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Improving Fatigue Life of Gears by Shot Peening

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Introduction

Shot Peening is a very well recognized and documented process in the realm of wrought metals and alloys but the same cannot be said for Powder Metals (P/M). Yes, shot peening is being used very effectively to combat metal failures by a few companies who use it on millions of P/M parts but there is a great reluctance to talk about it so thaat published data from test results or real life applications is almost non-existant. The intent of this paper is, then, to bring to light some of what little documentation there is to show that the use of controlled shot peening can have a very positive effect on the fatigue life, for instance, of P/M parts. Also reviewed will be the benefits of some recent innovations that enhance the use of shot peening. It is hoped that other P/M users and producers will see in shot peening a way to extend the useful range of P/M parts and even save weight (and powder!) by considering the use of shot peening from the design stage.

Controlled Shot Peening

Shot Peening, when properly controlled and applied, plays a very important role in extending the failure resistance of wrought metal gears for a very wide range of sizes and purposes. Tiny pinion shafts for miniature motors are shot peened for the same reason as forty foot diameter turret gears for huge draglines used in open-pit mines. In both cases, the purpose for the shot peening is to introduce beneficial compressive stresses into the surface of the metal. Millions of automotive transmission gears are shot peened to combat both bending fatigue and pitting. It is a well-known engineering fact that many forms of metal failures are caused by cracking that initiates at the surface in areas of greatest tensile stress concentration. These failures include metal fatigue from bending, torsional, axial and contact loads, as well as stress corrosion cracking and corrosion fatigue that are strongly influenced by the operating environment. Shot peening, a process by which the surface of the metal part is bombarded by high velocity beads of hard steel or even glass or ceramics to introduce compressive stresses, will therefore prevent or greatly retard these modes of tensile-related failures.

Powder Metal Gears

Powder Metal gears, like their wrought counterparts, respond well to the introduction of compressive stresses by shot peening but only when the density is high enough to retain the induced residual stress. Our information indicates that densities below 7.4 g/cm^3 do not respond well because the pores become fracture initiation points[1]. As with wrought metals, the same tenets hold true for P/M parts: the harder the metal at the surface, the higher the residual stress induced by shot peening and therefore the higher the resistance to failure *but to reach the highest residual stress at a suitable depth beneath the surface, the part must be peened with a shot that is as least as hard as the surface being peened.* Please see Figure 1[2].

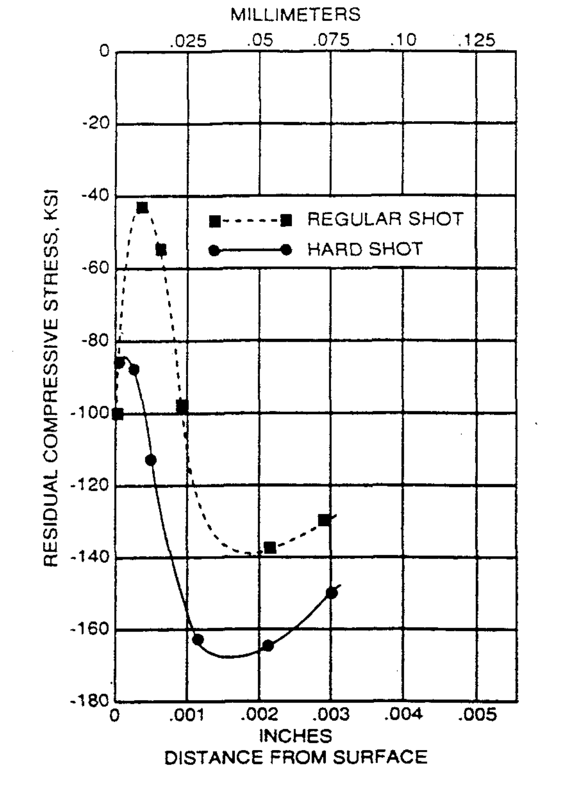
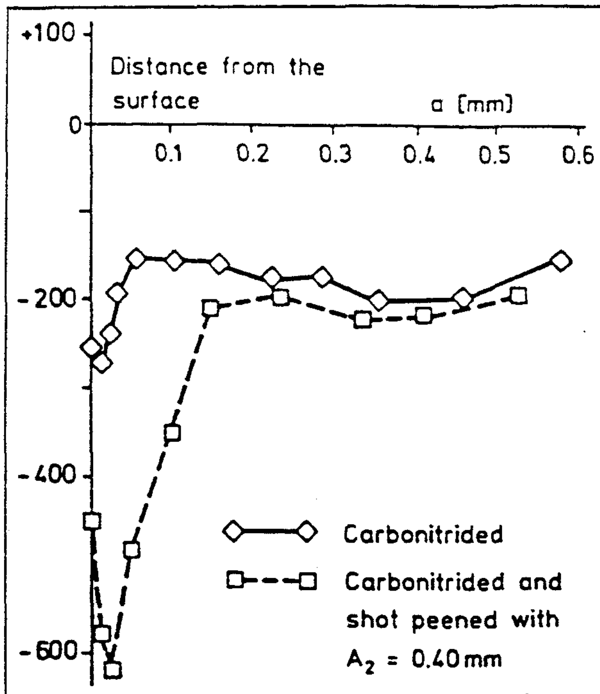


