CHARACTERIZATION OF MANUAL SHOT PEENING PROCESS: PRELIMINARY RESULTS

H. Diep*, H. Bae and M. Ramulu

Department of Mechanical Engineering, University of Washington, Seattle, WA *
The Boeing Company, Seattle WA, USA

ABSTRACT

To increase the fatigue life of the material and to ensure the quality of shot peening effects, shot peening parameters should be optimized. In this paper correlations are made to characterize the intensity, saturation and coverage by varying the impingement angle, stand-off-distance, and supply pressure for manual shot peening. The manual peening conditions were successfully applied on 7050Al flat coupons and the results were found to be reproducible in Aluminum alloy.

INTRODUCTION

There are many processes used today to treat the surface of metals. Cold working the surface of materials is a widely used method that has been around for centuries and shot peening is one of the many methods of this type of surface treatment [1-5]. Although the mechanism of shot peening is a simple concept but the process is complex. Shot peening produces several changes in the workpiece material, including changes to microstructure, residual stresses, and topography. Some of these changes are beneficial, and some are potentially detrimental [6-9]. However, the effectiveness of the shot peening process is dependent upon the uniformity of the induced compressive residual stresses and the energy transfer that occurs during the impact of the shots with the target surface. Generally shot peening is applied via highly controlled, automated equipment, but occasionally, due to component shape and or size, manual shot peening treatment is the only available method to induce compressive residual stresses [3]. However in manual peening operation, the control of intensity and coverage is of vital importance to produce high quality surface treatments [4].

In practice, the process efficiency is established by means of coverage, intensity and saturation. Intensity and saturation can be found for varying input conditions which are stand off distance (SOD), impingement angle, air pressure, shot size, shot properties and material properties. There is a need to understand the relationship between peening parameters and intensity. There are very few published studies on the effects of manual peening on component parts but there exists a real need for a much more extensive study to cover all the aspects required for optimizing the manual peening process. The purpose of this paper is to investigate the manual shot peening process and characterize the peening process parameters such as intensity, saturation and coverage.

EXPERIMENTAL METHOD

The test strips used for this study were A type Almen strips, an SAE 1070 CRS (cold rolled spring steel) with a standard hardness of 44-50 HRC. The shot material was Cast steel shot S230. The manual shot peening system used for this study was a

Vacuum-blasting system from Vacublast, run with fixed air pressure at 69KPa with a 6 mm diameter nozzle. The A- Almen test strip meets the requirements of MIL-S-13165C, AMS-S-13165, SAE J442, SAE AMS 2430M and SAE AMS 2432B [10-13]. The basic shot peen parameters were cast steel shot S230, per MIL-S-13165, with a 0.58mm (0.023in) nominal diameter was used at a mass flow rate of 17.64Kg/min at 69KPa. A fixture was designed and fabricated to maintain a constant SOD for a selected angle of impingement in this manual shot peening experimental study. Two standoff distances were used, 304 mm was the maximum used in the vacuum chamber. Table 1 lists the settings used for experimental tests during this characteristic study. The experimental setup is illustrated in Figure 1.

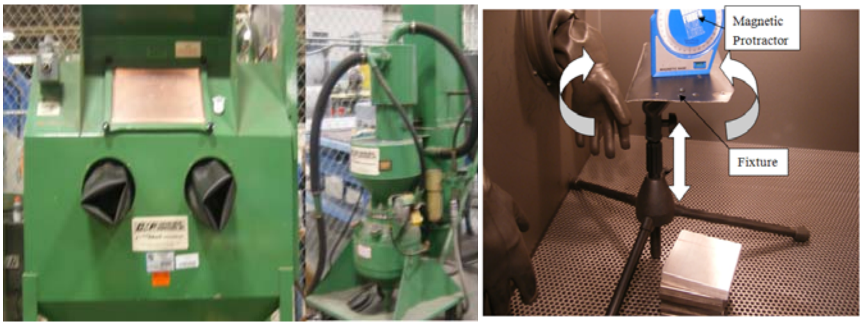


Figure1 Shot peening system and experimental setup

Table 1 Peening conditions of the Almen test strips, pressure=69kPa (10psi)

Standoff Distance (SOD) (mm)(Inch)	Impingement angle (Degree)
152.4 (6)	90
	60
	45
	30
304.8 (12)	90
	60
	45
	30

Test specimens were examined with an Almen gage using a flatness tolerance of +/-0.0005 [2] to gather Almen test strips. Coverage, which is the percentage area of a surface that has been impacted, was measured using an image analysis system. As stated earlier, expectations for these experiments is to determine the correlation between three variables, air pressure, SOD and impingement angle and the goal of

100% coverage. Fourteen test specimens for this study were fabricated from Al 7050-T745, each specimen was a 100mm x 100mm x t block. The peening conditions were varied (air pressure (69-249kPa), stand of distance (152-304 mm) and angle of impingement (30-90 degrees)) and design of experiments yielded a total of 14 combinations. All intensities were defined via the saturation curve process. To get uniform coverage X-Y coordinated movements at a travel speed of 20mm/sec of shot stream was applied to the flat blocks.

