Important Considerations For Utilizing Shot Peening As A Design Tool

Roger S. Simpson and Robert P. Garibay, Advanced Material Process Corporation, Wayne, MI, U.S.A.

Purpose

The purpose of this paper is to ennumerate important considerations involved in utilizing the shot peening process as part of the design strength of a workpiece. It should be noted that, due to the need for brevity, much of the details essential to implementing shot peening into design strength have gone unmentioned.

Introduction

The worldwide marketplace and competition in industrial products has generated new demands on the performance and reproducibility of metallurgical processes. Cost competitiveness demands that products acceptably perform in their intended environment at a minimum cost. This trend increasingly precludes the use of processes for which no benefit is factored into the design strength of the workpiece it is applied to.

A recent trend in the shot peening discipline has been to emphasize increased variable control. This approach has an incipient assumption, well founded on data, that variability in process parameter levels can produce variability in component performance. Indeed, recent published literature indicates much greater fatigue life and stress corrosion resistance sensitivity to process variable level changes than had been previously assumed. (1) (2),(3),(4),(5),& (6) The logic that some levels of process variables are more beneficial to workpiece benefits, in this case fatigue life, than other levels of the same process parameter is not a phenomenon unique to shot peening. Indeed, most metallurgical processes could fall within this logic.

Shot peening for years has been a process whose potential benefits were widely known to be substantial, and if reproducible in a production factory floor environment, would have been highly cost competitive when compared with other processes utilized to increase the design strength of components. Engineers have been reluctant, however, to use the potential benefits shot peening as part of the design strength of fatigue sensitive components. It is the authors' opinion that this has largely been due to the fact that shot peening often produced variability in process induced benefits which ranged from the high levels possible to at or below the scatter range of unpeened specimens. (1), (7), (8)

The shot peening industry as a discipline has responded to the demand for increased consistency in process induced benefit by making changes to lower the incremental tolerances of process parameter levels experienced in production processing. While qualitatively "good", this approach alone is insufficient in that it ignores the original logic: that some levels are better than others at producing process induced benefit. In light of recent data concerning the effect of process induced surface damage and its effect on the quantitative position of optimum intensity, if some process variable levels are better than others at producing fatigue strength benefits, merely controlling variable levels to "tighter" tolerances in no way assures that the nominal value controlled to, or range of tolerance used, are the right ones. Quantitatively identifying the best levels of each process variable, the effect on induced benefit of quantitative variance from these levels, and establishment of cumulative process tolerances which produce the desired benefit level should be considered a minimum requirement where weight reduction, material substitution, or significant increase in load are to be accomplished by adding shot peening.

Extending the logic discussed above, several critical questions need to be addressed. They include:

A) Are the workpiece chemical and physical characteristics and operational load environment well understood?

B) Have all shot peen process variables whose quantitative level, if changed would yield changes in workpiece fatigue life, been identified for the workpiece chemical and physical characteristics and operational load environment in question?

C) Have acceptable nominal levels of each of these variables been quantitatively identified in testing which accurately represents the workpiece chemical and physical characteristics and operating environment for the component in question?

D) Have tolerances for each of these nominal levels, including cumulative specification, process variable, and measurement instrument and gauging tolerances, been quantitatively identified as inducing acceptable benefit levels in the workpiece throughout their entire combined tolerance ranges.

E) Have production means been identified, either through statistical process control or electronic closed loop feedback process monitoring and control, such that the nominal process parameter levels and acceptable tolerances can be absolutely assured of staying within the defined ranges or identified as being out of tolerance on a 100% basis?

Implicit to this is the understanding that process reproducibility within levels quantitatively defined to produce acceptable benefits must be accomplished in a production environment on the factory floor.

In order to facilitate discussion of engineering a shot peening process, the pertinent variable groups are divided into categories as illustrated in Figure 1. (7), (9)

