TRUE CAPABILITY: A STATISTICAL PROCESS CONTROL CONCEPT QUANTITATIVELY LINKING PRODUCT VARIABILITY WITH PROCESS VARIABILITY

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ABSTRACT

Typical approaches to statistical process control assume that process specifications against which process variability is being statistically measured are tightly held with no unexplained significant variations as relates to acceptable and/or unacceptable product variability.

The concept of directly linking the statistical relationship between product variability and process variability is a statistical process control concept called True Capability.

In this paper the author explores the use of True Capability to measure the shot peening process including how to establish what level of product variability is acceptable, how to quantitatively link acceptable product variability with cumulative shot peen process specifications, and how to use statistical process control tolerances to obtain True Capability.

KEY WORDS

Shot peening, True Capability, Statistical Quality Control, Process Control

INTRODUCTION

The purpose of this paper is to explore conceptually an approach to shot peen process implementation that overcomes the lack of production reliability that has so long plagued the shot peen process.

As early as the 1950's when the Chrysler Corp. was investigating the fatigue strength enhancement of axle shafts by shot peening, one of the authors at that time in his role in engineering at Chrysler found that, while mean fatigue life for shot peened axle shafts was significantly increased, fatigue scatter was sufficiently broad that some of the shot peened axles were no better than unpeened axles.

The current state of the art in the shot peen discipline continues to be such that few product engineers trust the benefit level the shot peen process can induce to be reliable enough to be used as part of product design strength. For many engineers, shot peening is considered a process of last resort due to its long history of production unreliability. Yet many of these would agree that shot peening would be an obvious process of choice if all one considered was potential for fatigue strength enhancement.

In this paper the authors discuss the general problems inherent in the current state of the art and recommend a completely different conceptual approach that has been demonstrated at Advanced Material Process Corp. to yield high statistical process reliability in high volume production.

THE CURRENT STATE OF THE ART:
A Brief Examination of Some Common Assumptions

There are several commonly accepted assumptions about shot peening that have been shown in the literature to be untrue. Several of these assumptions, together with an analysis of them, follow.

Assumption #1:

If a part has a tested fatigue strength after being peened to a certain Almen Intensity, one can expect the same improvement in fatigue strength for the same parts in production if they are peened to the same Almen Intensity.

Discussion of Available Data

The data in published literature indicates that, as early as 1943, John Almen identified the phenomenon of an intensity "sweet zone" for workpiece fatigue life. (see Figure 1). This phenomenon has been repeatedly identified in the literature. This would suggest that it is impossible to find the intensity sweet zone for the workpiece in question without process controls significantly "tighter" than prescribed in today's specifications.

A given Almen Intensity value can be arrived at in literally an infinite number of combinations of process and measurement system variable values, each combination having a unique effect on the workpiece. (see Fig. 2) An example of this is to lower shot to workpiece impact angle and raise peening nozzle air pressure. This can yield the same Intensity as the original condition, but will generate significantly different

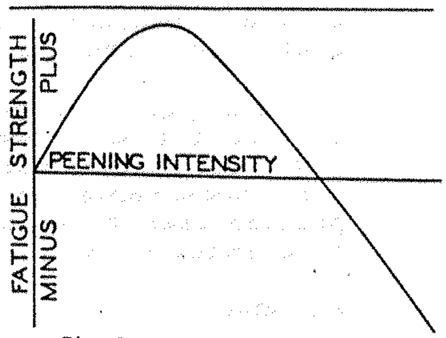


Fig. 1

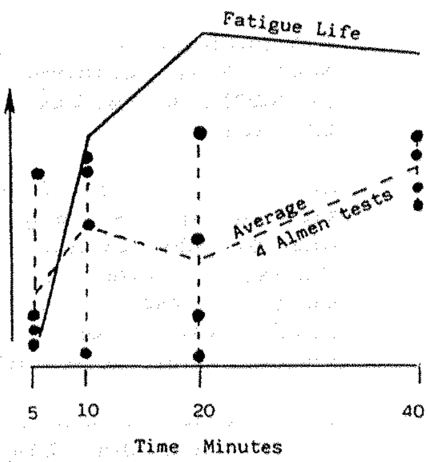


Figure 2

residual stresses and often different fatigue strength. The key to this quandary is that specifications like MIL-S-13165C do not have any processing tolerance requirements for either impact angle or nozzle air pressure or, for that matter, a number of other critical process and measurement system variables. Not only are nominal process variable levels left to the discretion of the processor; so is the range. (Ref. 14, 18).