Image Analysis [14], public access software from the National Institutes of Health, was utilized to calculate the percentage of area shot peened (coverage). 40X and 60X images were collected using a stereomicroscope with a digital camera the microscopic photos were taken so that indentations from shot peening were represented as white and untreated area as black, which were produced by adjusting the angle of impingement of light on the surface of the test specimens in the microscope. The optical micrographs were taken at nine pre-selected points on the test specimens, i.e., the corner, edges and middle of the blocks. Percentage of coverage in each peening condition was defined as the average value of the percentage coverage of the nine points. Surface topography was evaluated using optical microscopy and surface profilometry.

RESULTS AND DISCUSSION

Saturation

All arc heights of the Almen test strips were measured using an Almen gage. Figure 2 illustrates the relationship between arc heights and peening times. It also illustrates how the intensity changes at different angles of impingement for a given

Table 2. Almen Strip Saturation points

Cast steel shot S230, Shot dia. = 0.58mm Air pressure = 69.4kPa, Shot flow rate = 16.9Kg/min

Saturation			
SOD (mm)	Impingement angle (Degree)	Saturation time(minute)	Saturation arc height (mm)
152.4	90	0.63	0.15
	60	0.7	0.13
	45	0.6	0.11
	30	1	0.09
304.8	90	1.9	0.15
	60	1.14	0.13
	45	1.99	0.10
	30	1.88	0.08

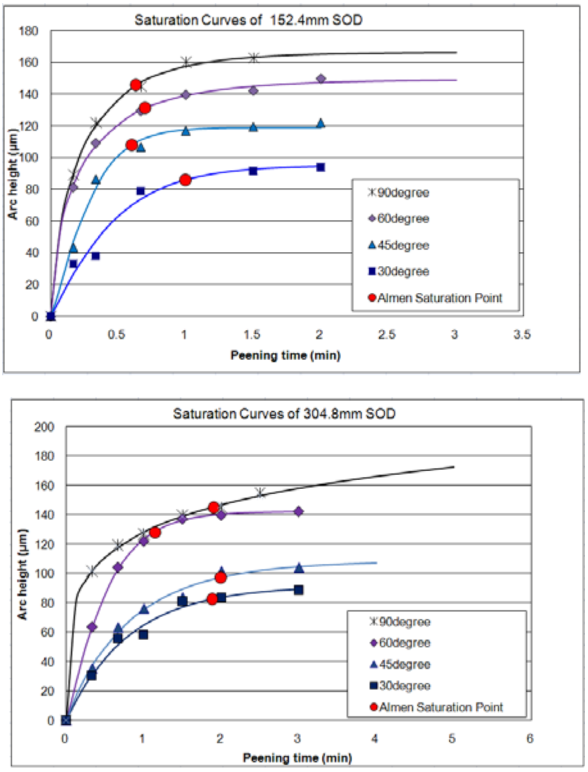


Figure 2 Almen strip's Saturation Curves of two Stand Off Distances (SOD) (p =69KPa)

SOD. Increasing impingement angle, which is 30 degree to 90 degree, increased the intensity almost linearly. Table 2 gives the summary of Almen strip arc height and time at the saturation. The results clearly show how SOD affects the saturation arc heights and times. Increasing SOD caused decreasing arc height and increasing saturation time.

Coverage

Coverage analysis was performed by evaluating optical micrographs. Figure 3 illustrates the typical image used for coverage analysis obtained from Almen strips. Included in figure 3 are the original micrographs, the binary images and the graphical representation of the relation between the coverage and the peening times deduced from this series of experiments.

Figure 4 shows the coverage analysis by Image J and the development of coverage with exposure time for Al 7050 flat coupon. Table 3 provides a summary of the times to reach 100% coverage for the test specimens. As expected, higher intensities reduced the time to reach 100% coverage. We therefore conclude that energy is closely related with coverage time. Increasing air pressure and impingement angle from 30 degrees to 90degrees decreased the coverage time for a constant SOD. It is also observed that by decreasing SOD, for a given impingement angle, 100% coverage time was found to be reduced.

