

Optimized High Production Shot Peening
for the Automotive Industry.

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ABSTRACT

This paper presents an overview of high production shot peening technology for automotive applications where specific fatigue strength benefits must be produced. Requirements, challenges, and benefits are discussed in light of auto industry trends. Examples of process engineering testwork required and successes from a technology and cost viewpoint are provided.

KEYWORDS

Strength/weight, "process of choice", statistically capable, capability index (Cpk), bilateral tolerance, peened surface extrusion folds (PSEF).

INTRODUCTION

Due to the intense competitive pressure within the auto industry, especially in the areas of technology, quality, and cost, and the demand for greater fuel economy and performance, technological advances in engine and drive train systems as well as increases in design strength/weight are necessary to survive.

The potential fatigue strength benefits of shot peening are well known within certain engineering circles. However, cost/effective utilization of the process to impact component design has been limited due to lack of reliability. The statistical reliability or capability of every manufacturing process is increasingly recognized as one of the critical arenas in the battle for quality. If the shot peen process is to become a "process of choice" to increase strength/weight characteristics of component design, rather than a process of last resort, it must become a statistically capable process whose process parameter values and tolerances are based upon workpiece specific fatigue data.

A statistically capable process is one which meets a predetermined level of conformance resulting in acceptable product variability. The capability of a process is quantified via a capability index (Cpk) that defines the percentage of conforming product within a normal distribution of process parameter measurements taken over time. A Cpk index is determined by the range of process parameter data and the distribution of that process parameter data with respect to the mean of a bilateral tolerance or control limit. The bilateral tolerance for each process parameter, that can affect workpiece fatigue strength, defines the maximum variation around a nominal value that will still produce acceptable product variability within the design intent.

Table I lists the peening process parameters that can affect workpiece fatigue strength.

- | | |
|---------------------------|--------------------------------------|
| 1. Shot velocity | 8. Shot impact angle |
| 2. Shot diameter | 9. Shot flow rate |
| 3. Shot size distribution | 10. Shot blast pattern |
| 4. Shot shape | 11. Nozzle to workpiece relationship |
| 5. Shot hardness | 12. Workpiece exposure time |
| 6. Shot type | |

Table I: Peening process parameters that can affect workpiece fatigue strength.

The issues and steps surrounding the engineering of a statistically capable process are too numerous to be contained within the confines of this paper. Issues such as the statistical reliability of the almen test strip measurement system, engineering for cumulative process parameter tolerance stack up, designing statistically reliable peening machines, etc., will be addressed in subsequent publications.

The scope of this paper will be to describe the starting point for engineering a statistically capable shot peen process; defining optimum almen intensity value. (See [1] for details of almen intensity development). Due to the required confidentiality of most of the testwork performed at Advanced, the example presented is taken from two previous publications. [1] [2] The subsequent work of identifying the optimum nominal value for each of the parameters in Table I and its direct effect on fatigue strength will be presented in a future paper.

BACKGROUND

Numerous publications support the fact that unique optimum peening process parameter values or ranges exist for specific workpiece characteristics. [2] [3] [4] [5] As far back as 1943, John Almen identified the concept of an intensity "sweet zone." [5] Simpson and Chiasson [4] studied the effect of almen intensity on fatigue life in Ti alloys, Al alloys and AISI 4340 steel hardened to 48 - 50 Rc. They concluded that optimum fatigue life performance through shot peening is influenced by balancing the benefits of process induced residual compressive stress and peening induced surface damage. There is a relationship between almen intensity and the forming of surface laps or peened surface extrusion folds (PSEF). Beyond an intensity threshold, PSEF is produced which begins to deteriorate fatigue strength optimum value.

The purpose for this testwork was to determine the optimum almen intensity range for a carburized helical gear by evaluating tooth bending fatigue life, residual stress, and the influence of PSEF.

