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Shot Peening Process Optimization: A Cost-Effective Means of Improving Component Life and Performance

INTRODUCTION

The material in this brief article has been used in previous articles in this publication; however, here the emphasis is different. Here the emphasis is that not only can process optimization be considered; it must be.

It certainly is recognized that process optimization may not be possible for everyone. If you are a peening operation doing work for a customer who specifies a fixed level of coverage, then obviously you must perform peening to customer requirements. If you are a prime with specific coverage requirements per internal specification, then you are constrained to those requirements. On the other hand, an organization which either has design authority for a part or is free to change a process is a prime candidate for shot peening process optimization.

Creation of optimized shot peen processing will lead to substantial cost savings and even improve durability and quality of parts as a result. Read further to see how this can be accomplished and the justification for doing so. In previous articles, the case has been made to show not only that peening can successfully involve less than full coverage, but that the level of partial coverage, properly assessed and employed, can produce equivalent or better part quality and durability than application of full or greater than full coverage. Rather than send the reader back to previous articles on the subject, some of this information will be repeated herein for completeness and convenience.

BASIC JUSTIFICATION

There is no free lunch with peening. The benefits in part quality and durability gained by creation of a subsurface layer of compressive stress may well be mitigated by surface damage such as laps, folds, dents and defects caused by surface deformation. An example of surface plasticity-induced defects created by excessive coverage is shown in Figure 1, a metallographically prepared section through the peened surface of a fatigue tested truck leaf spring. Here a fatigue crack is seen emanating from a plasticity induced defect created by peening to an excessive coverage level, >200% in this example.

The information presented in this article flies in the face of conventional wisdom and lore in shot peening, which essentially embodies the belief that islands of unimpacted material on a part surface constitute sites at which fatigue crack initiation will occur preferentially and prematurely relative to a part peened to full coverage. This is simply not so. It is not the relative incidence of shot peening impacts on the surface that is relevant, but the effect of impacts on the subsurface material and the overlap of the plastic zones created by the impacts. Alternately stated, if subsurface plastic zones overlap, then the physical overlap of impact dents on the surface is not needed. This is illustrated schematically by Figure 2, which indicates the relative proportions of a peening dent and the attendant plastic zone. As represented by Figure 2, the plastic zone extends radially from the dent to a much greater extent than the size of the dent itself. Thus, it is not necessary to create overlapping impact dents on a peened

Figure 1 – Metallographically Prepared Section of Steel Leaf Spring Normal to Peened Surface after Fatigue Testing

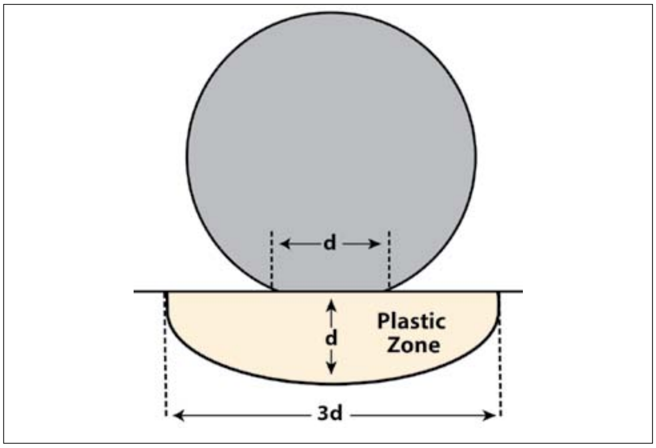

Figure 2 – Schematic Illustration Showing Relative Proportions of Impact Dent and Resulting Plastic Zone

surface for full peening effect. It requires only the creation of overlapping plastic zones at and below the surface. The authors do not warrant that the relative sizes of dent and plastic zone for different materials will always be the same. Thus, desirable optimization of results from the peening process will require experimental investigation.

OPTIMIZATION STRATEGY

The authors certainly recognize that optimization of the peening process may involve peening parameters and considerations other than coverage. Certainly, choice of media and intensity may also be involved. The authors are not dismissive of the importance of these factors, but the importance of coverage is overshadowing as regards to process cycle time and resulting cost savings.

The elements of coverage optimization strategy are as follows:

1. Control media flow rate to achieve consistently the same coverage for any given cycle time.
2. Consistently measure coverage.
3. Measure surface and subsurface residual stresses at selected coverage levels to determine at what coverage level the residual stress distribution is stabilized.
4. Verify durability and quality by testing, e.g., fatigue or stress corrosion cracking.
5. Determine process tolerance for robustness, i.e., determine the effect of varying coverage about the optimum on results.