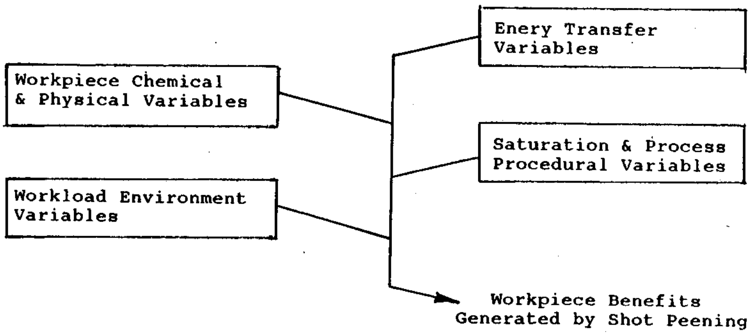

Fig. 1: Process Variable Groups

Workpiece Chemical and Physical Characteristics

A clear understanding of what the pertinent chemical and physical characteristics of the workpiece in question are is essential to designing the peening process to the particular workpiece. It is important to emphasize that current Military and industry specifications grossly oversimplify matching workpice material to Almen intensity and acceptable intensity range. (1), (3)

Workpiece Chemical Content

Since shot peening induces radical plastic deformation of the workpiece surface layer, any changes or tolerances in chemical content of substances (such as nickel content) which would change the effect of the plastic deformation and hence the formation of process induced surface damage, should be assumed to affect the position of optimum Almen intensity values. As such, it may also affect workpiece fatigue life. (1),(2),(3),(10) This should be considered the case unless data is available that would indicate otherwise for the particular workpiece.

Workpiece Hardness

Much needs to be learned concerning the effects of changes in workpiece hardness on the position of optimum Almen intensity. Research to date is inconclusive as to the effect of increases in material hardness on the position of optimum intensity range. Until this information is available it should be considered that changes in workpiece hardness will change fatigue life benefits.

Hardness case depth is an important consideration in designing a shot peening process. Any situation where the maximum case depth changes could be affected by the shape of the process induced residual stress profile.

Pre-processing workpiece surface integrity is critical to the quantitative position of optimum intensity range. Knowledge of the worst case scenario for pre-processing workpiece surface integrity should be obtained and utilized as the standard in designing the peening process. (11)

Workload Environment

It is relatively simple to demonstrate through concurrent graphing of residual and applied stresses that use of shot peening as part of the design strength of a workpiece will be affected by the type of load the workpiece experiences in its oeprational environment. (12)

The magnitude of applied load and the stress gradient will effect the amount of residual stress reduction caused by shakedown. (7) The load spectrum, if available, provides valuable information concerning LCF and HCF questions.

Corrosives and maximum acceptable damage tolerance are critical information to have when designing a shot peening process as they will definitely change the shape of the optimum residual stress profile if any appreciable penetration of the workpiece surface is anticipated.

Energy Transfer Variables

Examination of shot peening energy transfer variables through the authors' experiences in performing such testing programs and examination of published technical data lead to the formation of the matrix illustrated in Figure 2.

Almen intensity is necessary, but insufficient, information to succinctly describe any given shot peening process. Almen intensity, in and of itself, may or may not correlate with a specific amount of process induced benefit. (5),(13),(14) Almen intensity readings are, however, necessary. If certain caveats for the Almen strip and gauge are met, the monitoring of variables for which there is currently no electronic monitor available can be accomplished through Almen intensity readings. (14)

While developing fatigue test data, it is critical that each process variable be measured in increments small enough such that a one increment change in any variable will not affect workpiece fatigue life. Test specimen peening in whatever production machine is utilized for production processing, regardless of its level of control, is a highly questionable practice. The argument that this represents the "real world" is insufficient support for this approach. While this approach has significant drawbacks when utilizing shot peening as an "insurance policy"; where utilizing shot peening as a part of the design strength of a component, it is entirely unacceptable. Since the specific parameter values experienced during processing of given fatigue test specimens are not known, much less recorded, specific variable levels cannot have a corresponding workpiece fatigue life benefit associated with them.

Saturation and Process Procedural Variables

Figure 2 illustrates a chart of workpiece saturation parameters, variables, sub-variable groups, and sub-variables. As with intensity, it is important to note that lack of a quantified understanding at any point in the chart means that no associated point farther to the left in the chartx, including saturation or intensity, can be assumed to be fully quantified as to causality of the affected fatigue strength benefits generated.

The greater in number of points on the chart that are ill defined, the greater the risk of production processed parts not matching the benefit levels of laboratory testing. Again, the logic is that if control is necessary, then some levels must be most beneficial and others less beneficial. A succinct numeric understanding of these relationships is essential. (2)

Important considerations in process procedure are use of Almen test strips which are of sufficiently close tolerance to provide valid information and use of part rotational and nozzle or wheel traverse speeds which do not have primary or secondary patterns that effect saturation uniformity.(9) (14)

Process Optimization Study

Using the concepts described above one must construct a fatigue test battery. Using a statistical experiment design often greatly reduces the number of specimens required.