Test Procedures

TEST GEARS - The gear material was AISI/SAE 4023 steel. The gear was carburized at 925 C (1700 F) and oil quenched such that the case depth to the hardness of 50 RC is in the range of 0.75 - 1.15 mm (0.030 - 0.045 inches). The gear was then tempered at 200 C (400F) so as to maintain the surface hardness of 58 Rc minimum. (See Figure 1)

SHOT PEENING - The shot peening machine used was equipped with a microprocessor. The process parameter nominal values and tolerances were programmed into the microprocessor. In the event of a process parameter value exceeding the set tolerance the microprocessor would alarm, shutdown the peening machine, indicate

which parameter was at fault and retain in memory the necessary information to continue the peening cycle from the process interrupt point once the fault was corrected. There were no alarms during the peening of the test specimens.

The gears were peened to 110% workpiece saturation, which was double the time required to reach 100% almen saturation (See [1] [6] for determining workpiece saturation), to three almen intensity "A" levels (0.012, 0.018, and 0.024 inches) using shot size of S-230, and to one almen intensity "C" level of 0.008 inches with S-280 shot. All other parameters were held constant within the tolerances given in Table II, except for air pressure (shot velocity) which was increased when the intensity increased.

<u>Parameter</u>	<u>Value</u>
Shot flow rate	± 2 oz/min
Workpiece Saturation	110% (200% Almen Saturation $\pm 10\%$)
Lance speed	9 in/min ± 1 in/min
Lance stroke length	9 in $\pm 5\%$
Specimen rotation	30 rpm ± 1 rpm
Angle of impact	90 degrees $\pm 2\%$
Air pressure	± 1 psi
Shot size & shape	Exceeds MIL-S-13165-B Table 1 requirements
Shot Hardness	54-60 HRC
Almen strip flatness	± 0.0005 in
Almen strip hardness	45 HRC ± 1 HRC

Table II. Shot Peening Process Parameters.

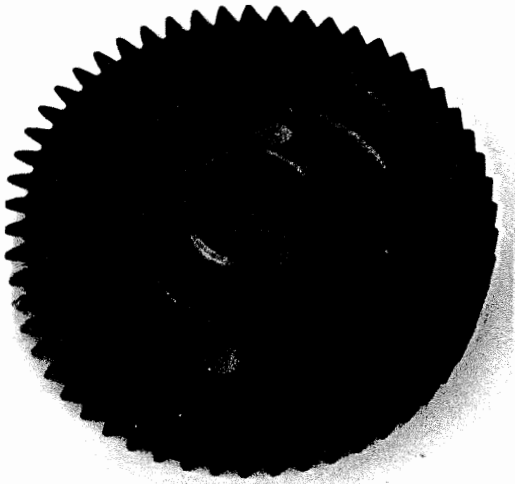
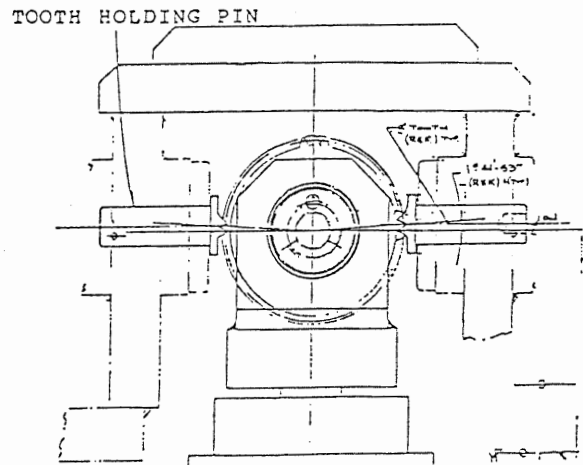


Figure 1 Testwork helical gear



Output Gear Fatigue Test Fixture

Figure 2

Each test gear had two test teeth located 90 degrees from the other. One of the two teeth was masked during peening to provide a corresponding unpeened baseline value. Neighboring teeth were ground away after peening to avoid damaging the gear holder pins when tooth failure occurred.

