Measuring Intensity in Small Areas with Complex Geometry using Mini Almen Strips

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Abstract

Mini Almen Strips provide a direct intensity correlation, rather than simply an arc-height correlation, in small, hard to reach areas on a peening surface. Currently, there is no direct way to measure the intensity of areas smaller than 31.75 mm by 19.05 mm since this is the measuring distance for a standard Almen Strip on a standard Almen Gauge. Current practices utilize shaded Almen strips to correlate an arc-height from a standard, unshaded Almen strip saturation curve to a Shaded Almen Strip arc-height. This correlation compares a single point on a curve, and thus creates some ambiguity in the collected data. When a Shot Peening parameter changes, a complete saturation curve must be developed to determine the new intensity. By comparing two points, one from a saturation curve with set parameters and one from a Shaded Strip in a new orientation, it is not a guarantee that the points both occur at the T1 validation point on the intensity curve. Mini Almen Strips provide a solution to this uncertainty. Measuring 25.4 mm by 3.175 mm, Mini Almen Strips can fit on most small peening locations. Since Mini Almen Strips are composed of 1070 Steel, just as standard Almen strips, and maintain the Standard Almen Strip thickness for both "N" and "A" types, they should follow the same material properties and plastic deformation as the Standard Almen Strips. Therefore, Mini strips should follow the 10% Rule to create a full saturation curve and allow for an intensity correlation to Standard Almen Strips, rather than just arc-height correlation. Using this logic, Avion Solutions conducted a Mini Almen Strip study for a Critical Safety Item for the U.S. Army using Ultrasonic Shot Peening (USP). These Mini Almen Strips will allow for an intensity confirmation when the designed USP chamber has an opening smaller than the measuring distance for a Full Almen Strip.

Keywords: Mini strips, Shaded strips, Intensity correlation

Introduction

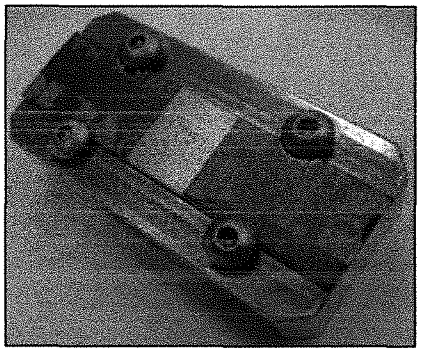
Currently, there are no direct methods to calculate the peening intensities in small areas or across complex geometry. In order to develop a saturation curve using standard Almen strips, the area of interest must be larger than the measuring distance on a standard Almen Gauge, 31.75 mm by 19.05 mm .This significantly limits intensity measurements in tight spaces, such as the inner diameter of small holes. The conventionally accepted method for monitoring peening intensities in these small areas is shaded Almen strips [1]. This technique utilizes a comparison of arc-height readings between an unshaded Almen strip and a shaded Almen strip. Each strip is exposed for the T1 time calculated from an unshaded Almen strip saturation curve. However, some potential issues arise using this method if the peening environment changes from the original saturation curve. As a shot peening industry standard, there must be a new saturation curve developed every time a shot peening parameter changes to ensure a maintained desired intensity with the new settings. For example, when the peening environment changes to an enclosed hole from an open environment, a new saturation curve may be needed to define this area fully and can result in a new intensity and T1/T2 times. Therefore, the ability to obtain a saturation curve and directly measure intensity in small, localized areas is necessary. This will allow for the comparison of intensity calculations, rather than a single point, or arc-height, comparisons. In an effort to find a better solution, Avion began to investigate Mini Almen strips, a new technology for shot peening.
Mini Almen strips, also known as Sub strips, were developed as an alternative method to shaded standard Almen strips, allowing for a quick and effective arc-height measurement in small areas

