HIGH TECHNOLOGY SHOT PEENING FOR THE AUTOMOTIVE INDUSTRY

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ABSTRACT

The purpose of this paper is to present a technical overview of the shot peening process, comparing the conventional "controlled" process to state-of-the-art precision shot peening. The fatigue strength/cost benefits as well as the challenges and obstacles to reproducibility are examined in light of high production automotive volumes. Examples of applications where precision shot peening can most effectively be utilized to increase the strength/weight design characteristic of automotive components are provided.

KEYWORDS

conventional controlled shot peening, precision shot peening, workpiece saturation, process optimization, process control.

INTRODUCTION

Historically, where fatigue is the limiting design factor, it has been demonstrated that fatigue strength increases due to shot peening of approximately 10%, are obtainable. However, once applied in high production volumes much, if not all, of this gain is eliminated due to large data scatter. The reasons for this are due to lack of adequate process understanding, optimization and reproducibility. This process, which we shall call conventional controlled shot peening, in most cases, cannot consistently provide a fatigue strength increase that is of significant magnitude to affect the design.

If conventional controlled shot peening could consistently and cost effectively provide a 20% + fatigue strength increase, the automotive industry's utilization of the process would be much more extensive. The explanation lies in the false assumption that the fatigue strength improvement derived is relatively insensitive to process parameter values and variation. This is not supported by available data. [1] [2] [3] [4]

Many general specifications in use today, by making broad process parameter recommendations, fail to recognize that unique optimum process parameter values may exist for specific components. Therefore, it is also erroneous to say that a prescribed set of process control tolerances can be universally applied with reliable results.

Additionally, the word control has been used as an adjective to shot peening for decades and can mean almost any level, including manual shot peening. For instance as recently as 1981, Clarke and Birley [5] stated "Controlled shot peening can be achieved satisfactorily with manual operations".

Greater understanding of the affect of peening process parameters on the workpiece as well as microprocessor and electronic sensor development have created an opportunity for more significant and reliable fatigue strength increases in high volume application, than indicated by historic lab and *production data. This is, however, obtainable only after process parameter optimum nominal values and tolerances are defined for a particular component and the production process is maintained within the requirements of each parameter.*

This process, which we shall call precision shot peening, is providing new opportunities to the auto industry for substantial, reliable design strength gains from a previously discounted or discarded process, at a net cost savings over alternative processes or materials. When considering, in design, the effect weight reduction has on all other components in the vehicle, additional weight and cost savings can also be generated. [6]

DISCUSSION

In the face of numerous developments in high strength materials and state-of-the-art heat treating processes such as ion nitriding, laser hardening and contour induction hardening, why consider precision shot peening? Simply stated, the reason is strength gain per dollar invested, or cost effectiveness. Precision shot peening has two advantages : 1) greater fatigue strength provided over conventional controlled shot peening as well as other strengthening processes and 2) lower cost compared to alternative processes and/or materials.

The following application examples are the result of developmental work performed with various automotive component manufacturers. References are provided for instances where the data has been published; otherwise, approval has been obtained for discussion.

Strength Increase

The most frequent application of shot peening today in the automotive industry is on leaf and coil springs. The reason is that the combination of metallurgical and physical characteristics with the type and frequency of the applied stresses makes for a workpiece that is particularly responsive to the shot peening process yet comparatively quite forgiving to process variation. Nevertheless, in comparative testing, fatigue life gains of approximately 100% are possible with precision shot peening over conventional controlled shot peening.

Perhaps the most fertile field for strength improvement processes is in transmission design. During the late 1970's, in the effort to lower fuel consumption, the engine and drivetrain systems were downsized. Now, as a result of new engine technology, these downsized transmissions are faced with torque requirements beyond their original design capacity. Precision shot peening has been effectively utilized to boost the design ratings of transmissions, regardless of whether conventional controlled shot peening or no shot peening had been applied. The torque design rating gains range from 15%-40% depending upon the application. These gains have been generated for the fatigue failure modes of spalling as well as bending and torsion. The components include final drive pinions, input gears, idlers, output gears, splined shafts, planetary pinions, sun gear and turbine shaft lube holes, differential side gears and pinions, and hypoid ring and pinions.

Cost and Weight Savings

Examples of the cost savings available with precision shot peening are numerous. In the case of splined shafts, fatigue strength increases *comparable to induction hardening were demonstrated at a savings of \$.35 - \$0.45 per shaft. An order of magnitude increase in fatigue life over split sleeve cold expansion of lube holes was generated at a savings of approximately \$0.50 per part. A savings of \$0.50 per gear is being obtained by precision shot peening 8620 carburized gears, thus avoiding the more expensive exotic alloys. Through precision shot peening, cast iron hypoid ring and pinions have demonstrated performance superior to carburized steel while generating approximately a 10% savings in cost and weight.*

Reduction of reciprocating weight in engines is a high design priority. A 20%-30% increase in fatigue strength of some connecting rod designs have been consistently obtained. Preliminary test data indicates that increased contact fatigue strength and lubricity through precision shot peening can result in a \$0.50 savings per rod by elimination of the brass bushing and oil hole.

