Manual shot peening intensity and coverage effects on fatigue performance of aluminum alloy

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Abstract

Shot peening has been developed to enhance the fatigue strength of metallic parts. However, improper shot peening can decrease the fatigue life due to induced high surface roughness and residual tensile stress. The effectiveness of the manual shot peening process is accomplished by the control of the process parameters to provide a uniform intensity and coverage throughout the work piece. This research reports the results of manual shot peening conditions and develops a relationship between the fatigue life and peening process parameters on Al 7050-T7451.

Introduction

Cold working of 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]. Shot peening is a simple concept, but the process is complex. The shot peening process produces several changes in the workpiece material, including material folding, changes to microstructure, residual stresses, and surface roughness. Some of these changes are beneficial, and some are potentially detrimental [6-9]. Modern day shot peening is a highly controlled automated process, complex shape and/or size components necessitate the need for manual shot peening treatment to induce the compressive residual stress [3]. However, in manual peening operation, the control of intensity and coverage is of vital importance to maintain consistent process quality [4]. The intensity can be found for varying input conditions which are Stand-Off Distance (SOD), impingement angle, air pressure, shot size, shot properties, and material properties. Limited manual peening studies and their impact on components are published and there exists a real need for extensive experimental study to cover all the aspects that make for optimizing the manual peening process [10, 11].

The purpose of this paper is to investigate the manual shot peening process parameters on intensity and coverage and also to evaluate the fatigue performance of a manually peened aluminum alloy under high cycle loading conditions. This investigation also provides information on process parameters used to identify optimal manual shot peening conditions and to develop a relationship between the fatigue life and coverage and intensity.

Experimental Setup and Procedure

The A type Almen strips used to produce the test strips are an SAE 1070 CRS (cold rolled spring steel) with a standard hardness of 44-50 HRC and the shot material is cast steel shot S230. The manual shot peening system, which is a vacuum-blasting system from Vacublast, was employed with a 6 mm diameter nozzle. The A - Almen test strip meets the requirements of SAE J442 and SAE AMS 2432B. The range of applied pressure is from 55 kPa to 242 kPa (8 psi to 35 psi). A specially designed and built fixture was used to maintain a constant stand-off distance for a selected angle of impingement in this manual shot peening experimental study. Three stand-off distances were considered (152 mm, 192 mm and 305 mm) and a 305 mm SOD was the maxium stand-off distance between the work piece and the nozzle. A maximum flatness of +/-0.01 mm was employed [2] and Almen test strips with more or less maximum flatness tolerance values were rejected. To obtain coverage and intensity data on test material, Aluminum 7050-T7451 square blocks (100 mm

X 100 mm) were utilized for generating intensity and coverage. The peening conditions were varied as follows: air pressure (69-249 kPa), stand-off distance (152-305 mm), and angle of impingement (30-90 degrees). The design of experiments analytical method yielded a total of 14 experimental combinations. Image analysis [12] was utilized to estimate the percentage of the coverage area and further experimental details can be found in Refs.10 and 11. Surface topography was evaluated by using optical microscopy, surface profilometry and the subsurface quality was evaluated by microhardness measurements.

The effect of the manual shot peening process induced intensity and coverage on the fatigue life of an aluminum alloy (Al 7050-T745) was evaluated. The fatigue specimens were manually shot peened with four variables: air pressure, stand-off distance, impingement angle, and peening time. Peened and unpeened hourglass-shaped circular cross section specimens of Al 7050-T745 were fatigue tested in completely reversed rotation bending (R = Smin/Smax = -1). Based on intensity and coverage, all specimens were devided into seven groups. Each group consists of a minimum of 5 specimens. The fatigue life from 10^4 to 10^6 cycles was the desired target range and one maximum stress of 310 MPa (45 ksi) was chosen. A commercial R. R. Moore rotating bending fatigue test machine was used at rotational speeds of 1,200 RPM.

Results and Discussion

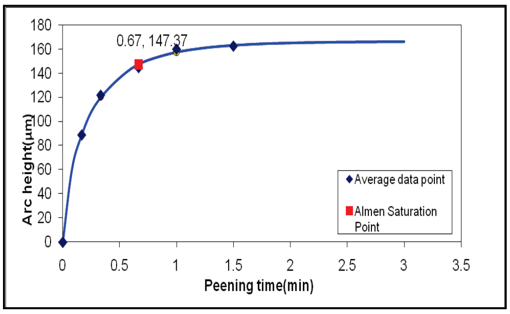
Intensity

Figure 1 shows typical Almen saturation curves and the effects of peening parameters on Almen intensity. Each data point on saturation curve (Fig. 1a), is the average of three arc height values at each time. Saturation point (Intensity) was found as a point on the graph, where a doubling of the peening time does not result in more than a 10% increase in arc height of the strip curvature. All strips (at or beyond saturation) are also visually examined after peening to assure that a 100% coverage is achieved.