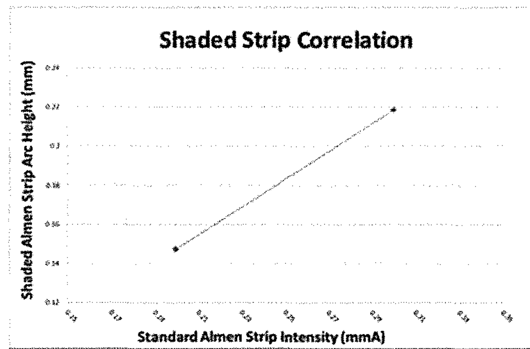
or on complex geometry. The use of Mini Almen strips eliminates the masking need associated with shaded strips, as well as creating complex and costly test fixtures for hard to reach peening areas. Mini Almen strips are created from the same 1070 spring steel material as standard Almen strips, but are much smaller in dimensions. A standard strip measures 76.2 mm long by 19.05 mm wide, whereas a Mini strip only measures 25.4 mm long by 3.175 mm wide with a maintained thickness. Mini Almen strips are available in both "A" (12.954 mm) and "N" (7.874 mm) thicknesses; they are not commercially available in "C" (23.851 mm) thickness. Since standard and Mini strips are composed of the same material, they maintain the same hardness properties, HRc 44-50. [2] Therefore, Mini Strips should follow the same 10% Rule used to create a full saturation curve and calculate the achieved intensity. This allows for an intensity/intensity correlation between standard and Mini Almen Strips, rather than an intensity/arc-height correlation using shaded strips. Due to the reduced size and ease of application, Mini Almen strips are ideal for small, difficult to reach applications such as dovetail slots and the internal bore of a spring. However, just as with shaded standard Almen strips, the development of a correlation chart with Mini Almen Strips is necessary before using them in these locations.

Current Shaded Strip Procedures

Many shot peening facilities utilize a technique known as shaded Almen strips for peening areas that are smaller than the measuring distance of a standard Almen Gauge, 31.75 mm by 19.05 mm. Shaded Almen strips are achieved by masking a standard Almen strip using a vinyl tape or permanent mask to expose only the center of the Almen strip at a length of the surface to be peened. Figure 1 illustrates a Shaded Almen Strip example. In order to determine the process parameters for a small area, the development of a correlation chart between an unshaded and a shaded Almen strip is necessary. First, run a saturation curve at the lower end of the specified intensity range. This is achieved by exposing four standard Almen strips to the shot stream at increasing times on a standard Almen block to produce the desired lower intensity. Using the arc-heights collected, generates a saturation curve. This saturation curve produces the calculated intensity and T1/T2 times. Using the calculated T1 validation time, a single Almen strip of the same thickness is exposed to the shot stream to confirm an arc-height reading similar to the calculated intensity. Next, another Almen strip is masked so that only the center of the strip with a width of the desired peening location is exposed. The masked strip is peened using the T1 time previously calculated for the unshaded strip. Next, remove the masking and measure the resultant arc-height; this is the correlated arc-height for the lower intensity specification range. This process is repeated for the upper intensity range [1]. By plotting these data points, a correlation chart can be determined; Figure 2 illustrates the range of allowable arc-height readings for the given intensity. For the example of the intensity range 0.20 mmA - 0.30 mmA, the allowable arc-height range for the shaded Almen strip is between 0.1473 mm and 0.2184 mm, shown in Figure 2.

The use of this shaded Almen strip procedure presents a few items of concern. The first concern faced when using shaded Almen strips is creating an adequate test fixture. The process to create a test fixture that simulates the small, localized areas or areas with complex geometry of a peening surface can be very costly and difficult to incorporate a standard Almen block. Another issue can occur by using the T1 time developed for the unshaded Almen strip under slightly different conditions. These altering conditions create a potential for erroneous intensity verification tests. If the peening conditions change between the unshaded and shaded Almen strips, this requires a new saturation curve. Since the intensity and T1 time are calculated based on the environment of the unshaded strip, the new setup for the shaded Almen strip can adjust the peening intensity and T1 validation time. However, due to the size and space restrictions in the area of interest, developing a new saturation curve using standard Almen strips is improbable and difficult to substantiate. The final point of concern is that this correlation utilizes the arc-height measurement as a validation for intensity under potentially different peening conditions. Since an arc-height is a single point along the saturation curve and intensity is a calculation derived from the curve itself, the possibility of some ambiguity can occur with this method. By changing the peening environment, the single point verification of intensity may now fall at a different place along the saturation curve under the new peening parameters, yet indicate that the intensity is still within acceptable range. Figure 3 depicts this phenomenon. While the arc-height reading in both cases would remain 0.122 mm at a given time, 18 seconds, the intensity does not remain the same due to a change in the peening environment.