Precision shot peening of non-hardened crankshaft journal fillets was compared to fillet rolling, laser hardening and ion nitriding. Fillet rolling outperformed laser hardening and ion nitriding. Precision shot peening provided approximately 15% greater fatigue strength than fillet rolling.

Non-peened SAE 5454 automotive road wheels utilizing standard SAE Dynamic Cornering Fatigue Testing resulted in a failure range of 230,000 to 396,000 cycles. Precision shot peening produced a mean life increase of 470% with a reduction in scatter. [2] Also precision peening of low carbon steel may, depending upon wheel design, provide similar fatigue strength to non-peened HSLA.

<u>Challenges to Production Application</u>

In spite of the above mentioned advantages that make precision shot peening very attractive as a booster of strength/weight in design, there are some significant challenges to overcome to successfully implement this into high production, and some technological breakthroughs necessary to ease these challenges as well as provide more "comfort" in utilizing the process more universally. The reason is, the shot peening process is much more sensitive to parameter values and fluctuations than historically deemed to be the case. [1] [2] [3] [4]

If the goal is to consistently maximize fatigue strength in high production volumes, we must ensure that all critical process parameter optimum nominal values and allowable production tolerances are quantified in relationship to workpiece fatigue strength. When the process engineer understand the weaknesses in current monitoring methods it becomes obvious that quantification, via testwork, of optimum nominal value and allowable tolerances for each critical parameter contributing to almen intensity and workpiece saturation is essential. [7] The final process specification must include the cumulative aspects of the monitoring instrumentation tolerances.

Historically, conventional controlled shot peening has utilized the almen strip and visual coverage as the primary process monitoring tools. Although at this point, still necessary, this is insufficient information to assure optimum fatigue benefits. For example, in carefully executed testwork, carburized gears peened to identical almen intensities produced, at identical torque values, a mean life of 16,375 cycles and a B-10 life of 2,663 cycles for conventional controlled peening versus a mean of 33,167 *cycles and B-10 of 11,953 cycles for precision peening. [3]*

Data indicates that the reasons for this are three fold:

1) *Almen intensity provides an indication of the aggregate amount of energy transfer to the workpiece without defining the individual contributing components. [8] [9]*

2) *The effect of the cumulative tolerances within the almen strip itself will, in most cases, result in undetected process variation that is is too excessive for acceptably reliable performance. [10]*

3) *Visual coverage is a qualitative attempt to relate almen saturation to workpiece saturation. They rarely occur simultaneously due to differences in surface hardness and metallurgy. Besides the obvious weakness of inspector judgement, tracer dyes and coatings notwithstanding, it is impossible to visually discern coverage levels above 100% and between primary or secondary impact impingement. [9] Additionally, in many cases the optimum workpiece saturation level is above 100% coverage. [4]*

Table I lists the major process parameters that, in most cases, are critical to precision peening.

<u>Table I: Process Parameters Critical to Precision Peening.</u>

1. *Shot velocity*
2. *Shot diameter*
3. *Shot size distribution*
4. *Shot shape*
5. *Shot hardness*
6. *Shot type*
7. *Shot density*
8. *Shot impact angle*
9. *Shot flow rate*
10. *Shot blast pattern*
11. *Nozzle to workpiece position relationship*
12. *Exposure time*

Although, the testwork required to relate critical process parameters to fatigue strength for a particular component can initially appear overwhelming, as the testwork data base expands over numerous workpiece parameters, testwork can be abbreviated or eliminated by drawing on previously established process and workpiece parameter relationships.

Most workpiece parameters fall within two groups: Workpiece Chemical and Physical Variables or Workload Environment Variables. [10] Table II lists many of the workpiece parameters which can influence critical process parameter optimum nominal values and tolerances. [10] [11]

Table II: Workpiece Parameters That Can Influence Critical Process Parameters.

1. *Hardness distribution*
2. *Yield strength*
3. *Work hardening rate*
4. *Residual stresses*
5. *Surface topography*
6. *Phase composition*
7. *Phase stability*
8. *Material defects*
9. *Shape*
10. *Type and magnitude of applied stresses*
11. *Frequency of applied stresses*
12. *In service foreign object surface damage*
13. *In service corrosive surface damage*

Although not always economically feasible, the actual component or part should be used as the test specimen workpiece. See [4] and [12] for examples of the type of testwork involved in quantifying critical process parameter nominal values.

Conventional controlled shot peening process requirements limited to industry specification tolerances, almen arc height, and workpiece coverage have resulted in machinery whose only requirements were to throw enough shot at high enough velocity coupled with material handling capable of covering the area to be peened in the anticipated production volumes. In most cases this equipment was essentially identical to a blast cleaning machine.