Based on the above, the authors find Assumption #1 to be false.

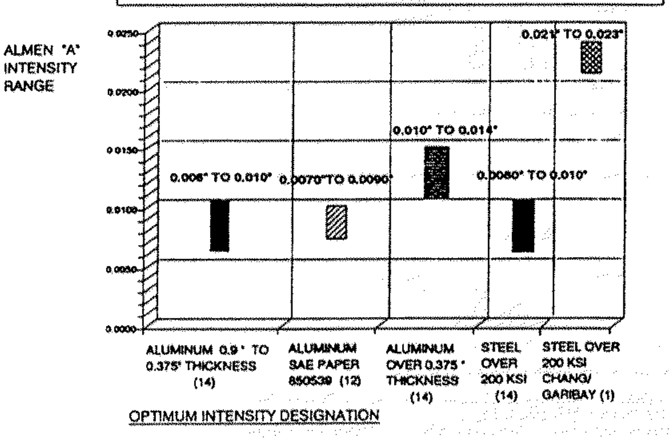
Assumption #2:

If one shot peens a workpiece to a prescribed intensity range listed in typical industry and military specifications, then one can assume consistent fatigue results from part to part if intensities are held within these specified ranges.

Discussion of Available Data

There are at least two clear and unavoidable problems with this assumption. The first is that a large battery of data indicates that the intensity range prescriptions found in such specifications are grossly oversimplified (see Figure 3). The relationship between workpiece chemical and physical characteristics and workpiece operational load variables versus shot peen process variable levels which occupy the "sweet zone", first described by one of the authors in 1986 (Fig. 4) (Ref. 13), and subsequently in numerous other publications is far more complex than the prescribed intensity tables in typical specifications. (Ref. 14).

FIG. 3 OPTIMUM INTENSITY DESIGNATION AND RANGE COMPARISON BETWEEN MIL-S-13165C AND ACTUAL DATA FOR TWO CLASSES OF MATERIAL



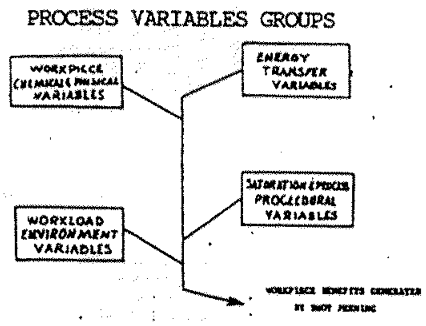


Figure 4

This often leaves production shot peen applications which use typical specification prescriptions occupying the "front slope" or "back slope" of the intensity versus fatigue strength (or intensity versus stress corrosion resistance curve) with substantial differences between fatigue results at one end of the intensity range and the other.

The second problem with Assumption #2 is that typical specifications' prescribed intensity ranges are often far too broad to occupy only the peak area of the intensity "sweet zone" curve. (Ref. 1, 2, 11, 12).

Based on the above, the authors find Assumption #2 to be false.

Assumption #3:

If one conducts a brief battery of fatigue tests on pre-production workpieces processed to a given shot peen intensity and these tests yield acceptable results, then enough information is available to implement a production process utilizing typical specification prescriptions for process and measurement system variable tolerances other than intensity. These variable controls will yield production workpiece fatigue test results consistent within a narrow band with the original battery of tests.

