way to measure coverage in terms of amount and uniformity of fluorescent tracer dye removal.

COVERAGE is defined as a uniform and complete denting or obliterating of the original surface of the part or work piece as determined by visual examination using a ten-power magnifying glass. To compound the problem, it is extremely difficult if not impossible, to visibly examine large areas using a ten-power glass. Fillets, cavities, grooves and holes are also difficult to inspect because of inacessability of visual instruments.

Clean bare metal objects appear as a deep purple color under U.V. light.

Fluorescent tracers are ultra-violet visible compounds, not as highly sensitive as used in penetrant inspection, but are more sensitive than color tracers such as dye-marker blue. Fluorescent visibility under U.V. light is clearly superior to 10X visual coverage, and also superior to other natural light ink coatings.

Tracer liquid coating responded to all intensity changes.

Shot striking elastic tracer film breaks away film in shot impact area only. Low angle of impingement and ricochet peening will not remove tracer coating without increasing peening time.

Tracer remaining on a part shows flat spots and incomplete denting of surface. The remains or absence of tracer liquid viewed after peening by a U.V. light give evidence as to the degree of removal, or percentage of coverage applied to the part by shot peening.

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