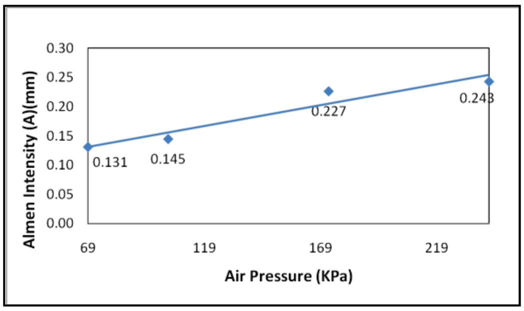
Figure 1 (b) illustrates the relationship between Almen intensity and air pressure at 152 mm (6 inch) SOD and 60° impingement angle. The Almen intensity increased from 0.131 mm(A) to 0.243 mm(A) when the air pressure increased from 69 kPa to 242 kPa (10 psi to 35 psi). The variation in air pressure exhibits a nearly linear increase in Almen intensity. An increase in impingement angle causes an increase in Almen intensity. Figure 1 (c) shows how the intensity changes at a different impingement angle for given 305 mm (12 inches) SOD and 172 kPa air pressure. The intensity varies from 0.147 mm(A) to 0.243 mm(A) when the impingement angle changes from 30° to 90°. The gradient of the first linear curve at a lower impingement angle is greater than the second one. Based on this result, it is clear that changes in impingement angle have a pronounced effect at low angles and very little effect at angles greater than 70°. The graph of Almen intensity versus SOD is shown in Figure 1 (d) for varying impingement angles. Increasing SOD from 152 mm to 305 mm decreases the intensity and SOD at lower impingement angle has the greater effect on intensity.

Coverage

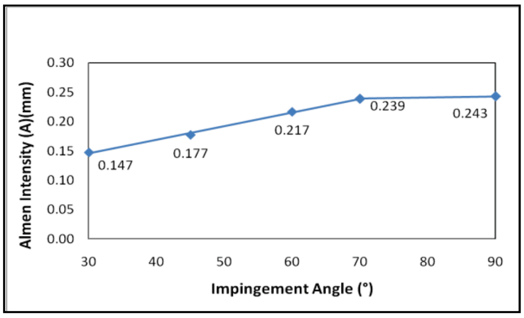
Figure 2 shows the typical coverage analysis by Image J for both an Almen test strip, and Al 7050 flat block specimen. The original micrographs and binary images shown are for typical low coverage points and the relationship between the coverage and the peening times deduced from this series of experiments are also shown in the plot. Higher intensities caused a reduction in the time to reach 400% coverage as expected. Therefore, the energy is closely related with coverage time. Increasing air pressure and impingement angle from 30° to 90° decreased the coverage time for a constant SOD and is consistent with the work of others [9]. It is also observed that by decreasing SOD for a given impingement angle, the time needed for 100% was found to be reduced.



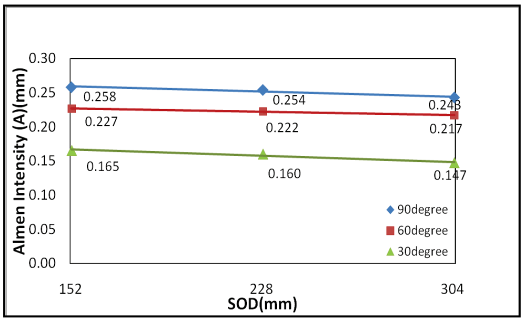
(a) Typical Almen saturation curves



(b) Intensity vs. Air pressure
(SOD: 152 mm (6 inches), impingement angle: 60°)

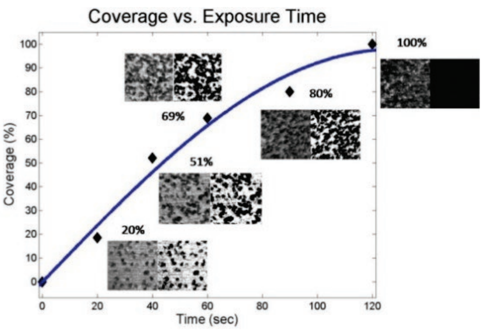


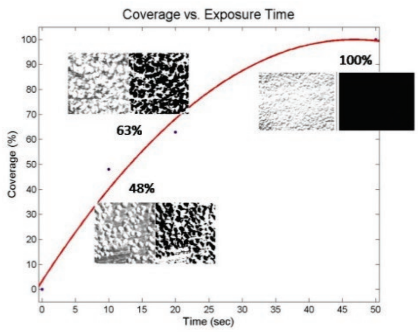
(c) Intensity vs. impingement angle
(air pressure:172 kPa, SOD: 305 mm (12 inches))