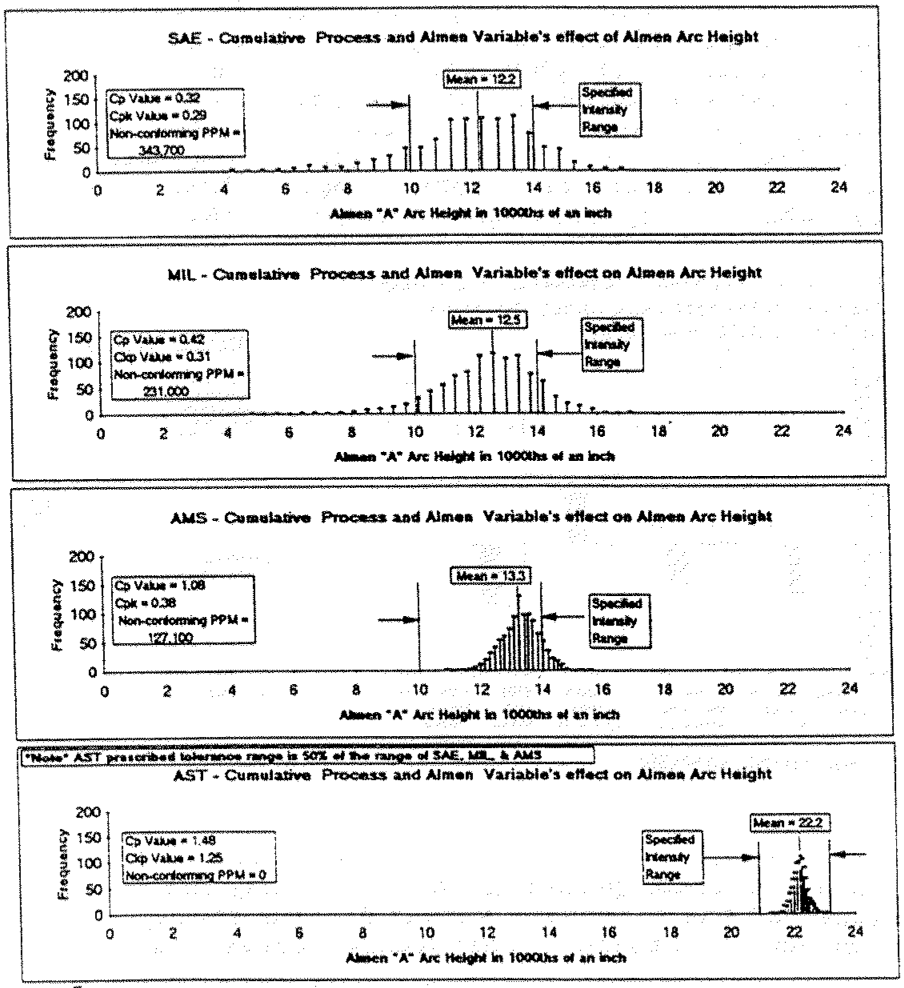


Figure 5: Histograms of the Cumulative Effect of ten Process and Measurement Variables on Almen Arc Height. Level Two Analysis reflecting +/- 3 Sigma Capability for each variable.

Discussion of Available Data

A serious lack of statistical reliability for intensity can be predicted if one meets, but does not exceed in any substantive way, current industry and military spec. requirements for process variable control. (Ref. 2, 17, 18, 19). (Fig. 5).

Based on the above, the authors find Assumption #3 to be false.

A DIFFERENT APPROACH

Having questioned several of the discipline's current paradigms for the application of its technology in production on the factory floor, the authors wish to suggest a completely different general conceptual approach to supercede these paradigms. This different approach has the concept of True Process Capability as its end goal.

Statistical Process Capability refers to a process' numeric likelihood of maintaining the requirements of a given specification. This likelihood is based on a mathematical analysis of variable data points taken over time from actual production processing. The emphasis is on the quantitative relationship of the process to a specification.

True Process Capability relates the minimum acceptable level of critical product characteristics, like fatigue strength or stress corrosion resistance, for a given workpiece with specific quantitative levels of all critical process variables that individually and cumulatively have been established to yield the required level of fatigue strength or stress corrosion resistance. From this is generated a process specification with the necessary tolerance. By doing this, the specification moves from being the cause of the problem to being the solution to the problem.

Rather than use prescribed process tolerances, the authors suggest establishing acceptable process and measurement system tolerances and controls based directly and quantitatively on the minimum product results required. Figures 6 and 7 illustrate the conceptual difference between the approach taken in the current state of the art and the approach the authors are suggesting.

This new approach may seem like a relatively small conceptual change from the current state of the art; but the difference in the results they achieve is quite dramatic.

The key is that required processing characteristics are determined by acceptable product variability for the workpiece in question, not by a specification incapable of defining consistent results. At the core of this approach is a mathematical understanding of the relationship between shot peen process and measurement system variability and acceptable product characteristic variability.