Fig 1: **Carburized Hypoid Pinion Gears, shot peened with hard (55-62HRC) and Regular (45-52 HRC) shot.**

This means that if the surface of a gear is carburized or carbonitrided, the most effective peening must be performed with hard shot in the 58-62 HRC range. Standard hardness shot in the 45-54 HRC range will deform itself on contact rather than indent the surface of a very hard part and without surface indentation, the magnitude of the residual compressive stress may be high but the depth of this compressive stress will be very shallow, as is shown in Figure 2, and may be insufficient to retard crack initiation especially so in a part formed of metal particulates. This is the likely explanation why Sonsino, et. al.[3], did not see any difference in fatigue life between the "as carbonitrided only" specimens and those that were "carbonitrided and shot peened" with a shot that was 522 HV 1.0 or approximately 48 HRC. See Figure 3. It would be interesting to repeat their test using larger hard shot at a higher intensity and coverage. (Please see the section on Peenstress[sm] later in this paper.)



Material: Fe-1.5%Cu, ϱ = 7.4 g/cm³.

Fig 2: Residual Stress Distributions

Peening with Hard Shot

Figure 4 (also from Germany[4]) is an excellent illustration of the value of using hard shot to peen hard P/M parts, in this case gears of Fe-Mo alloy at a density of 7.5 g/cm³ and case hardened to 60 HRC. The shot hardness used was 63 HRC but the shot size and Almen intensity were very similar to those used by Sonsino, et. al.[3]. Two items are worthy of note on the S/N curve of Figure 4. First, the fatigue limit for the hard shot peened gear roots was 1030 Mpa, compared to the unpeened control gear specimens at 900 Mpa. Second, after grinding of the roots (no shot peening), the fatigue limit actually fell to 770 Mpa! This may come as a surprise to some because of the often accepted idea that smoother surfaces reduce stress risers and therefore improve fatigue characteristics. While this is generally true, it is also true that grinding to achieve smooth