FATIGUE TEST - Single tooth bending fatigue tests were conducted utilizing a rotating mass type of test machine (Sonntag Model SF-10) with 10,000 lbs loading capability. The test fixture is shown in Figure 2. The load with an amplitude of 2,500 lbs followed a sinusoidal waveform with a mean load of 3,200 lbs in tension-tension ($R = 0.12$) at 30 Hz.

RESIDUAL STRESS MEASUREMENT AND SCANNING ELECTRON MICROSCOPY - X-ray diffraction residual stresses were determined using a two angle sine-squared -psi technique. Measurements were made at the surface and as a function of depth in the root-to-crown (radial) direction just above the root fillet radius of a tooth. A scanning electron microscope (SEM) was used to observe surface topography changes due to shot peening.

RESULTS & DISCUSSION

Figure 3 shows the data produced during the fatigue life versus almen intensity study. Included on this data plot is the data from the same gear peened in a conventional controlled high production operation in an automotive plant to a 24A almen intensity. Although the almen intensity achieved was identical, the sub-parameter values, such as impact angle, shot size uniformity and broken particle content, as well as the level of workpiece saturation were different. These gears were fatigue tested on the same machine and fixture as the optimized peened data. Table III tabulates mean and Weibull B-10 life from Figure 3. The 24A specimen demonstrates the highest mean and B-10 life.

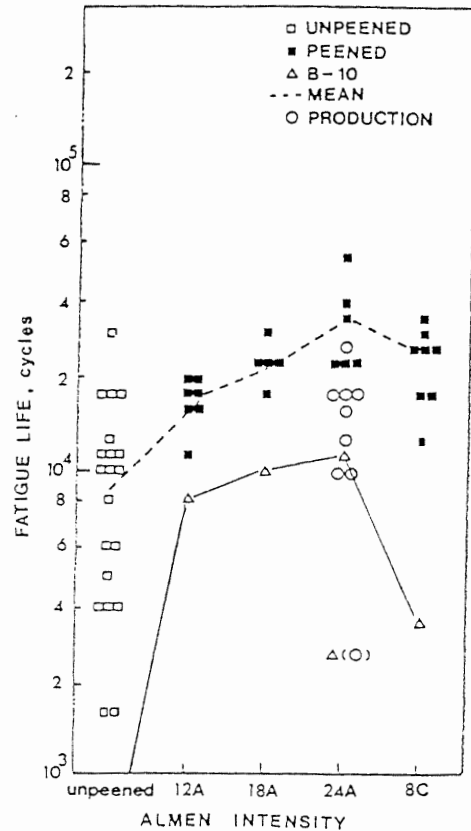


Figure 3 Effect of Almen intensity on fatigue life

	Unpeened	12A	18A	24A	8C	24A Conventional peened
Mean	9,850	16,571	23,800	33,167	24,750	16,375
B-10	56	7,708	11,512	11,953	3,568	2,663

Table III. Mean and B-10 life cycles to failure of various specimen groups

The fatigue life scatter is broader than normally experienced for this type of testwork. Unpeened baseline exhibits the broadest scatter with the mean relatively high in comparison to shot peened mean life values. This is due, in part, to LCF (low cycle fatigue) testing instead of HCF (high cycle fatigue).

The test stress for HCF was too low for the crack to propagate to complete failure. A LCF mode was necessary. Testing in a LCF mode suppresses the influence that different process parameter values have upon fatigue life. The reason for this is illustrated in Figure 4. Additionally, the life span in crack propagation dominates the fatigue life in a LCF test. It is therefore, difficult to detect any influence that the changes in almen intensity will have on crack initiation.

Since this testwork, the use of automated crack detection technology or servo-hydraulic fatigue test machines allows for HCF testing with fatigue life determined via crack initiation. This results in very pronounced optimum values, similar to those found in reference [4].