Historic Approach to Controlling Shot Peening

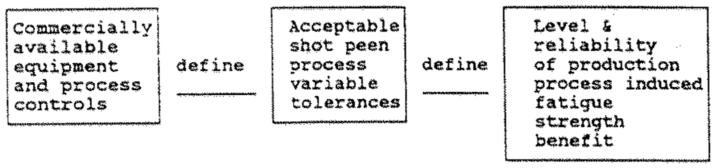


Figure 6

True Capability Approach to Controlling Shot Peening

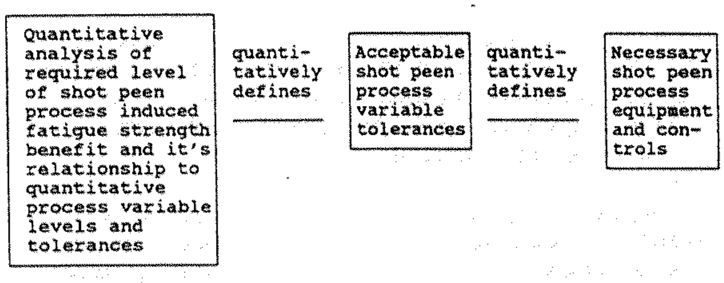


Figure 7

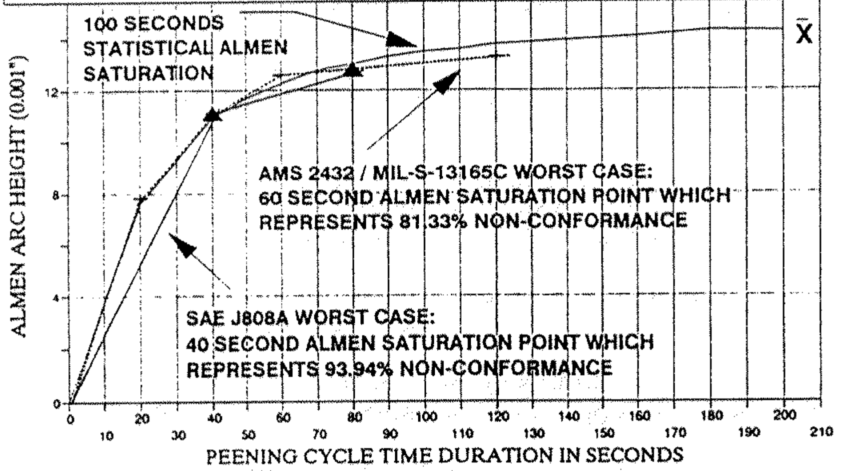
For the purpose of discussion, the use of shot peening for fatigue strength enhancement of automobile drive train components will be used. The basic approach is, however, valid for maximizing other types of benefits attainable from shot peening.

Step 1: Process Research: Building a Valid Data Base

Gaining sufficient understanding of the quantitative interrelational effect of individual and cumulative shot peen process variable changes on the fatigue strength of the various types of workpieces, materials, surface conditions, load types, etc. is perhaps the most daunting step to those who would seek a shot peen process with true capability in production.

The need, however, for quantitative process control information begins far before initiating production processing. Without crisply and quantitatively defining and obtaining process control methods and equipment that are statistically capable of far tighter tolerances than those typically used in shot peening, accurate determination of process variable "sweet zones" and their relationship with the desired product characteristics is highly unlikely. Every process and measurement system variable, which can have a significant effect on the acceptability of the final

FIGURE 8: WORST CASE PERCENT OF DATA NON-CONFORMING WITH THE REQUIREMENTS OF ALMEN SATURATION USING CURRENT SPECIFICATION GUIDELINES FOR DETERMINING ALMEN SATURATION



product, must be quantitatively defined as to the effect of that variable on the statistical reliability of the benefit.

Special care must be taken to make sure that one is using a statistically capable Almen Test System and a statistically capable level of Almen Saturation. (see Fig. 8) (Ref. 6, 17, 19).

If one begins with no valid data, Step #1 is not easy. A quantitative data base takes some effort and time to build. It is, however, absolutely necessary to be thorough and exhaustive here, or later attempts at true process capability will be frustrated.