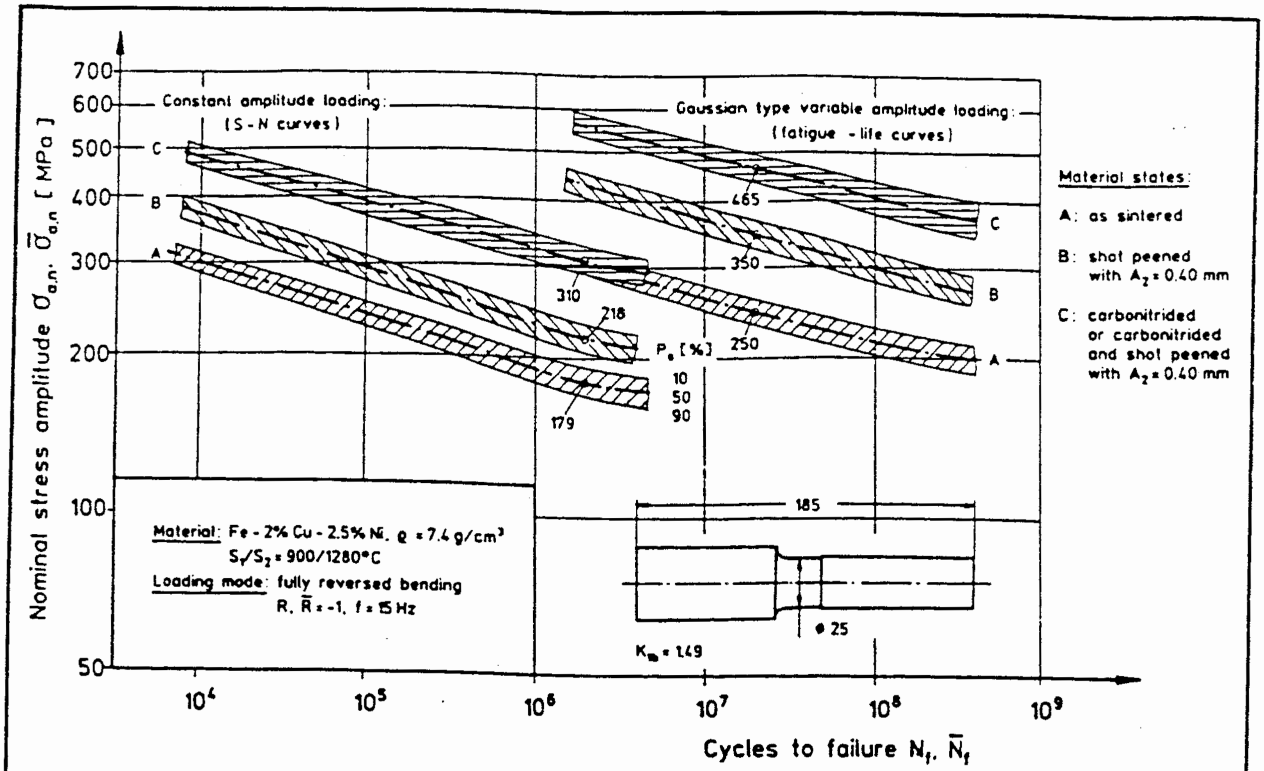
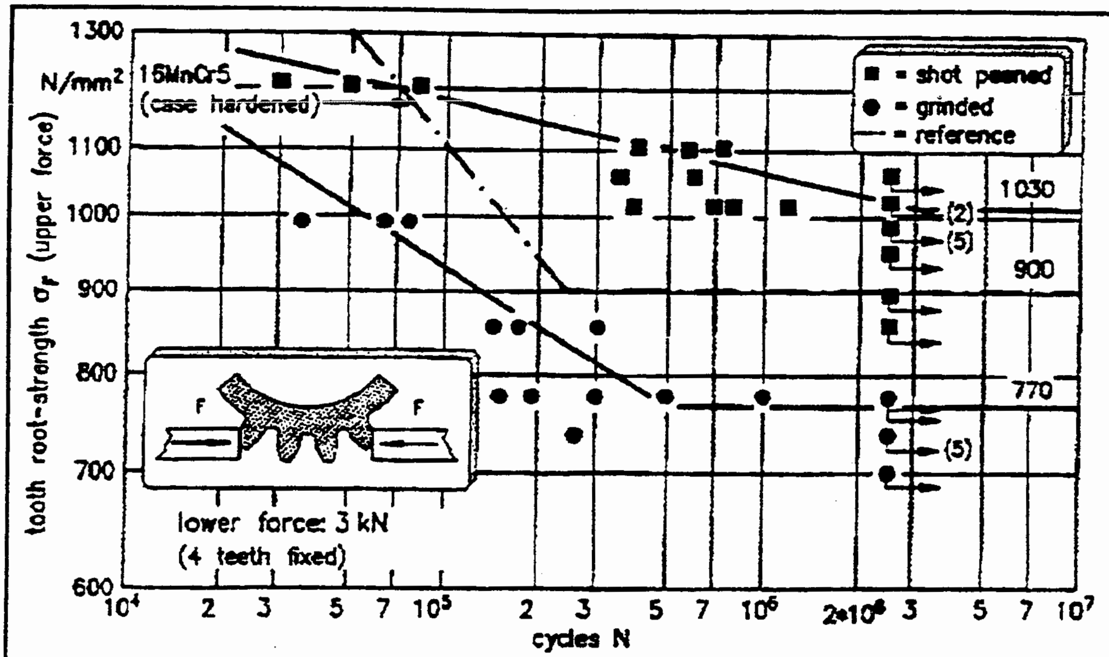


Fig 3: Influence of different post sintering treatments on the fatigue behaviour of the sintered steel Fe-2% Cu-2.5% Ni under constant and variable amplitude loading



Gear data:
m_n = 3,5 mm b = 20 mm
z = 25 x = +0,35
α = 20° β = 0°

Material data:
• Fe-Mo alloy system
• able to calibrate
• ρ = 7,5 g/cm³

Heat treatment:
. case hardened
• surface hardness: 60HRC
• C_{edge} = 0,85%

Fig 4: Tooth Root Fatigue of a High Density P/M Gear. (50% probability of failure) surfaces will usually introduce residual stresses in tension sometimes exceeding the yield strength of the metal. When these residual tensile stresses are added upon by the tensile stresses of the applied loads, the combined residual and applied stresses can exceed the ultimate tensile strength of the material and very rapidly promote the formation of fatigue cracks. This is true for any metal, P/M or wrought. However, grinding followed by shot peening can be very beneficial.

