The Effect of Inherent Tolerances in the Almen Test Strip On Shot Peening Process Reliability

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Introduction

Defining current allowable tolerances for Almen Test Strips per applicable U.S. Military and industry specifications, and how they affect shot peening process reliability and reproducibility, is the purpose of this paper.

The Almen strip has historically been and currently is the only available non-destructive measurement instrument utilized to represent the amount of aggregate energy transfer to a workpiece resulting from the shot peening process. Since there is currently no available means of shot peen process non-destructive test performed directly on a workpiece, the importance of the Almen strip continues to remain high.

An area of much recent discussion in technical circles concerned with the shot peening process has been what quantitative and qualitative information the Almen strip can provide, and what it can and cannot measure in terms of process effectiveness. While important, there is another concept which needs considerably more definition than is currently available in technical literature. This is Almen test strip reliability and succinct quantitative definition of how reliably the Almen strip, as currently specified in applicable U.S. Military and industry specifications, measures Almen intensity.

As in any process measurement, the cumulative acceptable tolerances of gauges and measurement instruments are of critical importance. Commonly specified production Almen intensity ranges are +/- 2A. (1) Not uncommon is +/- 1A. During research conducted by the authors, several phenomena associated with the Almen strip have been identified as affecting its capacity to reliably measure processes specified to a +/- 2A or smaller intensity range.

Strip Hardness

Current SAE, AMS, U.S. Military and other industry specifications list a hardness range of 44-50 Rc as the acceptable range for A,N, and C type Almen strips. This hardness tolerance range introduces significant variability in arc height readings taken from Almen strips peened under identical processing conditions.

During fatigue testing involving shot peening specimens under precisely controlled conditions (See Table 1), mean values obtained from 44 Rc Almen strips shot peened at identical values varied significantly from the same values obtained from peening 50 Rc Almen strips. Table 2 illustrates the hardness tolerances utilized for Almen strips during this testing which account for +/- .00016 in arc height at 0.012A.

The effect of Almen strip hardness variability on saturation is more difficult to identify and quantify. Some background explanation is helpful. The Brinnel hardness test works on the principle that workpiece materials of varying hardness will be dented to varying diameters by a constant hardness ball pushed with a given force against a workpiece. The concept of peening coverage is technically similar. Workpieces much softer than Almen strips, such as aluminum alloys, will achieve full peening coverage up to three times faster than the Almen strip when processed under identical conditions. Workpieces much harder than an Almen strip will obtain coverage only after being exposed to the same blast stream for much longer durations. (2)

This effect on peening coverage, and hence the workpiece saturation rate of varying hardness workpieces, is similar for Almen strips of varying hardness. Because of this phenomenon, the process measurement of Almen saturation, (an Almen arc height at the first point in time when doubling exposure time yields less than a 10% increase in Almen arc height,) can vary up to 30 % from 44 Rc Almen strips to 50 Rc Almen strips.

VARIABLE	TOLERANCE
Air Pressure	+/- 1.0 PSI
Turntable Speed	+/- 0.5 RPM
Nozzle Distance	+/- 0.25 Inches
Angle of Impact	+/- 2.0 Degrees
Nozzle Orifice Dia.	+/- 0.002 Inches
Media Flow	
Glass Bead	+/- 3.0 Grams/Min.
Steel Shot	+/- 3.0 Oz./Min.
Stroker Speed	+/- 0.25 "/Min.
Cycle Time	+/- 1.0 Second

TABLE 1: Process Variable Tolerances

VARIABLE	TOLERANCE
Inter-Strip Hardness	2.0 HRC
Intra-Strip Hardness	1.5 HRC
Flatness	+/- 0.0001"
Thickness	+/- 0.001"
Width	+/- 0.0025"
Length	+/- 0.015"

TABLE 2: Almen Strip Experimental Tolerances

Strip Flatness

Current industry standard for determining Almen strip flatness is represented by the following statement. "The curvature of the strip is determined by a measurement of the height of the combined longitudinal and transverse arcs across standard chords. This arc height is obtained by measuring the displacement of a central point on the nonpeened surface from the plane of four balls forming the corners of a particular rectangle." (3),(1) Any measurable variation from zero deflection or completely flat is significant as the change in this "flatness" is what is measured as Almen arc height by reading the amount of curvature or deflection in the strip after peening. Current U.S. Military specifications list this flatness as having an acceptable pre-shot peen processing tolerance of +/- .0015". This tolerance, in and of itself, is greater than the specified intensity tolerance range of many components shot peened in actual production.