Note that any published data based on process control levels and requirements similar to those in typical specifications may be burdened with the inherent process variability incumbent in many process controls. Unfortunately the vast majority of published data concerning production shot peening is so tainted.

Step 2: Process Application Development

In this step we apply the information in our data bank to a new specific shot peening problem. This can be expensive and time consuming, but need not be if adequate steps are taken.

In automobile manufacturing the value of individual component production parts is relatively low and their availability relatively high. Tests conducted using actual production or pre-production workpieces is highly cost effective, but care must be taken to make sure that the prototype peened and tested are typical of actual production parts. Dynamometer testing of automotive engines, transmissions, drive trains, braking systems, suspension systems, etc. can be extremely expensive, involving an entire assembly. If, however, primary failure mode and important secondary failure modes can be simulated on a simple fatigue test machine, developing the appropriate individual and cumulative process variable "sweet zones" by testing only the workpiece in question can be quite straightforward, fast, and relatively inexpensive. This testing involves establishing a load type and level representative of what the workpiece will experience in dynamometer testing (which should be representative of actual field loads) and performing simple A versus B fatigue tests of unpeened versus peened parts where primary field and dynamometer failure mode is duplicated and S/N curves are thoroughtly developed.

There are several key indicators of adequate process tolerance definition and control. They are as follows:

A) Like any other battery of tests, good testing procedures and scientific method application should be followed.

B) A key, even critical, indicator of both long term process reliability and long term processing cost is whether shot peened workpieces have a total fatigue life range equal to or less than the unpeened control specimens, assuming the control and peened specimens are tested at the same location on their respective S/N curves. It is the author's experience that a higher level of fatigue scatter in peened parts versus unpeened parts has an assignable cause linked to variable process control and/or a lack of crisp individual and cumulative process variable "sweet zone" identification. (Ref. 1).

C) As Step 2 is repeated for different workpieces, it becomes less expensive and time consuming as one follows the learning curve. The technical data base that is progressively compiled greatly enhances the knowledge resident in Step 1, and thereby progressively reduces the knowledge necessary for Step 2.

Step 3: Product Engineering Validation Testing

Validation testing of a sub-system or system is normally done as an assembly on a dynamometer. This step is typically deemed a necessary part of engineering change management to finalize any system going into production with new materials, processes, or dimensions. If, however, Steps 1 and 2 have been properly done, the addition of a shot peen process to a component of a sub-system or system will require extremely brief dynamometer testing.

Step 4: Production Quality Control

Maintaining statistical quality control in production for the shot peening process is much more difficult to do than it is for most production processes because of the number of significant interactive process variables inherent in the process and the difficulty of controlling them within the narrow limits required. The steps to accomplish statistical quality control at Advanced Material Process will require another paper to describe.

Cause and effect studies of failure modes, periodic checks of the process capability of the system, and statistical analysis of random fatigue tests on actual production parts must all be conducted on a continuing basis to insure True Process Capability.

SUMMARY

Shot peening is a process that is capable of increasing the fatigue capacity of highly stressed components by over 50%, yet it is infrequently and grudgingly specified by engineers except as a last resort. This is because the process has never produced consistent fatigue improvement on parts in production; the scatter in fatigue test results can be typically up to several times the scatter in fatigue test results of the same parts before peening.

The cause of these inconsistent results can be traced to lack of process control. Since the shot peening process has numerous independent process variables, the significance of any one of which can cause unacceptable losses in fatigue strength by varying within conventional limits, Advanced Material Process Crop. has found it mandatory to hold these critical process parameters to much closer tolerances than those recommended by current specifications. This much closer control of the process is not only necessary to get consistent fatigue strength improvement in production parts, but is also required to find the "sweet zone", or optimum Almen intensity to maximize fatigue strength for a given part.

The authors describe a shot peening process that holds tolerances in production on the critical variable process parameters close enough, both individually and cumulatively, to guarantee a minimum fatigue strength benefit for a statistically acceptable percentage of parts peened as having <u>True Process Capability</u>. A peening process with True Process Capability will typically produce parts with less fatigue scatter than the scatter of the same parts unpeened.

The arduous step-by-step process necessary to develop a shot peening operation with True Process Capability is described.

The conventional wisdom shared by most of the shot peening community is challenged, and the data sources are provided to prove them false.

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