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Shot Peening Process Variables.

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ABSTRACT

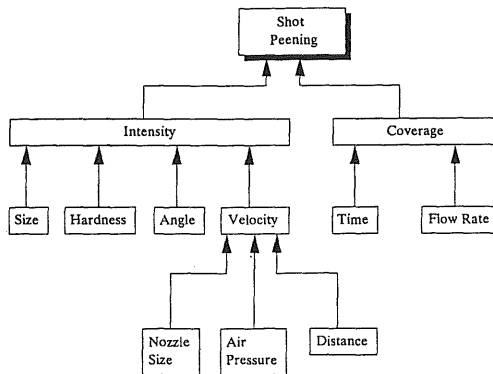
There are many process variables in the peening process. In order to have a consistent peening result, the dominant process variables must be identified and properly controlled. Once the relationship of the process variable to the peening result is established, then a proper tolerance can be placed upon the variable.

KEYWORDS

Shot peening, sensitivity analysis, peening variables, process control

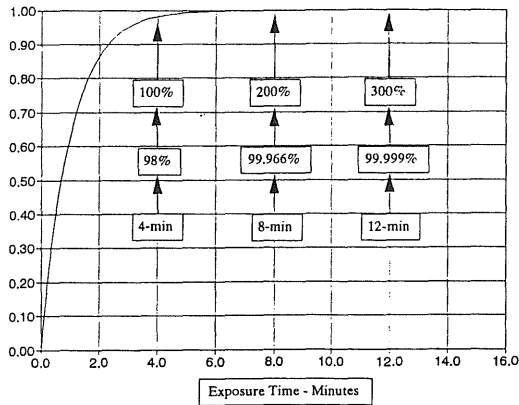
INTRODUCTION

Shot peening is performed to enhance the fatigue characteristics of metal components. This might provide longer service life, higher load range, better corrosion resistance, etc. Shot peening is also used for part straightening and peen forming. For any of these treatments to be effective and consistent, the process variables must be identified and their variations must be controlled to a defined tolerance.

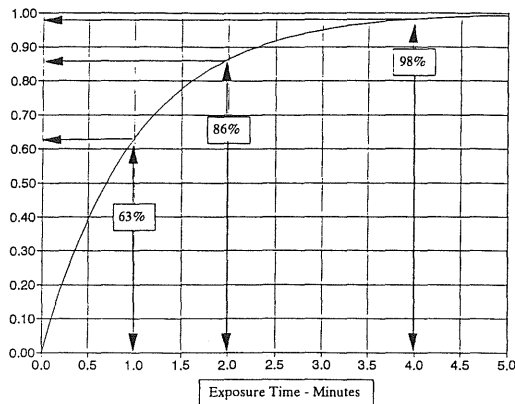


Shot peening "call-outs" or procedures, generally specify the peening intensity (arc height) and coverage. These are the most prominent specifications. Additionally, the shot size and hardness is usually specified in order to control surface finish and to assure that the shot is harder than the part and the Almen strips. Therefore, the shot size and shot hardness should always be specified in addition to the peening intensity and coverage.

Peening coverage, the area of the surface dimpled by the peening process, is usually specified in terms of percentage coverage. Although 100% coverage is difficult to estimate, the term 100% usually will mean 98% coverage. (Theoretically, 100% coverage may take an infinite amount of exposure time.) Conventional practice, therefore, uses 100% interchangeably with 98% coverage. 100% coverage represents the complete denting of the surface. Call-outs for coverage higher than 100% require exposure times proportionally longer. 200% coverage will require exposure time to be twice as long as 100% coverage exposure time. This is often requested as a "safety factor" to insure that 100% coverage was actually achieved.



There are also occasions when less than 100% coverage is appropriate. When 63% coverage provides the necessary peening benefit it may not be economical to spend the extra (exposure) time to achieve 100% coverage. The time to achieve 63% may be one minute, while it could take four minutes to achieve 100% coverage. To achieve 300% coverage would require 12 minutes. In high volume production this could be an important factor.



Let's assume that a given requirement has been established and the four variables - shot size, shot hardness, intensity and coverage have been clearly stated. These four items are called primary variables - they affect the peening benefit.

Additional variables that influence the primary variables are called secondary variables. Secondary variables include: shot impact angle, shot velocity, shot flow rate, exposure time. Each of these secondary variables will have an effect on the primary variables.

Questions regarding the primary variables need to focus on the peening benefit. Changes in shot size, shot hardness, intensity and coverage may enhance or diminish the component performance. Theoretically, the peening call-outs will recognize the tolerance available for each of these items in order to maintain an expected peening benefit.

Shot size, for example, is controlled by shot size specifications using screen shaking separators to classify the shot by size. Individual shot sizes vary within a tolerance band and they can be described using a Gaussian distribution function (bell shaped curve). For the most precise peening you could use precision ball bearings (often used in peen forming of large aircraft wing skins). However, it may not be necessary to use a precision shot size. Determining how much precision is needed can be done by experimental methods. Peening with a large shot size and then again with a smaller shot size and then comparing the component's performance will reveal the importance of shot size. It may be found that a broad range of shot sizes can be used with little or no significant influence on product performance. Similar experiments can be performed for the other primary peening variables using shot hardness, intensity and coverage to qualify the "Peening Recipe". Throughout this article it is assumed that only one variable will change at a time. In the shot size experiments the shot hardness and intensity and coverage must remain constant so as not to affect the results.