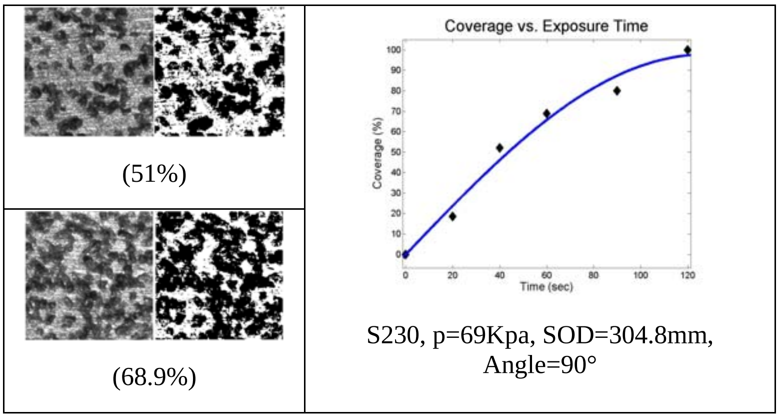


Figure 3 Example of coverage analysis by Image J and the development of coverage with exposure time for Almen strip.

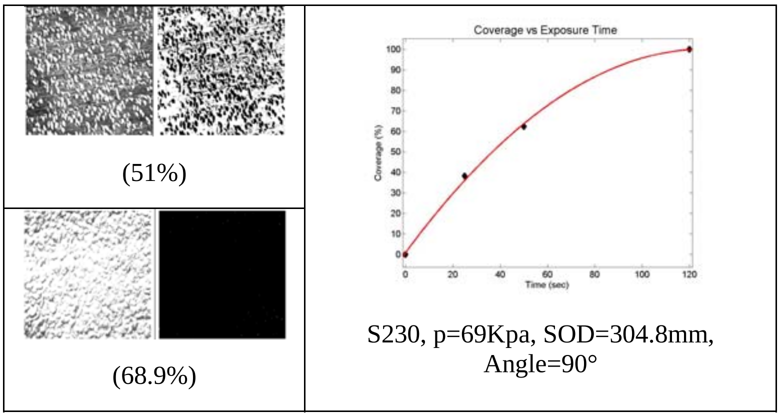


Figure 4. Coverage analyses by Image J and the development of coverage with exposure time for Al 7050 flat coupon.

Surface and Sub-surface Characteristics

Surface topography and resulting surface roughness from shot peening is clearly dependent on coverage and operating conditions. Maintaining a constant air pressure, of 69kPa, and increasing peening time caused an increase to surface roughness values as shown in Figure 5. This is to be expected, given that longer peening times, impart more kinetic energy as shots impact the material surface. By increasing impingement angle from 30 degree to 90 degree, surface roughness values increased. This is because shot impacting normal to the surface transfers more kinetic energy than oblique impacts, thus causing more surface damage.

Table 3. Al 7050 Flat Surface Specimens Time to reach 100% coverage

Air pressure (kPa)	Sample#	SOD (mm)	Angle of Impingement (degree)	Saturation Intensity(A) (mm)	Time to reach 100% Coverage (sec)
82.7	13	304.8	90	0.14529	120
68.9	7	203.2	90	0.14173	130
103.4	6	152.4	50	0.14478	110
	12	228.6	60	0.14376	110
137.9	5	228.6	30	0.14249	110
	14	304.8	50	0.16002	90
172.4	1	304.8	30	0.14732	110
	2	152.4	90	0.25806	35
	3	304.8	70	0.23876	50
	4	228.6	30	0.16002	80
	9	228.6	90	0.25400	40
	10	152.4	30	0.16535	80
	11	228.6	60	0.22225	50
241.3	8	152.4	60	0.24308	35