Figures 1 and 2: Shaded Almen Strip using PVC tape and Correlation Chart for 0.20 mmA - 0.30 mmA

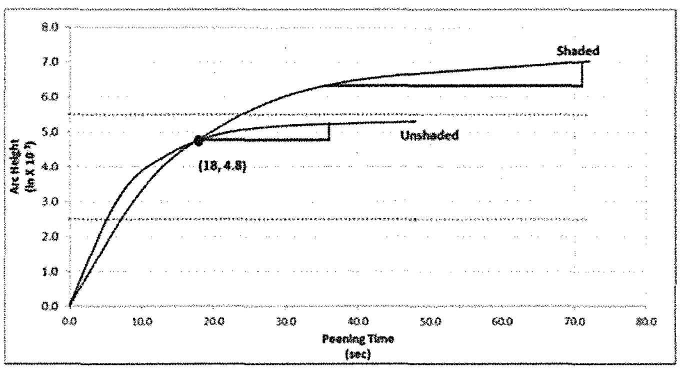


Figure 3: Incorrect T1 Validation Example

Intensity Correlation using Mini Almen Strips

This new Mini strip technology provides a quick and effective method to calculate intensity in small, localized areas. [2] Since Mini strips are composed from the same 1070 steel used on standard Almen strips, the material properties, such as lattice structure and hardness, are held constant, referenced in Table 1. Therefore, ideally Mini Almen strips should mimic the behavior of standard Almen strips.

These similarities should allow for the theoretical calculation of a Mini strip arc-height from a measured standard Almen strip arc-height using the arc-segment analysis shown in Figure 4 and Eq. 1. Set the chord d_1 as the constant measuring distance for a standard Almen strip, or d_1= 31.75 mm. Since a Mini strip Almen Gauge uses the entire length of the Mini strip as a measuring distance, set the chord d_2 equivalent to the length of a Mini strip, or d_2= 25.4 mm. Next, measure the resultant arc-height for a standard Almen strip exposed to a given shot stream. If a Mini strip is exposed to the same shot stream for the same peening duration as the measured standard Almen strip, the resultant curvature of each strip should be identical. Since both strips are receiving the same amount of energy from the shot stream, the plastic deformation, or bowing, should be proportional. Therefore, it can be assumed the resultant radii for the two arc-segments, $\widehat{AD}$ and $\widehat{BC}$, are equivalent; thus, the two equations can be set equivalent to one another. Finally, a theoretical Mini strip arc-height, h_2, can be calculated given a measured standard strip arc-height, h_1.

Table 1: Material Properties of Almen Strips

	Mini Almen Strips "A"	Standard Almen Strips "A"
Material	1070 Steel	1070 Steel
Thickness	12.954 mm	12.954 mm
Length	25.4 mm	76.2 mm
Width	3.175 mm	19.05 mm
Measurement Length	25.4 mm	31.75 mm
Hardness	44-50 HRc	44-50 HRc