Secondary peening variables (velocity, angle, flow rate, exposure time) will directly influence the intensity and coverage which then affect primary variables and peening performance. And to keep things interesting, a third level of variables can be identified. Velocity, a secondary variable, is influenced by wheel speed or air pressure, nozzle size and distance. And air pressure at the nozzle can be influenced by shot flow rate and hose condition.

Figure 4 illustrates the relationship of intensity to air pressure for various shot sizes. It can reveal the sensitivity of intensity to air pressure for a given shot size or it can reveal the sensitivity of intensity to shot size at a given air pressure. It also reveals the sensitivity of intensity to air pressure for a given shot size.

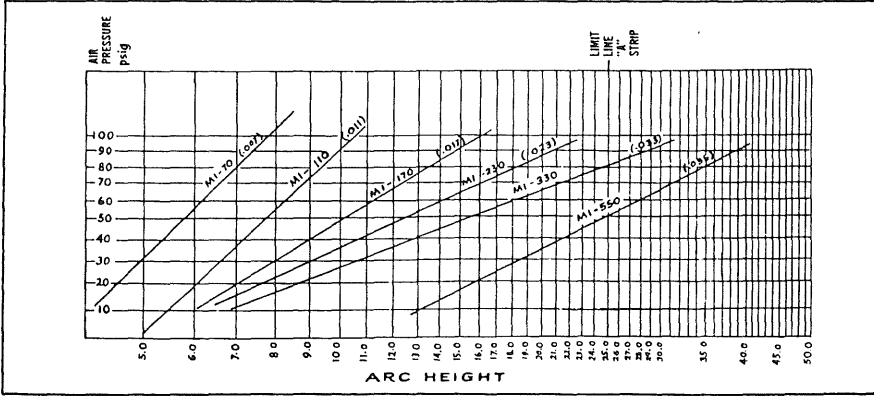


Figure 4. Shot peening intensity curves

For example, using a shot size 230 at an air pressure of 60 PSI yields an arc height intensity of 0.014 inch. To determine the sensitivity to air pressure, follow the line up the 70 PSI line and read the new intensity of 0.0162 inch. Next, follow the line down to the 50 PSI line and read the new intensity of 0.0125 inch. The sensitivity is now calculated as:

$$\frac{P_H - P_L}{I_H - I_L} = \frac{70 - 50}{0.0162 - 0.0125} = \frac{20}{0.004} = \frac{5}{0.001} \tag{1}$$

This reveals that changing the air pressure by +/- 5 PSI will change the intensity by 1 point. Conversely, if you expect to hold the intensity accurate to +/- 1 point, then you must hold air pressure accurate to +/- 5 PSI.

A second type of sensitivity can be seen using the same illustration. Again, use the S-230 shot size at 60 PSI to get the arc height intensity of 0.014 inch. If you hold the air pressure constant and change to S-330 shot, the intensity changes to 0.0185 inch. Next, change to S-170 shot size and you will get arc height intensity of 0.0112 inch. The sensitivity is now calculated as:

$$\frac{S_H - S_L}{I_H - I_L} = \frac{.033 - .017}{.0185 - .0115} = \frac{.016}{.007} = \frac{.0025}{.001} \tag{2}$$

This reveals that changing shot size by +/- .0025 will change the intensity by 1 point. Conversely, if you expect to hold the intensity accurate to +/- 1 point, then you must hold (the nominal) shot size accurate to +/- 0.0025".

To put our results into practice we must now implement process controls based on these two experiments. In the first case, we could install an air pressure regulator with an accuracy of +/- 5 PSI to hold our 1 point variation. Again, this assumes that all other process variables are held constant.

Maintaining intensity accuracy by controlling shot size is a little more difficult. Unless you are using precision ball bearings, the shot will have a range of sizes, or a distribution of sizes, for each standard shot size. In fact, in S-230 shot, it would not be unusual to find some shots from the S-170 size and some shots from the S-330 shot size. The shot "mix" or distribution of sizes will include percentages of adjacent shot sizes. The average shot size of the mix, approximately 0.023 inch for S-230 shot, must be held to .0215" to .0255" nominal diameter in order to maintain 1 point intensity. Unfortunately, unlike air pressure, there is no knob to turn to set this parameter. Shot size is controlled by screen separators, and if your separator is not working properly your intensity is going to vary.

Additional shot peening sensitivity experiments can be performed. Shot hardness sensitivity can be revealed by substituting first softer and then harder shot (although this may not be authorized by the metallurgist due to its affect on stress profile and may be affected by its relationship to Almen strip hardness).

