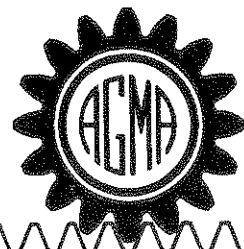


Three Innovations Advance the Science of Shot Peening

by: John S. Eckersley and T. Jeff Meister, Metal Improvement
Company



TECHNICAL PAPER

Three Innovations Advance the Science of Shot Peening

John S. Eckersley and T. Jeff Meister, Metal Improvement Company

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Controlled Shot Peening has long been recognized as a very effective process to prolong the fatigue life of all types of gears. Three recent innovations have extended the state of the art: 1) by a process that provides a smooth surface after peening to increase the resistance to surface fatigue; 2) by a coupon system that makes possible actual X-Ray diffraction curves to monitor production shot peening; and 3) by a computer program that permits a reasonable prediction of residual stress curves.

C.A.S.E.sm is an acronym for Chemically Assisted Surface Engineering. Frequently, when the bending fatigue life of very high cycle gears has been increased by shot peening the tooth roots, the next mode of failure is surface fatigue or pitting of the contact faces. There has been a need, particularly for automotive and aircraft transmissions, to extend the surface fatigue life beyond that provided by shot peening alone and smoothing the surface after peening has been found to be very effective. The C.A.S.E. process cuts the relative finishing time, after shot peening, down to just minutes for typical automotive sun gears and provides a surface which, in addition to the compressive stresses from the shot peening, can have an R_{sk} value of as little as -1.1 . Very significant increases in surface contact fatigue (pitting) life have been observed.

MILAMsm system. By the use of the new MILAMsm coupons, X-Ray Diffraction (XRD) profiles can now be furnished in a matter of days and at a fraction of the usual prices. The MILAM coupons are dimensionally similar to Almen strips but are thicker and made of the same material and hardness as the part itself. The coupons are used in the Almen fixture so that they reproduce the effect of shot peening in the most critical locations on the part. The convenient new system opens up the use of XRD as a production tool for the evaluation of shot peening quality and is adaptable to Statistical Process Control (SPC) without the need to destroy the part.

Peenstresssm is a computer program, developed in conjunction with ENSAM, a French engineering university, that permits the optimization of shot peening parameters during the process development phase. The program library now contains nearly 100 metals and alloys in various heat treatments and will accept inputs for shot size, shot type and Almen intensity. Peenstress will then calculate, and reproduce on screen, residual stress distribution curves for those parameters of a variety of part geometries.

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Introduction

After springs, gears are the most commonly shot peened parts, ranging in applications from 40 foot (12 m) diameter turret gears for mining equipment to miniature pinions for electric hand tools and from ultraprecise low volume gears for helicopter and turboprop transmissions to millions of sun and pinion gears that find their way into the transmissions of the most popular cars and trucks. In almost every case, the shot peening is specified on gears to increase their resistance to root bending fatigue. Controlled shot peening will introduce into the surface layers of a gear root a very high magnitude of residual compressive stress, at least equal to 50% of the ultimate tensile strength of the gear material. Since fatigue cracks generally start at the surface and always do so in an area where the tensile stresses are greatest, preloading the surface in compression, by shot peening, has the effect of rasing the root fatigue strength of gears by as much as 40%; even 50% when dual peening is employed. Three recent innovations that have extended the state of the art, relating to the shot peening process, are of particular interest to the gearing community.

THE C.A.S.E.sm PROCESS.

C.A.S.E. is an acronym for Chemically Assisted Surface Engineering and describes a two-stage process developed by MIC in England and first applied to racing car gears. It is a new process and all applications and tests have not been identified but the results on transmission gears, primarily to retard the initiation of pitting fatigue, are very encouraging. The two stage C.A.S.E.sm process requires first that the gears are properly shot peened, followed by chemically assisted superfinishing of the contact surfaces. Together, these processes extend gear life, allow increased root bending loads; allow increased surface contact stresses; convert, through cold work, retained austenite to martensite; reduce notch sensitivity; negate grinding abuse by changing the residual tensile stress remaining from the grinding to compression; and improve surface finish while retaining contact relief indentations. There are studies that show that if a gear contact surface is

totally smooth, there is no relief for the microscopic displacement of the surface under sliding and rolling pressure. The C.A.S.E.sm process leaves micro-indentations in the surface providing relief locations for this surface movement.