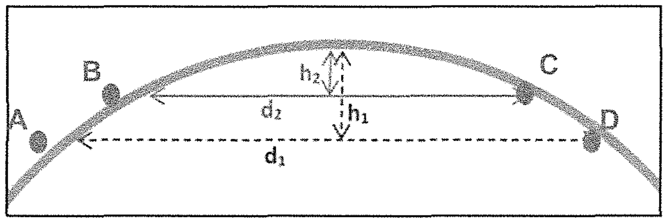


Figure 4: Arc-segment Analysis for Standard and Mini Almen Strips

$$R = \frac{h_n}{2} + \frac{d_n^2}{8(h_n)} \quad (1)$$

Where R is the radius of the circle, d_1 is the standard Almen strip measuring distance, d_2 is the Mini Almen strip measuring distance, h_1 is the measured standard Almen strip arc-height, and h_2 is the Mini Almen strip calculated arc-height. This shows that the Mini Almen strips should behave similar to standard Almen strips, and reach a point of saturation in which the arc-heights along the curve change exactly 10% with a doubled peening time, using the equation Arc Height=a(1-exp(-b*t)). This calculated saturation point using Mini Almen strips will be referred to as a Mini-intensity. The value obtained through this method is not the true intensity achieved at the surface of the component; however, since it is calculated using the same methods as a standard Almen strip, or true, intensity it can directly correlate to a true intensity. An "M" subscript denotes a Mini-intensity, for example if an "A" mini-strip is used to calculate a Mini-intensity, "A_M" would denote the Mini-Intensity results. This Mini-intensity calculation allows for an intensity/intensity correlation, rather than an arc-height/intensity correlation. This eliminates any ambiguity caused by comparing a single point (shaded strip arc-height) to a calculated intensity from a standard Almen strip in a different peening environment. Figure 6 a) and b) display a standard Almen strip saturation curve and a Mini strip saturation curve exposed to the same shot stream in the same peening parameters. In addition, Mini strips will have their own unique T1/T2 times due to the Mini-intensity calculation based on the specific Mini Almen strip arc heights in the saturation curve. Theoretically, the T1/T2 times for the standard and Mini strips should be very similar. The observation during actual testing revealed that the Mini strip saturation curves calculated longer T1/T2 times, attributed to edge effect of the smaller strips. $T1_M/T2_M$ denotes the T1/T2 times of these Mini Almen strips. Therefore, when performing a $T1_M$ validation test, the $T1_M$ time correlates the arc-height reading of the Mini Almen strip along the saturation curve where the 10% rule is applicable. It has been demonstrated that Mini strips can produce a saturation curve following the same equation used to calculate a true intensity, Arc Height=a(1-exp(-b*t)). However, before using Mini strips to correlate the intensity in tight, localized areas, the development of a correlation chart similar to that of the shaded Almen strips is necessary. To develop a correlation chart, just as with shaded strips, a saturation curve with standard Almen strips is run at the lower end of the specified intensity range. Next, a Mini Almen strip saturation curve is run under the same parameters as the standard Almen strips.

With exposure of four Mini Almen strips to the shot stream at increasing times on a standard Almen block, to produce a unique Mini-intensity and $T1_M/T2_M$. This calculated Mini-intensity is the correlated intensity for the lower intensity specification range. This process is then repeated for the upper intensity range. By plotting these data points, the range of allowable Mini-intensities for the given intensity range can be seen. Figure 7 shows this intensity/Mini-intensity correlation.

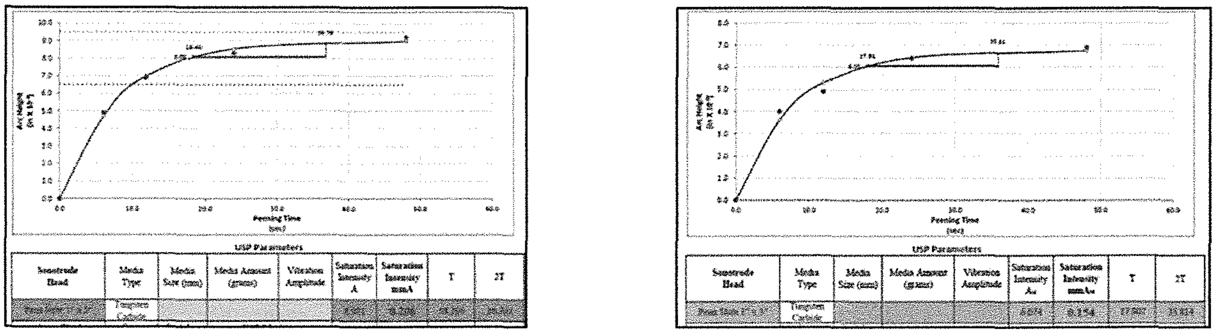


Figure 6 a/b: Saturation Curves with True Intensity 0.21 mmA and Mini-Intensity 0.15 mmA_M