AN OPTIMIZATION EXAMPLE

In this section the authors synopsize earlier work on peening optimization conducted at Lambda Technologies. This work formed the basis for the issue of a US Patent (US 7,159,425 B1, Method and Apparatus for Providing a Layer of Compressive Residual Stress in the Surface of a Part) involving peening coverage optimization.

Figure 3 shows the surface appearance of AISI 4340 steel coupons (38 HRC) peened at the various levels of coverage shown. Figure 4 shows the resulting coverage curve from 0 to 100% coverage. This non-linear curve is typical of peening, whereby the increase in coverage is high initially as many new dents are created at previously unimpacted sites. The rate of coverage decelerates as coverage increases, reflecting that as 100% coverage is approached, most impacts occur at previously impacted sites, and do not contribute to coverage increase. Figure 5 (page 14) shows the residual stress distributions associated with the coverages shown in Figure 3. Most interestingly, the depth of the residual stress distribution increases through coverages of 3%, 10% and 20%, but does not change systematically for coverages of 80% and greater. Beyond 80% coverage, the variation in compressive stress depth may be a reflection of scatter in stress and depth measurements; however, the clustering of results at less than full depth is remarkable. Certainly one may agree that no significant change in the residual stress distribution occurs beyond 80% coverage. Figure 6 shows fatigue S-N test results at various coverage levels. The most interesting features of the S-N data are the decrease in endurance limit for coverages greater than 100% and that life results for 80% coverage are essentially the same as for 100%. The overriding significance of these results is that coverage less than 100% (e.g., 80%) gave essentially the same fatigue life and residual stress distributions. Coverages greater than 100% also resulted in lower fatigue strength. The authors do not warrant that the same results will occur for all materials; however, essentially the same results were obtained from experiments with a nickel-base alloy Inconel 718. Other materials may give different quantitative results; however, it is highly likely,

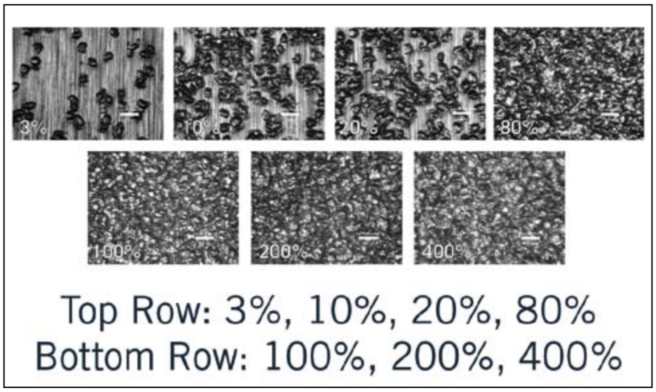

Figure 3 – Surface Appearance of AISI 4340 Steel (38 HRC) after Peening to Various Coverage Percentages

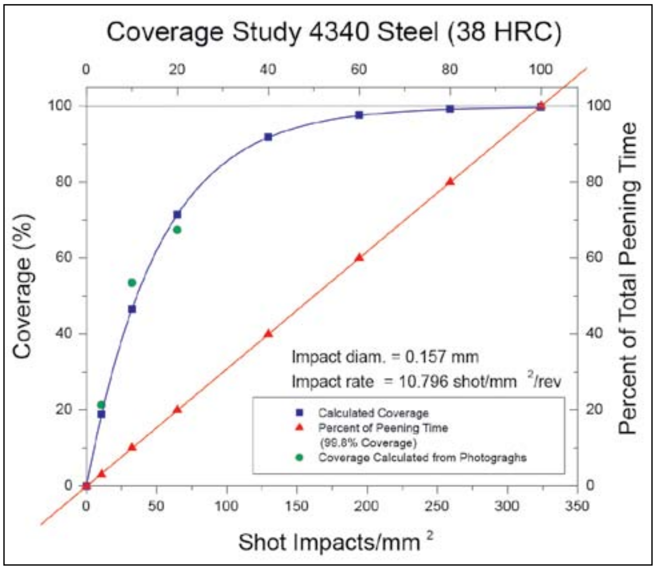

Figure 4 – Peening Coverage Curve Representing Coverage Progression from 0 to 100% for 4340 Samples

even certain, that results would show full peening benefit at coverage less than 100%.