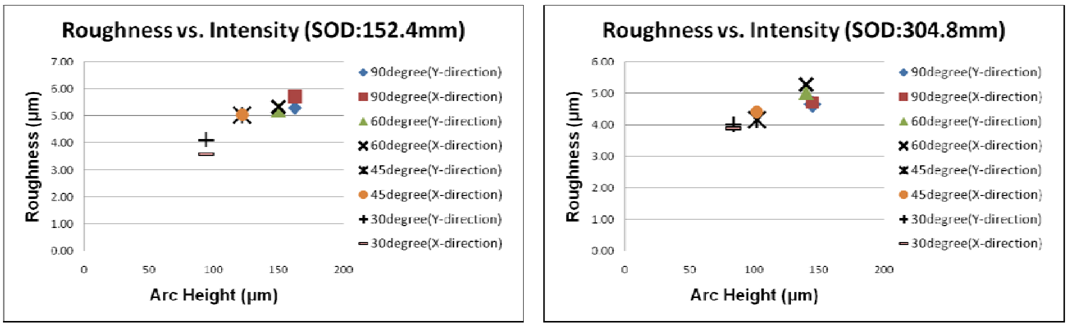
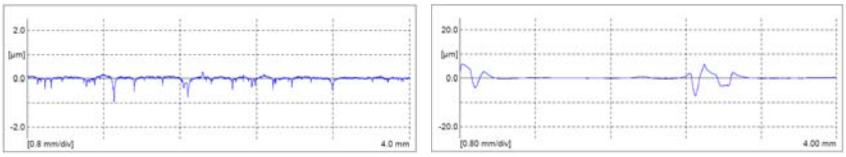
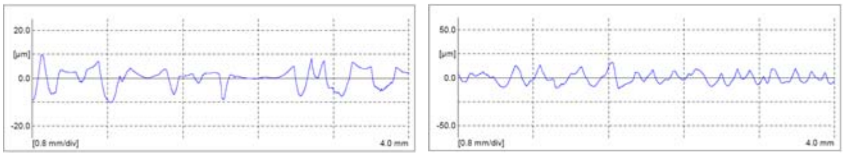


Figure 5 Surface roughness (Rz) vs. Intensity at 2min exposure time (p=69KPa)

Typical surface profiles recorded on shot peened Al 7050 block specimens with varying levels of coverage are shown in Figure 6. Average surface roughness values for 14 flat plate specimens computed by 10 random measurements on the surface are shown in Figure 7. These results indicate that increasing peening time increases the degree of surface roughness. Test results indicate that Al7050-T7431 is sensitive to coverage time since it is a soft material [15]. This fact is illustrated when looking at the data for specimen 1, for 200% coverage the surface roughness increased by a factor of 6 relative to an unpeened specimen. In addition, higher intensity increases the degree of surface roughness.



(a) polished surface(Ra=0.0055,Rt=1.22 Rz=0.75µm) (b) 28.4% (Ra=0.702,Rt=13.06 Rz=5.035µm)



(C) 52.5%(Ra=2.985,Rt=19.84 Rz=14.877µm) (d) 100% (Ra=4.664,Rt=27.51 Rz=21.762µm)

Figure 6 Surface roughness profiles of the various degrees of coverage (S230, p=172.4Kpa, SOD=152.4mm, Angle=90°)

Figure 8 show the normalized subsurface hardening for varying conditions of coverage. Note that the increase in hardness extends to a depth of 200 m. Increase in surface hardness was about 15-20%.