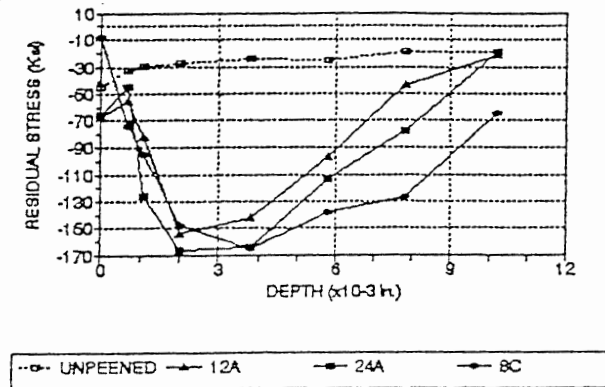
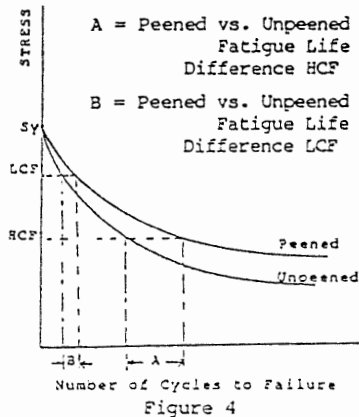


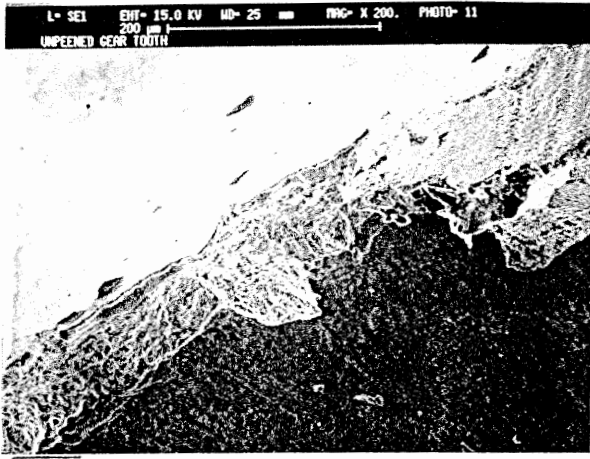
Figure 5 Residual stress of unpeened and peened gears

Figure 5 shows the residual stress distributions of unpeened and peened gears. Each of the shot peened gears maximum magnitude of residual stress is at least five times that of the unpeened gear. The overall aggregate amount of residual stress (area beneath the curve) is seen to increase with increasing almen intensity. Between 0.002 inches and 0.004 inches, the residual compressive stress for specimen 24A is higher than all others. The 8C specimen exhibits the lowest value of residual compressive stress at the surface, including the unpeened specimen.

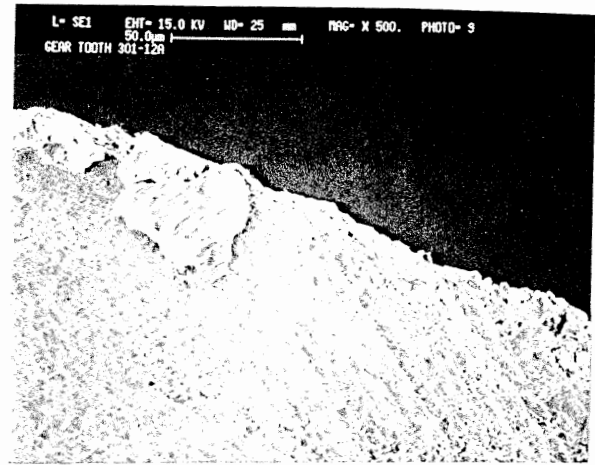
Figure 6 shows SEM photographs of the various unpeened and peened conditions studied. The hob machining marks and tooth edge burrs are clearly visible on the unpeened gear and aren't entirely obliterated until the 24A specimen. The 24A specimen shows what appears to be the early stages of PSEF formation while the 8C illustrates pronounced PSEF. This PSEF may have contributed or be solely responsible for the low magnitude of surface residual compressive stress exhibited by the 8C condition.