SUMMARY

These results argue that optimum peening results can be achieved by peening to less than 100% coverage. The resulting cost savings are reflected in an exemplary timeline shown in Figure 7. This clearly illustrates that peening to 80% coverage occurred in only 20% of the time required for peening to 100% coverage, as confirmed in Figure 4. The savings in cycle time, along with increase in durability relative to peening to greater coverages, virtually demands process optimization. Lambda Technologies has the capability to assist in this area.

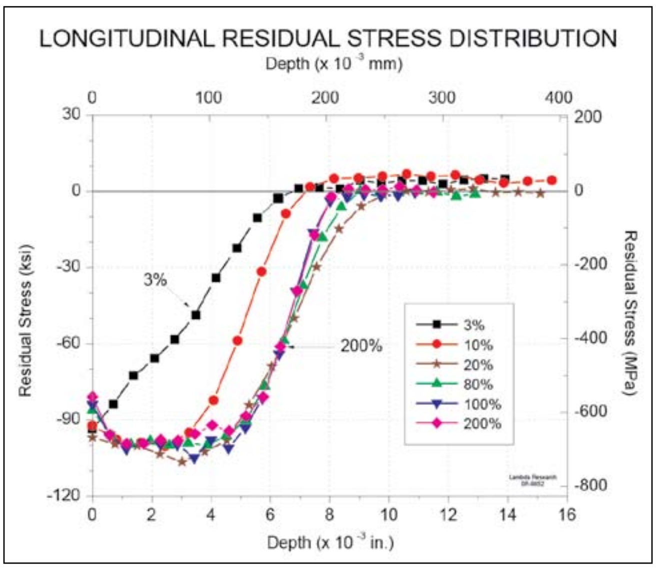

Figure 5 – Residual Stress v. Depth Distributions for Various Coverage Percentages of 4340 Samples

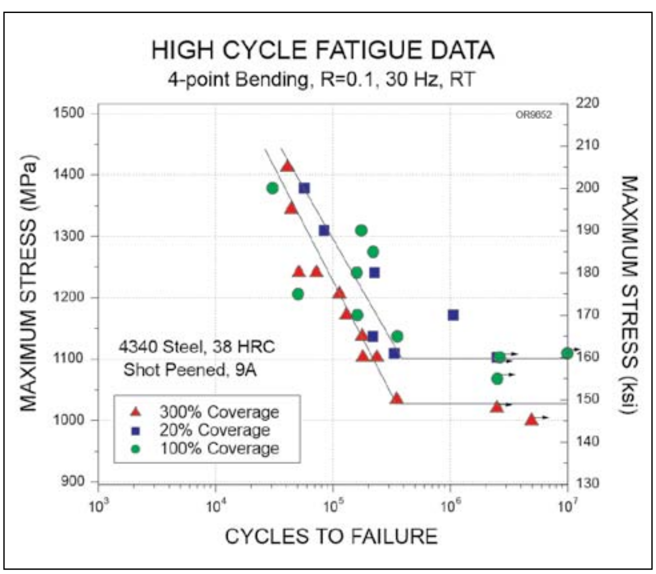

Figure 6 – Fatigue S-N Data for 4340 Samples

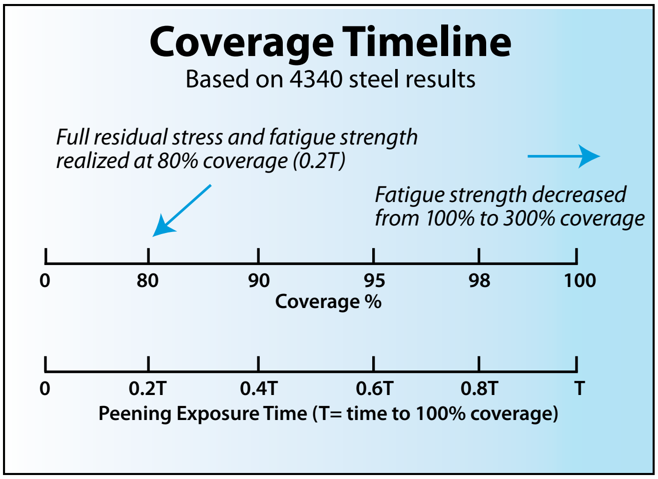

Figure 7 – Coverage Timelines Showing Relative Peening Times to Various Coverage Levels

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