(d) Intensity vs. stand-off distance
(air pressure: 172 kPa)

Figure 1. Typical Almen saturation curve and effect of peening parameters on Almen intensity



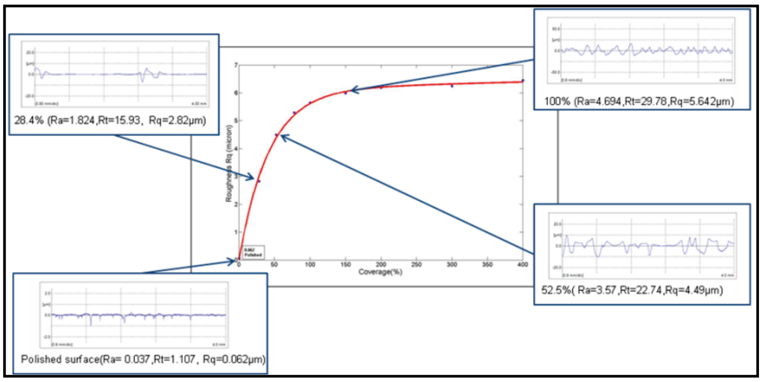


S230, p = 69 kpa, SOD = 305 mm, Angle = 90° S230, p = 172 kPa, SOD = 229 mm, Angle = 60°

Figure 2. Typical examples of coverage analysis by Image J and the development of coverage with exposure time for Almen strip and Al 7050 flat block.

Fatigue Life

Figure 3 shows a plot of root mean square surface roughness (Rq) vs. coverage for polished Al 7050 block peened using 172 kPa air pressure, 305 mm SOD, and 90° impingement angle conditions. Note that increasing % of coverage causes an increase in the degree of surface roughness because the more media impacts the material. Subsurface microhardness was measured and reported previously [11]. Subsurface microhardness varies depending on the degree of % coverage and the increase in surface hardness was found to be about 15-20%.



Conditions: S230, 172 kPa pressure, 305 mm SOD, and 90° impingement angle.

Figure 3. Surface roughness (Rq) vs. Coverage.

Figure 4 shows photograph of the as-machined and shot peened surface of circular hourglass-shaped bending fatigue specimens. Note the machining feed marks on the as-machined specimen. However, the shot peening process clearly suppressed and/or modified all the feed marks and generated a homogeneous peened surface.

Figure 5 shows the coverage effect on the fatigue lives of the specimens. It is clearly shown that the fatigue life of a shot peened specimen is higher than that of an as-machined specimen. The most fatigue life improvement occurred with Groups “S”, “N” and “P” which are at 0.15 mmA intensity and from 95% to 200% coverages. It is found that Groups “S”, “N” and “P” have roughly about 2.5 μm of surface roughenss (Ra) value and surface microharness was about 15% - 20% higher than the unpeened surface. These results clearly demonstrate that specimens were shot peened unformly on its entire surface, and the best coverage region is found to be from 95% to 200% in Al 7050**.**

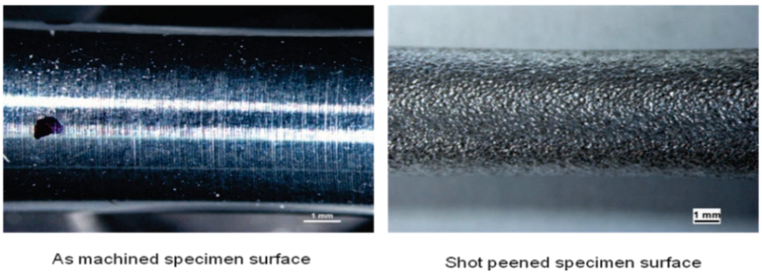


Figure 4. Typical surface images of as-machined and shot peened circular hourglass-shaped specimens.

The shot peening intensity effect on the fatigue life of Al 7050 is shown in Figure 6. The greatest shot peening effect on the fatigue life occurs at 0.1 mmA – 0.15 mmA intensity. The fatigue life was decreased as intensity increased to 0.25 mmA. Indeed, increasing shot peening intensity increased the surface roughness and decreased the fatigue performance. For example, when Group “M” and Group “O” were shot peened at 0.1 mmA and 0.25 mmA, respectively, the average surface roughness values of the two groups are about 2 μm and 5 μm, respectively, shown in Figure 6. The surface roughness of Group “O” is about 2.5 times higher than that of Group “M”. The fatigue life of Group “M” is about 250,000 cycles and it is about 1.67 times higher than that of Group “O”. It is clearly indicated that increasing the surface roughness induced by a higher intensity shot peening process creates a decrease in the fatigue life of Al 7050 specimens.