SUMMARY & CONCLUSIONS

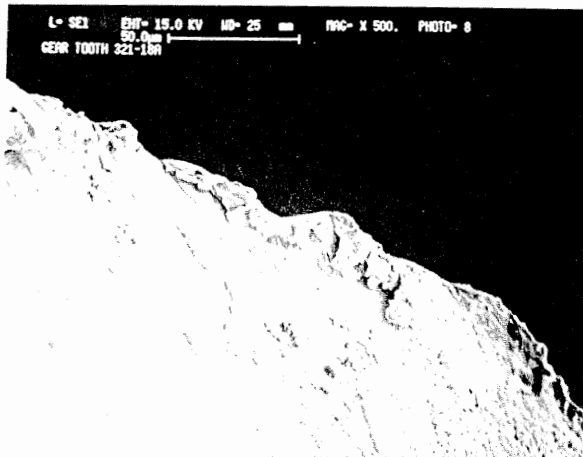
1. The optimum almen intensity is close to 24A with S-230 steel shot in a 54-60 HRC hardness range.
2. Mean fatigue life of optimum peened gears increased by more than 200% when compared with unpeened gears at a very high test load.
3. Optimum peened gears improved the mean and B-10 fatigue life by 100% and almost 350% respectively, compared with production gears conventionally peened to the optimum 24A intensity.
4. The improved fatigue life for 24A peened gears is attributed to the highest compressive residual stress incurred at the surface as well as overall maximum residual stress magnitude, while exhibiting little PSEF.