The superfinishing second stage is an improvement on the traditional vibratory finishing process. The addition of certain chemicals, primarily oxalic acid, permits the process to be accelerated so that it takes hours instead of days to produce a polished surface on a production lot of gears, making C.A.S.E.sm economically viable for even passenger car gears.

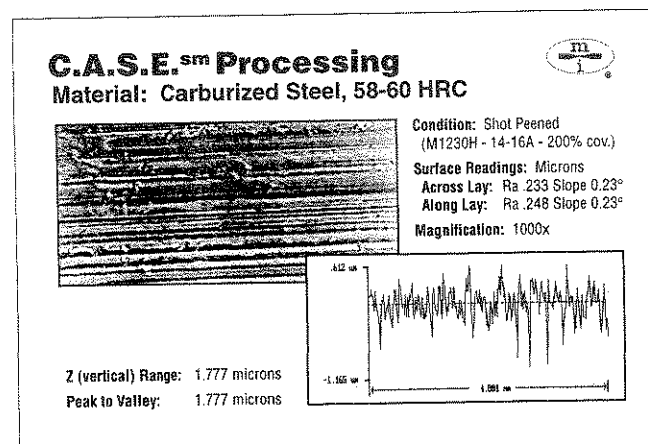


Fig. 1b Shot peened gear steel. Same as in Figure 1a but the surface is now shot peened.

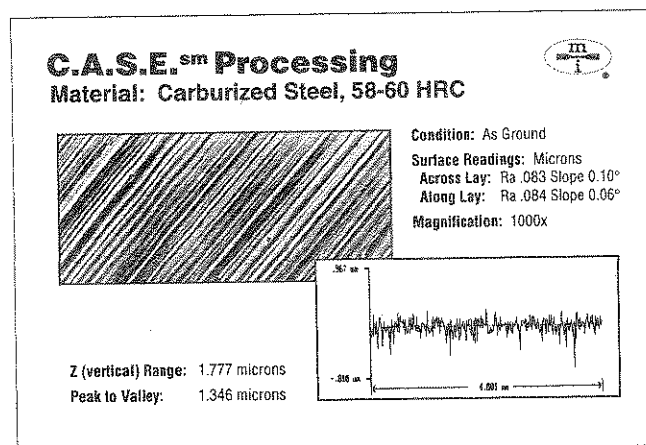


Fig. 1a "As ground" gear steel. Photograph and roughness trace of surface of gear steel after grinding.

Figures 1a and 1b depict some surface textures, both optically and as roughness traces. Figure 1a shows the "as ground" surface with an R_a of $83/84\mu\text{m}$: quite smooth for a ground surface. The Z range of $1.777\mu\text{m}$: this is the vertical range to which the profilometer was set. Figure 1b illustrates basically the same carburized and

ground surface but after shot peening with MI 230 Hard shot at 14-16A and 200% coverage, verified by Peenscan®. The R_a , of course, has increased to about $240\mu\text{m}$ as the instrument now records the dimples and peaks from the shot peening. However, beneficial high compressive stresses are now in the surface. Notice that the Z range is still the same but the trace has higher amplitude, typical of a rougher surface.

The surface shown in Figure 1c, at the same magnification of 1000X, is the final result of grinding, followed by shot peening plus the C.A.S.E.sm superfinishing. Visually, you can see large flat (polished) areas with interspersed indentations. This is close to the ideal surface for a potential pitting application. The R_a has dropped to about $44\mu\text{m}$ as compared to $240\mu\text{m}$ for the shot peened surface and $84\mu\text{m}$ for the ground surface. Again, the Z range is the same but the trace is much smoother, exhibiting more indentations than peaks.