The added quantitative effect of the applied stress generated by mechanically holding an Almen strip flat on an Almen block during peening when it was arced .0015" before peening is currently undefined. However, this certainly does not meet industry requirements for being free from external loading during peening. Qualitatively, it has been well documented that this type of "stress peening" results in significantly different workpiece residual stress profiles than a workpiece peened without external loading.

Test Specimen Holder

The test specimen holder described in Figure 4 of MIL-S-13165B has a thickness of three quarters of an inch expressed in a fraction. Engineering convention allows +/- .0625 for all fractional dimensions. Should this dimension be taken at the worst case on the mounting surface of the block, the test specimen could be significantly pre-stressed during mounting before peening occured. The extent of the effect on the post-peened arc height of the test specimen from this mechanical pre-stressing has yet to be established. Any effect, however, would have to be added to the effects from strip thickness tolerances.

Strip Thickness

Thickness of test strips, particularly thickness within a given strip, can yield process measurement tolerances as great as the thickness tolerance since it is possible for the strip to be the thinnest in its central portion where it is gauged, and thickest where it is held on the gauge. Test strip thickness tolerances per Mil-S-13165B are +/- .001.

Standard Almen #2 Gauge

The gauge utilized for measuring the Almen strip has, itself, a large measurement tolerance built into it. All Military and industry specifications the authors are aware of specify utilizing a dial gauge calibrated in thousandths of an inch. The implicit assumption is that no measurements finer than .001 or 1A can be measured on such a gauge. As such, total potential tolerances generated by the gauge itself must be considered to be as much as 1 A or +/-.0005".

Found in Table 3 is a summary of resulting arc height variability caused by hardness, flatness, thickness, and gauge tolerances.

VARIABLE	TOLERANCE
Almen Strip Hardness Variation (6HRC)	+/- .0005
Almen Strip Thickness	+/- .001
Almen Strip Flatness	+/- .001
Almen Gauge Mounting Plane	+/- .002
Almen Gauge Indicator Graduation	+/- .0005
CUMULATIVE TOLERANCES	+/- .005

Table 3: Summary of Arc Height Variability Caused By Currently Allowable Tolerances

As defined, cumulative acceptable tolerances per typical Military and industry specifications are therefore, +/- .005.

Intra Strip Hardness Uniformity

No requirement within applicable U.S. Military or industry specifications exists for hardness uniformity within a given strip other than the 44-50 Rc hardness range. While this area of measurement instrument tolerance is certainly important to consider, its effects are more difficult to document. At present, the authors are unaware of published studies concerning this phenomenon and have yet to study the effects of hardness variability within a given strip.

Almen Strip Chemical Content Uniformity

While the authors have not studied the effects of changes in chemical content of Almen strips, it is not anticipated that variation within the acceptable tolerance ranges of chemical content for 1070 spring steel will yield significant process measurement variance.

Discussion

The current trend in manufacturing processes is to carefully define the qualitative and quantitative benefit levels obtained from each manufacturing process at specific process variable levels, determine cost effectiveness vis-a-vis other potential substitute processes, and then precisely control the selected processes in production to the specific process variable levels known to generate the benefits achieved in developmental testing. It is the author's opinion that due to increasing competition in the world marketplace, the future production use of manufacturing processes for which quantitative benefit levels are ill defined will become increasingly rare. The use of any process in this type of precisely engineered, clearly quantified manner presupposes accurate, reliable measurement instruments. Clearly, the future use of shot peening as a part of the design strength of components requires reexamining the acceptable tolerances generated by Almen Strips. This is particularly true in light of recently published data concerning the sensitivity of workpiece fatigue life to Almen Intensity. (4) (5) (6)

The use of Almen intensity throughout the history of the shot peening process has been largely made without regard to the effect of cumulative tolerances generated by the Almen test strip and Almen gauge. Understanding that Almen intensity readings taken within an intensity range of 10-12A for example, can actually represent an intensity range of 5 - 17 A when inherent Almen strip and Almen gauge tolerances are accounted for, illustrates the problem. Clearly, when shot peening is utilized as part of the design strength of a workpiece, the presence of any level of process variability generated by Almen strip tolerances must be defined and quantitatively accounted for during developmental testing in terms of effect on workpiece fatigue life.