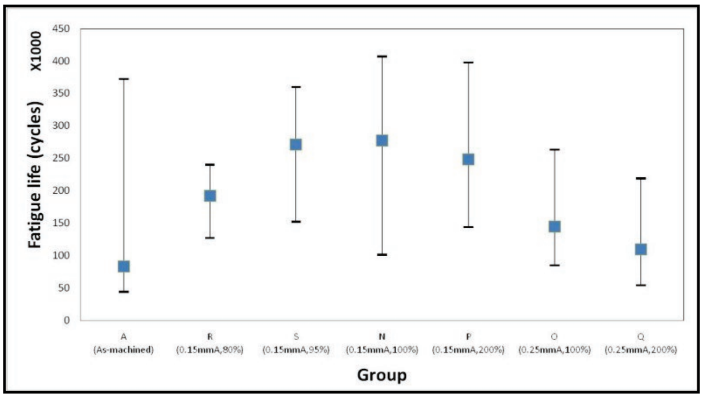


Figure 5. Shot peening coverage effect of the fatigue life of Al 7050.

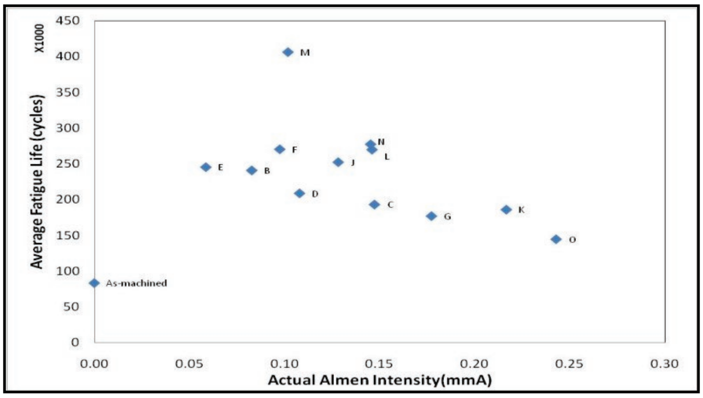


Figure 6. Shot peening intensity effect of the fatigue life of Al 7050.

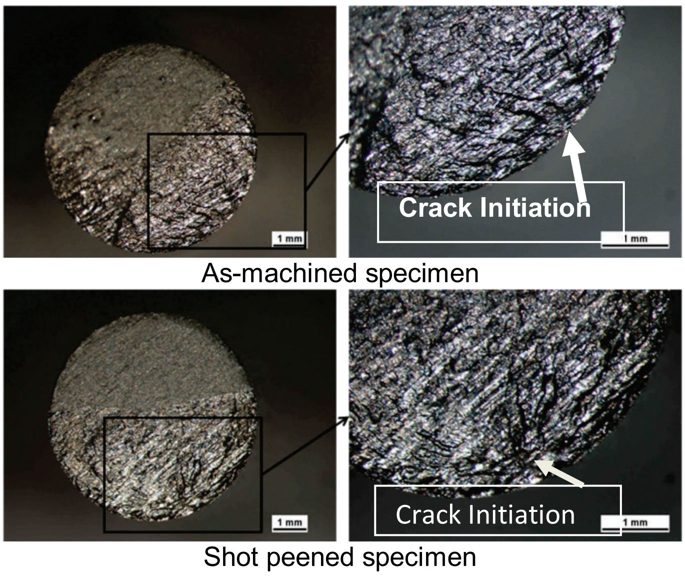


Figure 7. Typical fracture surfaces of as-machined and shot peened Al 7050 specimens.

Typical fracture surfaces of the fatigued specimens are shown in Figure 7. The fatigue cracks intiated on the surfaces of all the specimens tested in the as-machined condition. As expected, in all the shot peened specimens, fatigue cracks initiated in subsurface regions. Group "N" and Group "Q" have the same SOD and impingement angle but have different air pressure and % coverage. The fatigue lives of Group "N" and Group "Q" are 277,000 cycles and 101,000cycles, respectively, shown in Figure 5. It is clearly shown that the fatigue life of Group "N" is 2.7 times higher than that of Group "Q". The intensity and coverage of Group "N" produce a clean surface without micro-cracks and folding. However, the intensity and coverage of Group "Q" generate an over-peening effect on the material surface and induce large amounts of micro-cracks and folding. Excessive or aggressive peening leads to defects being buried in the sub-surface and forms very deep laps, which do not influence the surface roughness measurement, while greatly reducing fatigue life.

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, SOD, feed rate, and material properties. Intensity, saturation and coverage were determined experimentally by varying the processing conditions. Experimental study of manual peening showed that the benefits of the peening process is strongly dependent on control of peening conditions. This research evaluated the fatigue performance of manually peened aluminum under high cycle loading and it was found that intensity and coverage still needs of control in the manual shot peening process. It was also observed that high intensity and/or high coverage does not yield high fatigue life due to surface micro-crack formation and material folding.

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