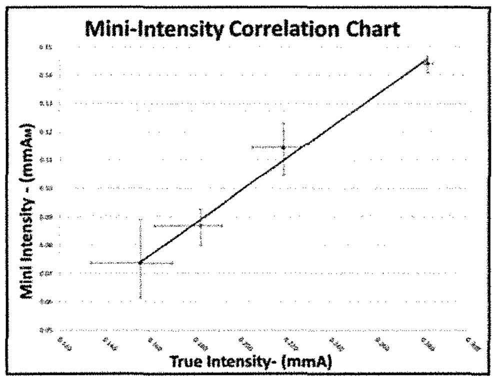


Figure 7: Mini-Intensity Correlation Chart

This innovative Mini strip technology, proved an ideal match with Avion's portable Ultrasonic Shot Peening (USP) capabilities. USP is a technology that establishes a small chamber that completely encloses a small repair area for re-shot peening after blending of a surface damage. This provides the ability to perform shot peen repairs at facilities where actual aircraft maintenance occurs without the need for large conventional shot peening machines. The system's basic function relies on the excitation of the peening media in a small chamber using a Sonotrode that carefully controls the resulting intensity of the shot peen repair. This process uses a small amount of media comprised of spherical balls rather than cast shot or cut wire. The consistency of spherical media provides for an improved surface finish and significantly reduces the media sorting process. The USP technology, StressVoyager®, depicted in Figure 8, uses the same Almen strip/Saturation Curve process used in the conventional shot peening process as defined in J442 and J443. The Almen block is integrated into the peening chamber in the same location as the component repair section to ensure the resulting intensity is representative of the production process. The STRESSONIC® technology provides the ability to peen small areas that are common in the Maintenance, Repair and Overhaul (MR&O) environment. These small repair areas do not lend themselves to the conventional shot peening process that provide for shot peening of the entire part/component as a separate item. In the MR&O environment, these components are usually part of a larger assembly or subassembly and only need a small repair area treated. Avion has experienced the need to re-peen small areas that do not provide for the incorporation of a standard

Almen block for saturation curve development. Initially, Avion used the shaded Almen strip process described above but quickly realized the benefits of using Mini strips to provide for calculation of Intensity. Using this USP system and Mini Almen strips, Avion developed a repair process for a U.S. Army Critical Safety Item (CSI). The repair area measured approximately 25.4 mm by 12.7 mm. Due to this size restriction, and the orientation of the location to be peened, Avion designed an enclosure that utilizes different chamber dimensions from a standard Almen block holder chamber. This peening parameter change requires a new saturation curve to verify the achieved intensity. Therefore, an arc-height comparison at the T1 time of the standard Almen block chamber would not provide adequate intensity verification in the newly designed chamber. Using the methods previously described, Avion developed a correlation chart between Mini Almen strips and standard Almen strips using calculated Mini-intensities and true intensities. The U.S. Army granted Avion repair authorization for this CSI component through the successful demonstration of proper peening intensity using the Mini-intensity correlation study.

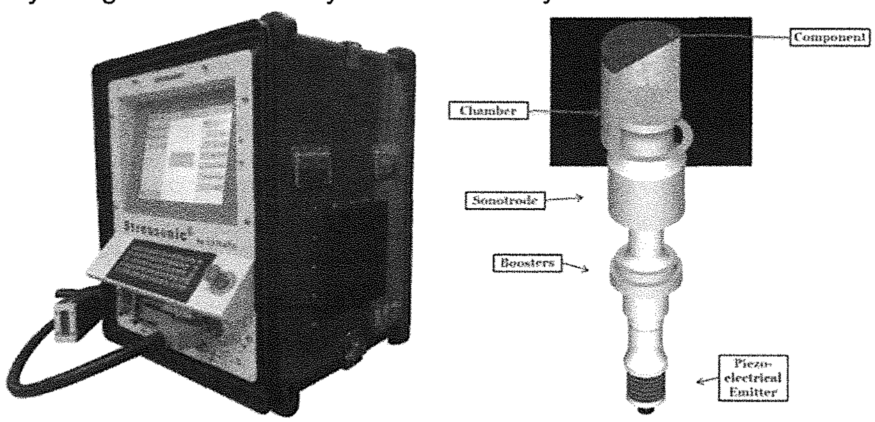


Figure 8: Portable, Ruggedized StressVoyager® USP System

Conclusions

Shaded Almen strips provide a T1/T1 correlation that does not adequately validate the intensity when a shot peening parameter changes from the derived environment of the T1 time. By modifying any parameter of the shot peening environment, the T1 time originally developed does not ensure a correlated T1 time for the new parameters. Therefore, the arc-height measured in the new environment may not be a reflection of intensity. Conversely, using Mini Almen strips allows for a direct correlation between intensities, since we can obtain a saturation curve by using Mini strips a Mini-intensity correlation, rather than an arc-height correlation. Therefore, we can measure intensity in a location too small to allow a full strip saturation curve, as opposed to simply measuring an arc height at a T1 time provided by a different peening environment.

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References

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