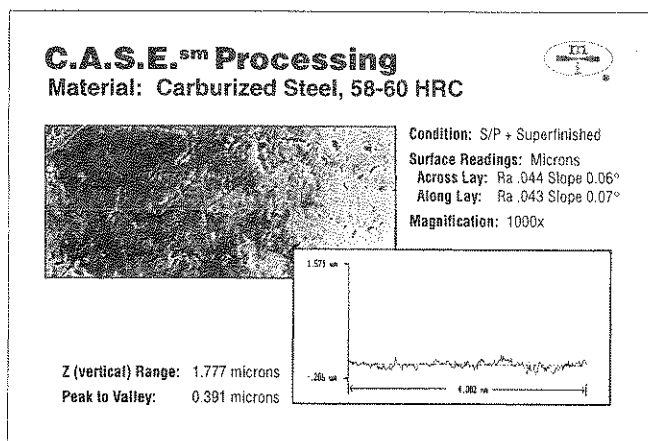


Fig. 1c C.A.S.E. Processed gear steel. Same as in Figure 1b but the shot peened surface has now been superfinished.

The roughness plots or traces in Figure 2 are from racing car gears. The traces are for hobbled and shot peened and then, on the right, superfinished. The R_a dropped from $494\mu\text{m}$ to 59: almost an order of magnitude in the reduction of surface asperities! However, we have introduced another measure of surface texture: R_{sk} . The "sk" stands for "skew" and it represents the ratio of peaks above the mean surface to indentations below the mean. A positive R_{sk} indicates that there are more peaks than valleys while a negative R_{sk} shows more valleys than peaks. R_a indicates, essentially, how high or how low these features are.

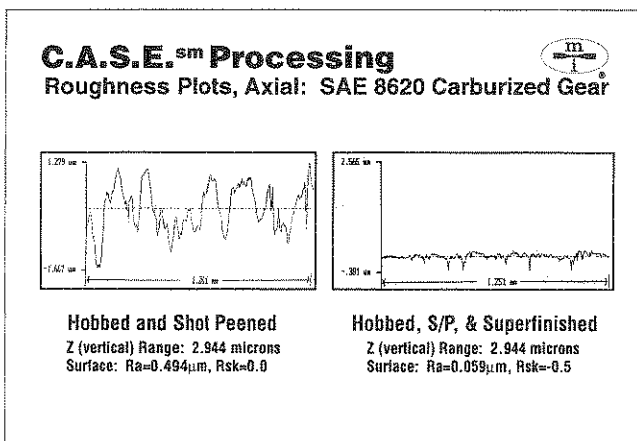


Fig. 2 Comparison of C.A.S.E. superfinished surface. The R_{sk} of only -0.5 indicates more micro-indentations than peaks: an ideal surface for gears to be used in a pitting application.

With the shot peened surface, on the left, the R_{sk} is at zero so that there are as many peaks as there are valleys. However, on the right, not only is the surface much smoother ($R_a = 59\mu\text{m}$) but the R_{sk} is a negative 0.5, indicating that there are many more indentations than high areas. The trace also shows that the indentations are sharper and deeper than the flatter plateau areas. Remember, though, when we are talking about highs and lows here, we are talking microns (μ): one millionth of a meter or 0.00004 of an inch! You would not be able to see the indentations with the naked eye yet they are there to retain lubricant and to allow for the micro-displacement of the surface under contact load. Also there and invisible are the residual compressive stresses from shot peening, helping to retard any crack initiation.

In Figure 3 are pictured the racing gears that were used for the traces illustrated in Figure 2. They are mating gears, about 3 and 4 inches in diameter, respectively. The one on the right is hobbed and shot peened only. The brightly polished surface of the C.A.S.E.sm superfinished one is on the left. The gear on the right, in the picture, is hobbed and shot peened only, so the surface of the teeth looks dull. Later, this gear was also C.A.S.E.sm superfinished like the other one, before being installed in the racing car transmission. How well did they work? Perhaps the test was not very scientific but the racing team reported that where before they had to change gears after every race because of pitting, with the C.A.S.E.sm processed gears, they ran for three races and even then had much less evidence of pitting.