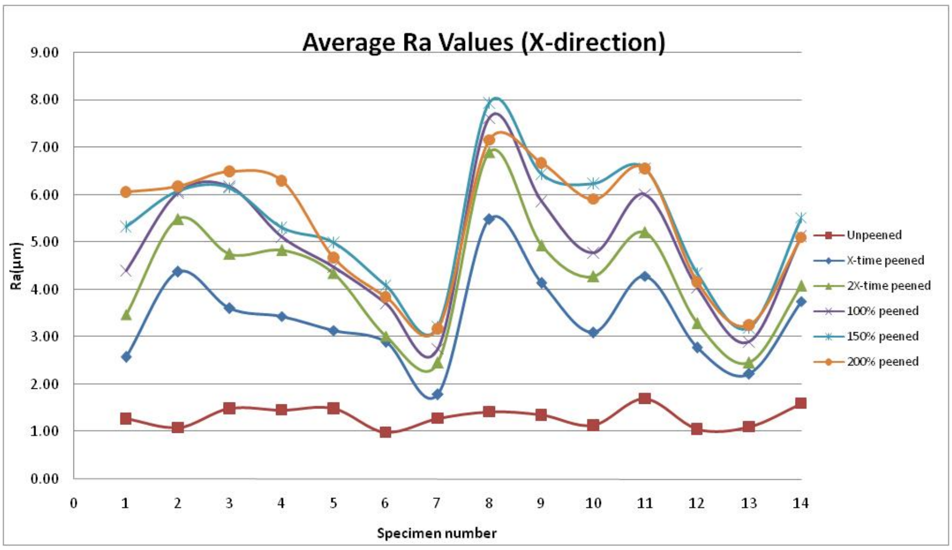


Figure 7. Average Surface Roughness ,Ra , for flat plates

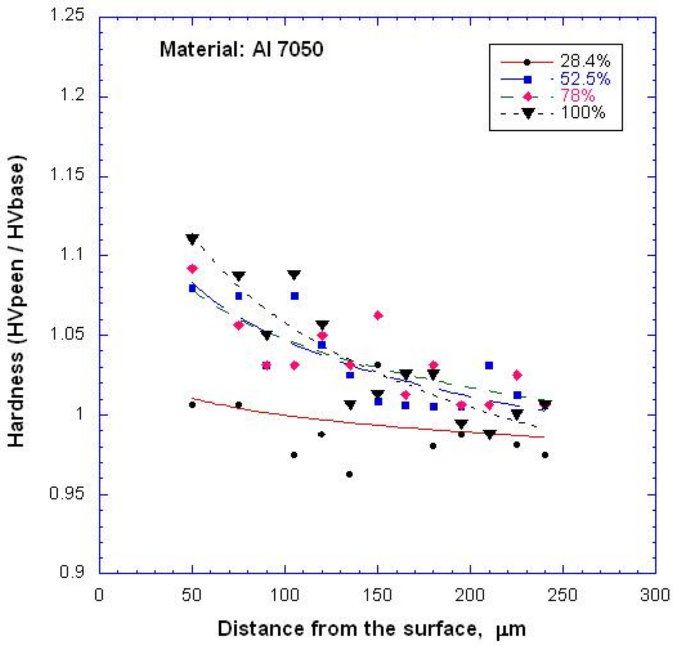


Figure 8: Normalized Hardness VS Distance from the Edge Surface (HVbase 100g=160)

SUMMARY AND CONCLUSIONS

A series of experiments were performed to characterize the shot peening process in terms of peening input parameters such as shot size and properties, air pressure, impingement angle, stand off distance, feed rate, and material properties. Intensity, saturation and coverage were determined experimentally by varying conditions. It is clear that intensity, saturation and coverage can be controlled by input parameters. Observations showed that the peening process is strongly dependent on control of peening conditions in manual operation. The results of this work show that with proper controls manual shot peening can be used to produce an optimum balance between surface hardening and surface roughness. Currently the work is in progress to evaluate the fatigue performance of manually peened aluminum and titanium alloys under high cycle loading.

ACKNOWLEDGEMENTS

The authors sincerely acknowledge the encouragement and assistance given by Mr. Jack Champaigne of Electronics Inc., Mrs. Meloney Olds and Mr. Patrick Buffington of the Boeing Company and the experimental assistance of Mr. Andrew M Cantrell.

REFERENCES

1. Niku-Lari, A. “Shot-Peening”, First Int’l. Conf. on Shot Peening, 1981, pp.395-403.

2. Champaigne, Jack, “Shot peening overview”, Electronics Inc. Mashawaka, In. 2001

3. David Kirk, “ Shot peening”, Aircraft Engineering and Aerospace Technology, Vol71, 1999, pp.349-361

4. D. Clarke and S. S. Birley, “The Control Of Manual Shot Peening”, Quality Assurance Directorate(Ordnance) London UK,1981,pp.167-174

5. M. K. Tufft, “Development of a Fracture Mechanics/ Threshold Behavior Model to Assess the Effects of Competing Mechanisms Induced by Shot Peening on Cyclic Life of Nickel-base Superalloy, Rene 88DT”, Ph. D. dissertation, University of Dayton, 1997

6. Adam Ashford Biggs, “Analysis of factors affecting Almen strip arc height after shot peening”, M. S. Thesis University of Washington, 1999

7. T. Dorr and L. Wagner, “Effect of shot peening on residual life of fatigue pre-damaged 2024 Al”, Sixth Int’l. Conf. on Shot Peening, 1996

8. Jack Champaigne, David Kirk, “The Curve Solver Program”, The Shot Peener, Spring 2007

9. L. Wagner, “Mechanical surface treatments on titanium, aluminum and magnesium alloy”, Material Science and Engineering, Vol. A263, 1999, pp. 210-216

10. SAE J442, “Test Strip, Holder And Gage for Shot Peening”, August 1979

11. SAE J443, “Procedures for Using Shot Peening Test strip”, January 1984

12. MIL-S-13165C, “Shot peening of Metal Parts”, 1989

13. AMS 2432, “Shot Peening, Computer Monitored”, 1990

14. Abramoff, M.D., Magelhaes, P.J., Ram, S.J. "Image Processing with ImageJ". Biophotonics International, volume 11, issue 7, pp. 36-42, 2004

15. T. Ludian and L. Wagner, “Coverage Effects in Shot Peening of 2024-T4, Proceedings of ICSP9, 2007, pp. 296-301.