So far we have focused our sensitivity discussions on issues that affect intensity. The sensitivity of coverage to exposure time or flow rate can also be explored. These experiments are relatively easy. In fact, exposure time sensitivity is really quite similar to the intensity development curve that is used to verify an intensity set-up. Increasingly longer exposure times of the Almen strip are used to check peening intensity. In the same manner, increasingly longer exposure times of your component (not the Almen strip) can be used to evaluate coverage (surface denting or fluorescent tracer removal). Once the exposure time gets beyond the "knee" of the curve, the coverage is less sensitive to exposure time variations. Let's look at two examples of coverage sensitivity. In the first case we will choose an operating point near 63% coverage. The second case will use an operating point near 95% coverage. The sensitivity will be seen to be much higher in the first case.

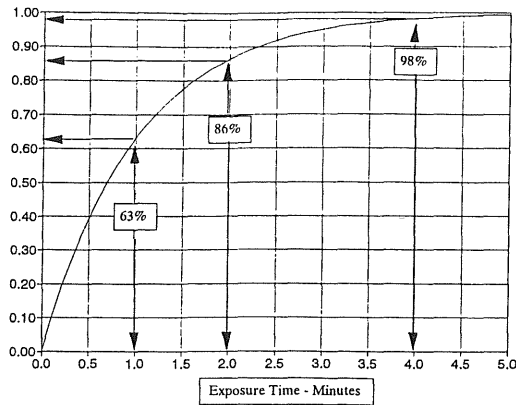
The sensitivity of coverage to exposure time near 63% coverage can be estimated by noting the time scale value of one minute for 63% coverage and determining the coverage for .5 minute and 1.5 minute. These values are 40% and 78% respectively. The sensitivity would be calculated as follows:

$$\frac{C_H - C_L}{T_H - T_L} = \frac{78 - 40}{1.5 - .5} = \frac{38}{1} = \frac{\%}{\text{min.}} \quad (3)$$

The sensitivity of coverage to exposure time near 95% coverage can be estimated by noting the time scale value of 3 minutes for 95% coverage and determining the coverage for 2.5 minutes and 3.5 minutes. These values are 92% and 97% respectively. The sensitivity would be calculated as follows:

$$\frac{C_H - C_L}{T_H - T_L} = \frac{97 - 92}{3.5 - 2.5} = \frac{5}{1} = \frac{\%}{\text{min.}} \quad (4)$$

The sensitivity in this latter case is much less than the first case. This can also be seen by inspection of the slope of the coverage curve.



The same type of graph can be used for shot flow rate sensitivity analysis. Coverage is a function of flow rate and exposure time and may be referred to as denting density or dimples per square inch. Instead of exposure time on the horizontal axis you can substitute shot flow rate in pounds/minute. Analysis of this nature assumes that the exposure time would be kept constant.

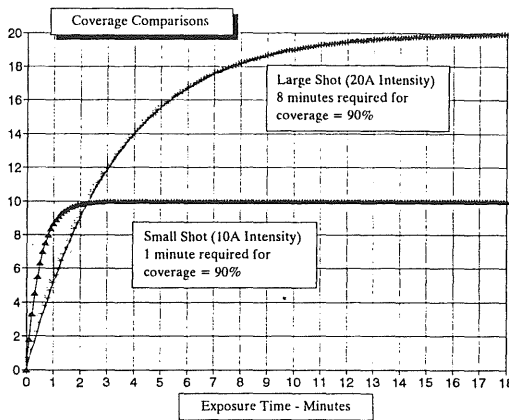
For peening operations that have fixed cycle times the number of passes through the machine could be depicted on the horizontal axis.

NOTICE: Shot size will have a large influence on coverage. Smaller shot sizes will provide very fast coverage and larger shot sizes will produce very slow coverage. The number of shots/pound will depend upon the shot size. Smaller shot sizes will have more shots/pound and conversely larger shot sizes will have fewer shots/pound.

SAE Shot Size (Mid-Range)	Shot Pellets Per Pound
780	8,000
660	14,000
550	26,000
460	45,000
390	65,000
330	110,000
280	210,000
230	360,000
170	520,000
110	1,700,000
70	6,000,000

The shot flow rate, usually thought of as pounds/minute, can actually be thought of as shots/minute. The product of shots/minute times exposure time in minutes will yield shots, or dents. This is what produces the coverage. The following graph illustrates how various shot sizes require different exposure times to achieve equivalent 90% coverage. Reducing the shot size by a factor of half will increase the number of shots/pound by a factor of 8. This also decreases the required exposure time by (approximately) a factor of 8. (The graph below is illustrative and is not intended to depict actual machine conditions.)

In general, a larger shot size provides a smoother surface finish compared to a smaller shot size. Therefore, in many cases, the largest shot should be used that can accommodate any small fillets. This increases the time required for coverage and a compromise may have to be selected. Although operators might prefer the short cycle time provided by smaller shot sizes, the metallurgist may not appreciate the surface finish created by smaller shots going deeper into the surface.



CONCLUSION

Sensitivity analysis can reveal the relationship of various process variables upon the peening process. Understanding this sensitivity can help establish proper tolerances on these variables.