Of even more immediate importance for the shot peening discipline is the fact that cumulative acceptable tolerances for the Almen strip in U.S. Military and industry specifications are broader than the vast majority of specified intensity ranges on components utilizing shot peening. While it appears to the authors that intensity specifications are at times arrived at rather arbitrarily, for manufacturing engineers to blindly assume that adding the tolerances inherent in current Almen strip specifications to the intensity tolerances listed on blueprint call outs will yield acceptable workpiece fatigue life benefits generated by peening is a highly questionable practice.

The resulting question is: how reliable is a process when, if actual process controls were such that process variable quantitative levels varied +/- zero, the process measuring instrument and instrument gauging cumulative acceptable tolerances would, in themselves, exceed the specified acceptable intensity range?

In testing accomplished for a large basic research program funded by the U.S. Government, Department of Defense, the authors utilized the Almen strip flatness, hardness, thickness, and gauging tolerances listed in Table 2. These yielded cumulative tolerances of .0012. The manufacturer of the strips worked closely with the authors to provide strips within the hardness range. Strips were then individually measured for flatness, and thickness. During this program, in which approximately 20,000 test specimens were utilized, no more than 30-40% of the strips purchased had to be rejected. At an original purchase price of $.17 (U.S.) each, this represents a $.05 to $.07 (U.S.) increase in price, or a total cost of $.23 -$.24 (U.S) each. It is the authors' opinion that this is an inexpensive price to pay for a strip capable of valid process measurement.

The use of strips conforming to these tighter tolerances provides new process trouble-shooting and monitoring capabilities. Shot broken particle content has long been known to be detrimental to peened workpiece fatigue life. Relatively small changes in shot broken particle content (5% or less) can cause relatively large degradations in workpiece fatigue life. Variability of Almen strip readings caused by cumulative inherent tolerances of strips meeting the minimum requirements of MIL-S-13165B was large enough that monitoring changes in energy transfer caused by small increases in broken particle content was impractical. Changes in Almen intensity of as small as .0003 are possible to monitor with these closer tolerance strips. This is a particularly important area to monitor, as broken particle content cannot be electronically monitored as can shot flow rate, air pressure, or other process variables. Identification of an increase in shot charge broken particle content can only be identified through subjective quality assurance analysis or changes in Almen intensity.

Assuming very tight tolerances on shot size uniformity (i.e. per MIL-S- 13165B, Table I) Almen saturation curves are obtainable such that the current industry requirement of not more than a 10% increase in arc height if exposure time is doubled for achieving saturation can be achieved at less than 100% coverage. It is not the authors' intent to suggest that this is valid. (2) It does, however, point out that the 10% (or for that matter, any %) can be attributed to process tolerances of one type or another. It is possible, with tighter process controls and tighter tolerance Almen strips, to reduce this 10% benchmark to 5%.

Conclusions

Shot peening for many years has held a "black box" image to many engineers. This is due to the large variability in process benefit levels typically experienced during production processing. A major trend over the past several years, as witnessed by technical publications, particularly at the First and Second International Conferences on Shot Peening, has been the use of electronic monitoring systems. While the shot peening industry as a discipline is just beginning to quantitatively understand how these process monitoring systems can be effectively used, it is clear that the very large levels of process variability generated by the current process benchmark in its currently defined state must be addressed before the shot peening process can become a quantified science. The current strips and gauges can be compared to attempting to monitor the temperature of a heat treat quench to +/- 1 degree C. with a temperature gauge that has known fluctuations of +/- 10 degrees C.

By taking relatively easy and inexpensive steps to specify Almen strips and gauges of the suggested tolerances outlined above, the shot peening process can become immediately far more reliable as a fatigue strength enhancement process.

References

(1) MIL-S-13165B

(2) R. Simpson and G. Chiasson; "Airtech Saturation: A New Concept for Defining Optimum Levels of a Critical Shot Peening Process Variable" Second International Conference on Impact Treatment Processes, September, 1986.

(3) SAE J-442, August, 1979

(4) N. Person; "Effect of Shot Peening Variables on Fatigue of Aluminum Forgings", Metal Progress, July, 1981.

(5) R. Simpson; "Development of a Mathematical Model for Predicting the Percentage Fatigue Life Increase Resulting from Shot Peened Components, Phase I.

(6) R. Simpson; "Optimized Shot Peening Variable Quantification: An Engineering Approach to Quantifying Surface Finishing Processes", Fatigue Prevention and Design Conference, April, 1986.