The challenge to the automotive process engineer of specifying, designing and applying equipment and systems capable of controlling and monitoring the dozen process parameters listed in Table I within tolerances tight enough to reproduce optimum peened workpieces in high production volumes can be formidable enough to deter utilization of the process. However, the pressures exerted by world competition will no longer forgive the waste of utilizing a process of unquantified financial and technical merit, nor can a cost effective quantified fatigue strength increase greater than 20% remain on the shelf. [6]

Precision shot peening cannot be performed with blast cleaning machines. Form must follow function, in that the shot peening machine specification must be an extension of the optimized process specification.

Although there are three methods of propelling the shot, (pneumatic, centrifugal wheel, and gravity) the most controllable and flexible is pneumatic. Therefore, in the interest of brevity the following discussion is limited to pneumatic machines. It is rare that in the precision peening of an automotive component that a properly designed pneumatic machine won't prove as productive as well as outperform the others in producing overall fatigue strength and consistency.

Of the twelve process parameters listed in Table I, nine of them can be controlled and/or monitored by the machine during processing. The remaining three: shot hardness, shot type and shot density must be monitored by the quality assurance department. The following is a typical example of a precision peening machine application and capability.

This machine was designed from a process specification developed through successful testwork. The requirement was to upgrade an existing transmission's torque rating by 20% while avoiding the costs of material upgrade or design change. Conventional controlled shot peening had failed. The machine has the capacity to precision peen individual gears at a rate of 1500/hour. (work is currently under way to increase this to 2400/hour). Table III provides a summary of the equipment's capability.

<u>Table III: Typical Example of Precision Peening Equipment Process Control Capability.</u>

			^	@
1.	Shot velocity via air pressure	+/- 2 psi	X	X
2.	Shot diameter	determined via testwork	X	
3.	Shot size distribution	95% retained on #40 and #45 screen	X	
4.	Shot shape	broken particle content < 5%	X	
5.	Shot impact angle	+/-2 degrees	X	*
6.	Shot flow rate	+/- 2 lbs/min	X	X
7.	Nozzle to workpiece position relationship:			
	via workpiece fixture position repeatability	+/- 0.001"	X	X
	via workpiece height fiber optic eye	- 0 + 0.062"		X
	via workpiece rpm sensor	+/- 2 %	X	X
8.	Exposure time:			
	minimum via timer	+/- 0.25 sec.	X	X
	maximum via computer	+/- 0.25 sec.	X	X

^ = maintained by the machine   @ = monitor electronically

*Although not necessary in this case, robotic systems provide electronic monitoring.

Process parameters not monitored electronically must be monitored via accurate sampling procedures and Statistical Process Control (SPC). See [13] for a discussion of accurate shot sampling procedures.

With striving for zero-defects as the emphasis of the 90's, all critical process parameters must be maintained within quantified tolerances. "Occasional failure is not inevitable. All errors are preventable". [14] Through the use of properly designed precision peening equipment, and a quality assurance staff trained in SPC and process understanding, a process parameter Capability Ratio (Cpk) in the 1.5 to 2.0 range is maintainable. Personnel involved with the process must acquire the skills essential for quick accurate diagnosis of process anomalies. Routine periodic training tailored to the needs of peening machine operators, maintenance and quality assurance personnel is essential. Each must demonstrate proficiency in their area via testing.

Although the above requirements form a considerable challenge to utilizing the process in design, there are some technological breakthroughs possible that would provide some relief. Three that would have significant impact are: increased electronic process monitoring capability, predictability software, and a nondestructive inspection.

Electronically monitoring shot size distribution and shot shape as it flows to the nozzles would eliminate frequent in process manual sampling.

An algorithm relating critical process parameter nominal values to workpiece parameters could greatly reduce the amount of empirically developed test data necessary to define an optimum peening specification.

If we know via testwork that A+B+C+D+E=F, then it stands to reason that if we can monitor A, B, C, D, and E in real time, we know when we have F (fatigue strength) even though we can't measure F nondestructively. However, the ability to monitor F in real time via a non destructive inspection provides increased statistical confidence in our drive toward zero-defects.

SUMMARY

As long as any metallic component operates below stress relieving temperature, not one has yet been found for which precision shot peening cannot provide a consistent fatigue strength gain. This is true regardless of the number and kind of strengthening processes the part has already undergone. When compared to other strengthening processes and alloys, precision shot peening is cost effective with considerable cost savings potential.

The challenges to successfully utilizing precision shot peening are as follows:

1. *Identification of optimum nominal values and allowable production tolerances for each critical process parameter contributing to almen intensity and workpiece saturation.*

2. *The production component must be processed on equipment capable of reproducing each critical process parameter nominal value and maintaining each within the required tolerances determined via process parameter optimization testwork.*

3. *Process parameters not monitored electronically must be monitored via accurate sampling procedures and SPC.*

4. *Personnel involved with the process must acquire the skills essential to quick accurate diagnosis of process anomalies.*

5. *Routine periodic training tailored to the needs of peening machine operators, maintenance, and quality assurance personnel is essential.*

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