Crush and Impact Improvement
There is not much data to be had in these areas but, whereas shot peening has little or no effect on either for wrought metals, it appears to have a remarkably significant effect on both the crush and impact resistance of powder metal gears. There are unpublished test results that indicate impact strength improvements of 70% are attainable by shot peening the P/M gears after heat treating. Another test showed that unpeened gear teeth broke at 16 inches in the drop test. Similar peened gears required a drop from 21 inches before breaking. An extensive crush test to evaluate the effect of shot peening on spur gears showed an average improvement of 44% as compared to the unpeened control group.

Powder Forging
Powder Forging should be the ideal P/M process for shot peening. Powder forging produces the same density as both wrought billet forgings and sand castings (7.82-7.84g/cm^3) but actually has a higher ultimate tensile strength (135-275 ksi or 930-1900 Mpa) than the other two processes[1]. Unfortunately, no data on shot peened powder forged parts were available to the authors.

C.A.S.E.℠ Process

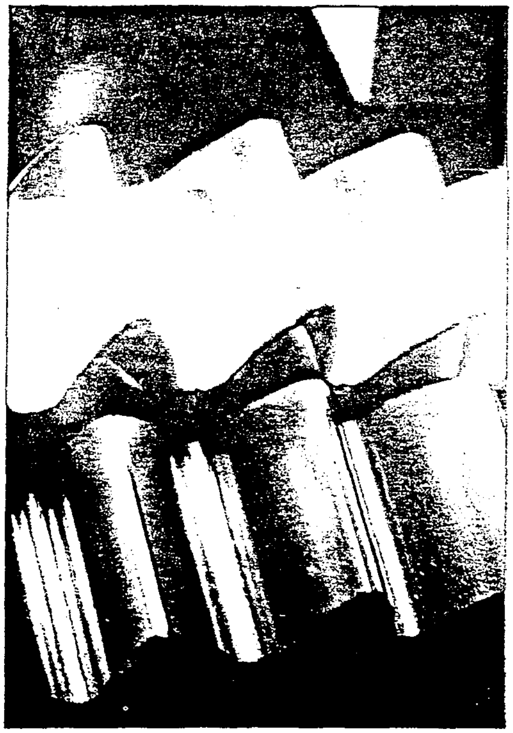


Fig 5: C.A.S.E.℠ Finished Gear, top, shows high polish from shot peening followed by micro-honing. The lower gear is as shot peened.

Chemically Assisted Surface Engineering (C.A.S.E.℠) is a two-stage process developed by Metal Improvement Company, Inc. that has significant application for high density P/M gears. The first stage requires that gear teeth, including the pressure faces, be shot peened in a normal manner. This is followed by the second stage: a fast micro-honing of the surface to almost a mirror finish but with a negative R_{sk} that retains lubricant. This is an ideal surface to promote increased pitting fatigue life of gear teeth.[5]

Peenstress℠ Software
Developed in conjunction with ENSAM Technical University in France, Peenstress℠ makes it possible to determine the close to ideal shot peening parameters for a given set of materials, hardnesses and geometries. It allows "what if" choices of shot size and intensities but it always assumes that the shot hardness is at least equal to the hardness of the metal to be peened and that the coverage is equal or

greater than 100%, i.e., total indentation of the peened surface[6].

Conclusion

Controlled Shot Peening and related processes offer to the P/M industry a convenient and economical method of increasing the failure resistance of high density gears and other parts. By applying the results of careful testing to design considerations, lighter, smaller parts can be achieved by taking advantage of the beneficial residual compressive stresses imparted by shot peening. The C.A.S.E.sm[sm] Process can be used to smooth surfaces without the fatigue robbing effect of grinding and Peenstress[sm] can be employed to determine the shot peening parameters thereby reducing the spectrum of test criteria. The information presented hopefully will lead to more research so that some definitive specifications can be written.

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For more complete information on Controlled Shot Peening, please request "Shot Peening Applications" Seventh Edition, an engineering manual, from Metal Improvement Company, Inc., 10 Forest Ave., Paramus, NJ 07652.
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