Fatigue specimen selection is of particular importance. The workpiece chemical and physical characteristics and workload environment should be matched as closely as possible. Where economically possible actual components should be used as fatigue test specimen.

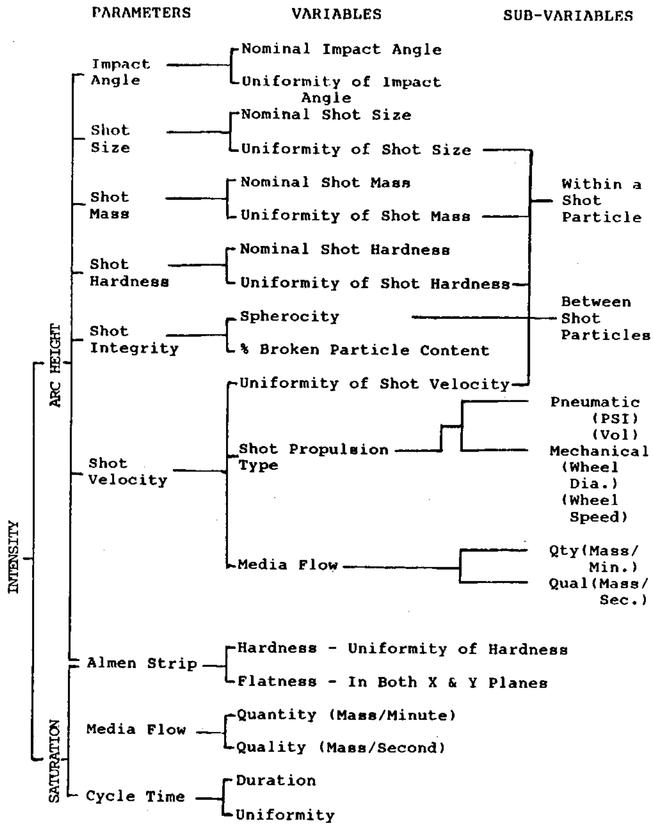

Fig. 2: Shot Peening Parameter, Variable, Subvariable Flow Chart.

Pre-Production Implementation

Providing a valid optimization study was performed, implementation of a quantitatively engineered shot peening process into production is relatively straightforward. Provision must be made to control all process parameters, variables, and sub-variables within levels which have been established as yielding acceptable benefit levels. Establishment of cumulative process tolerance effects (i.e. what intensity does low tolerance shot flow rate and high tolerance air pressure, and vice versa, deliver) is necessary in pre-production testing.

Production Implementation

It is suggested that the process parameter, variable and sub-variable levels established should be monitored, controlled and recorded via closed loop feedback electronic process control systems wherever possible. These controls should also be fitted with inner and outer tolerance alarms where experience the outer tolerance will cause automatic process shutdown and inner tolerance experience will cause alarm on the operator electronic panel and at the appropriate quality control station.

Discussion

While the methodology outlined above is time consuming it is both necessary and less time consuming the more it is used. Since most manufacturers make several similar components in their products, as data accumulates for different types of components, much of the data can be extrapolated to similar components with similar characteristics and load environments. As a data bank develops the only data generation required is where the component is significantly different in particular aspects (i.e. surface integrity, case depth, notch condition etc) than has been previously tested. It has been the experience of the authors over several years of this type of testing that use of an established and growing technical data bank continually reduces the time and expense required to obtain a quantitatively engineered process specification. Care should be taken to avoid being unscientific in applying this concept.

Conclusion

When utilizing the shot peening process as a part of design strength, there exists an acute need for a more sound engineering approach to shot peening specification formulation and subsequent process control. The approach of merely "tightening" historic process variable controls falls short of quantitatively understanding whether this is tight enough, too tight, or even whether all the critical variables have control applied.

If the process is quantitatively engineered, the potential payback in cost effectiveness can be very large due to the very high benefit/cost ratio of utilizing shot peening in design strength calculations.

It is the author's opinion that the only currently available method of establishing a quantitatively engineered shot peening process specification is to follow the basic format outlined herein. Formation of a large enough data base to predict optimum process levels for different components in varying load environments would be a major breakthrough in terms of reducing the cost and time required to use shot peening as a part of component design strength., The only apparent obstacle to this is the amount of data required.

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