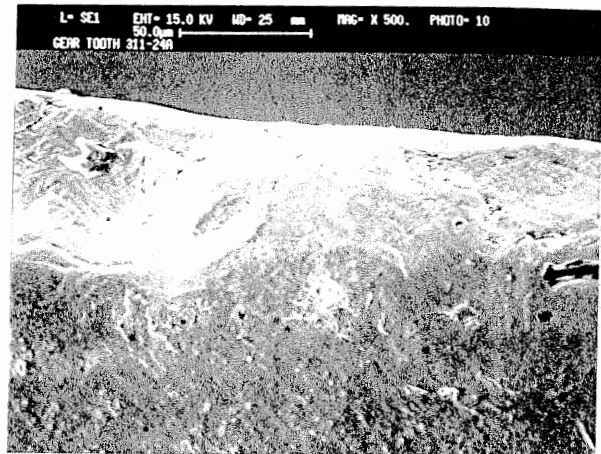
Unpeened



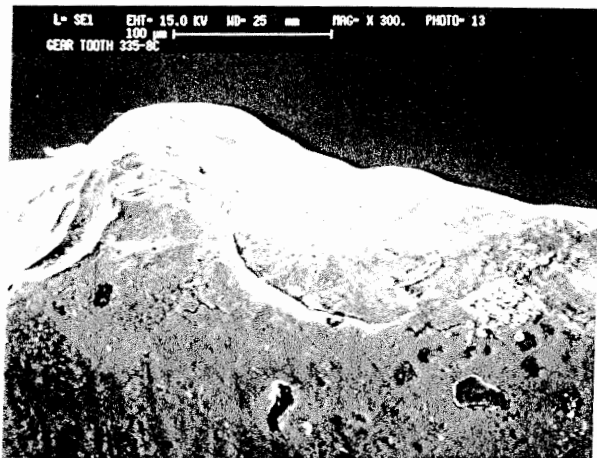
12 A



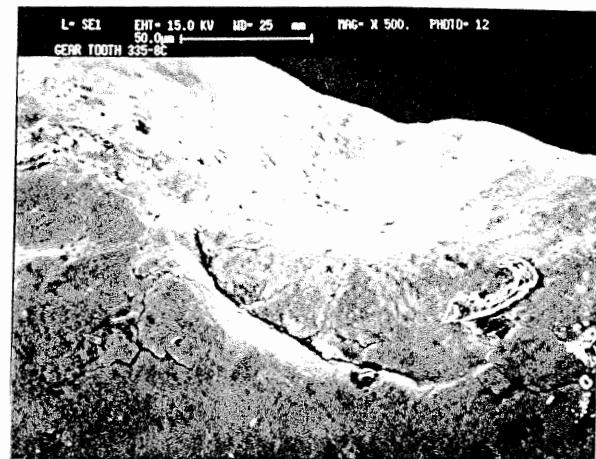
18 A



24 A



8C



8C

Figure 6 SEM photographs of unpeened, 12A, 18A, 24A, and 8C gear surfaces

5. The shorter fatigue life in 8C peened gears indicates that overpeening is possible due to the fact that optimum fatigue strength is a balance between peening induced residual stresses and surface damage induced by shot peening.

The next step in engineering a statistically capable process is to define the acceptable tolerance of each peening process parameter listed in Table I. This is accomplished via similar testwork which by-passes the almen test strip measurement system and relates each process parameter directly to acceptable fatigue strength variability. The need to eliminate the variability introduced by the almen test strip measurement system in order to engineer a statistically capable process will be addressed in future publications.

Every "process of choice" must have a justifiable benefit/cost ratio. The extensive fatigue testing required for a statistically capable fatigue strength based process can be quite expensive. However, when the benefits are compared to conventional controlled peening and the testwork costs amortized over the life of the part, the investment, in most cases, is profitable. The following is a brief description of recent technological and cost reduction achievements attributable to shot peening.

1. Increased torque rating of an auto transmission from 165 ft. lbs. to 215 ft. lbs. (horse power rating increased from 135 hp to 220 hp).
2. Increased torque rating of an auto transmission from 126 ft. lbs. to 165 ft. lbs. (horse power rating increased from 96 hp to 135 hp).
3. Increased crankshaft fatigue life over fillet rolling from 665,000 cycles to 7,277,000 cycles, representing 15% greater fatigue strength.
4. Increased Austempered Ductile Iron hypoid ring and pinion set fatigue life by 150% over carburized steel; a 10% savings in cost and weight.
5. Increased flywheel flexplate B-10 life over conventional controlled peening by 362%.
6. Precision shot peening 5454 automotive wheels produced a mean life increase of 470% with a reduction in scatter. [3]

REFERENCES

1. CHANG, N.S., and GARIBAY, R.P., "Maximizing the Fatigue Strength of a Carburized Helical Gear Via Optimizing Shot Peening Process Parameters Part I: Almen Intensity", ASME 1989 International Power Transmission and Gearing Conference, April, 1989.
2. GARIBAY, R.P., and CHANG, N.S., "Improved Fatigue Life of a Carburized Gear by Shot Peening Parameter Optimization", ASM International Conference on Carburizing Processing and Performance, July, 1989.
3. SIMPSON, R.S., and MCCAGG, D.R., "Effects of Peening on Fatigue Life of Wrought SAE 5454 Aluminum Automotive Road Wheels", Second International Conference on Shot Peening, May, 1984. P2121
4. SIMPSON, R.S., and CHIASSON, G.L., "Quantification of the Effects of Various Levels of Several Critical Shot Peening Process Variables on Workpiece Surface Integrity and the Resultant Effect on Workpiece Fatigue Life Behavior", Flight Dynamics Laboratory Air Force Wright Aeronautical Laboratories, October, 1988. P581
5. Almen, J., "Shot Blasting to Increase Fatigue Resistance", SAE (Transactions), Vo. 51, No. 7. P1540
6. SIMPSON, R.S. and CHIASSON, G.L., "A New Concept for Defining Optimum Levels of a Critical Shot Peening Process Variable", Second International Conference on Impact Treatment Processes, September, 1986. A 861