EFFECT OF SHOT PEENING METHODS ON THE FATIGUE BEHAVIOR OF ALLOY 7075-T6

G. S. Was*, R. M. Pelloux and M. C. Frabolot****

**Nuclear Engineering Department, University of Michigan, Ann Arbor, MI, USA*
***Department of Materials Science and Engineering, MIT, Cambridge, MA, USA*

ABSTRACT

The effect of wet and dry shot peening methods on the reverse bending and uniaxial fatigue behavior of aluminum alloy 7075-T6 is investigated. Fatigue specimens were shot peened in both the conventional manner (dry surface) and while coated with a thin film of mineral oil (improved process) to reduce surface roughening and increase the residual stress in the workpiece in excess of that due to dry impact. In reverse bending tests, conventional dry surface peening increases fatigue strength relative to unpeened specimens. Peening with an oil film failed to produce a significant systematic improvement in fatigue behavior over the dry peening process. In uniaxial tension-compression fatigue with zero mean stress, the two peening methods produce nearly identical results; an increase in lifetime at high stresses and very little change near the fatigue limit.

KEYWORDS

Shot peening methods; wet peening; improved process; residual stresses; alloy 7075-T6; fatigue limit; reverse bending fatigue; uniaxial tension-compression.

INTRODUCTION

The fatigue life of a shot peened component is a compromise between two opposing effects; the creation of a compressive residual surface stress layer which tends to increase life, countered in part by the initiation of surface microcracks which tend to decrease life. Recently a new shot peening process was developed (Finkin, 1972) for the purpose of increasing fatigue life by enhancing the first effect and reducing the latter. The new process, known as "the improved shot peening process" differs from the conventional process in that the workpiece is first coated with a thin oil film prior to shot peening. The presence of a viscous film is presumed to affect the peening process in two beneficial ways: first, the oil film prevents initimate contact between the shot particle and the workpiece, thus preventing the creation of additional fatigue initiation sites, and second, it creates a hydrodynamic pressure in the oil film which is in excess of that due to dry impact (Finkin, 1972). The following results are from a 2 phase experimental program undertaken to evaluate the merits of the improved process using alloy 7075-T6. The results describe the effect of different shot peening conditions on residual stress, surface roughness and fatigue performance of aluminum alloy 7075-T6.

EXPERIMENTAL PROCEDURES

Phase I of the program consisted of reverse bending fatigue ($\sigma_{mean}=0$) of cantilever beam specimens. Tests were conducted at 20 Hz on a constant amplitude machine in room temperature air. In phase II, uniaxial fatigue specimens were tested in tension-compression on a servo-hydraulic fatigue machine. Tests were conducted in room temperature air, at a nominal frequency of 30 Hz and with zero mean stress (R=-1).

Shot type, size, intensity, angle of incidence, exposure time, and distance from the workpiece were varied. The peening parameters for Phases I and II are given in Table 1. In the dry peening operation, specimens were given double coverage (four minutes) and subsequently cleaned for 20 minutes in a bath consisting of 200 ml of HNO_3 and 800 ml water at 60°C. Prior to wet peening, specimens used in Phase I were cleaned in acetone and dipped in oil for 30 minutes. During peening, the surface was kept wet by dripping the oil onto the specimen. During wet peening of Phase II specimens oil was reapplied every two minutes to maintain the same film thickness. The wet peening procedure deviated from dry peening in that twice as much time (8 minutes) was required to achieve the same intensity. After the peening operation, the specimens were cleaned with acetone prior to fatigue testing.

TABLE 1 Shot Peening Parameters

Parameter	Phase I	Phase II
Nozzle to workpiece distance	15cm	15cm
Angle of incidence	45°	90°
Air pressure	0.21-0.97 MPa	0.76 MPa
Almen "A" intensity	.0075A - .010A	.01A
Shot type	cast iron stainless steel	steel
Shot size	S170,S230	S230

Residual surface compressive stresses induced by shot peening were measured experimentally by progressively removing thin layers of metal from the Phase I cantilever specimens by electropolishing and measuring after each removal of a layer, the deflection of the specimen over a given length. The depth of the cold worked layer in Phase II specimens was determined by Knoop hardness measurements near the specimen surface.

The surface roughness was determined by the centerline average (CLA) and peak height distributions resulting from a profilometer scan of the specimen surface. The profilometer provides directly the CLA of all irregularities having a crest spacing of less than a preset cut-off value. Measurements were made on cantilever beam specimens from Phase I and on a sample bar from Phase II.

RESULTS

Figure 1 shows the effect of dry peening on fatigue life. In reverse bending, the dry peened samples exhibited a significantly higher fatigue strength. In axial tension-compression, the fatigue life of the dry peened specimen is larger at high stress with the curves converging as the stress decreases. Figure 2 shows that wet peening does <u>not</u> significantly increase the fatigue life at any stress level over that obtained by dry peening. Figures 3 and 4 show the effects of shot size and intensity for both dry and wet peening. The only visibly significant effect of the oil film is found when peening with S170 shot at an intensity of 0.0075A, Fig. 4. Here, the fatigue strength is increased by a very modest amount, 7%. The following observations are made from Figs. 1-4. No well-defined endurance limit is evident in these tests. This result is consistent with data of aluminum alloys (Dieter, 1976). Below a stress amplitude of 250 MPa, the fatigue life of unpeened specimens is greater in tension-compression than in reverse bending. The unpeened specimen curve shows a well-defined "hump" at about 240 MPa in tension-compression. Finally, the fatigue lives of wet and dry peened specimens are not significantly different under any peening condition.

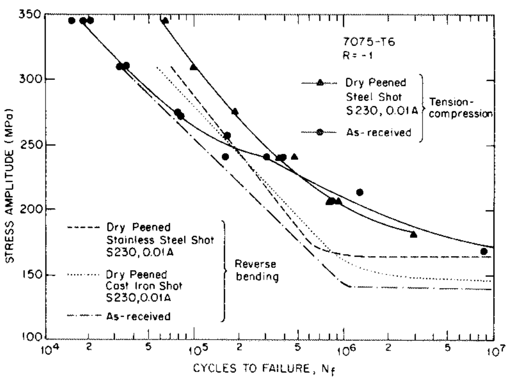

Fig. 1. Fatigue behavior of dry peened vs as-received 7075-T6 in reverse bending and tension-compression.

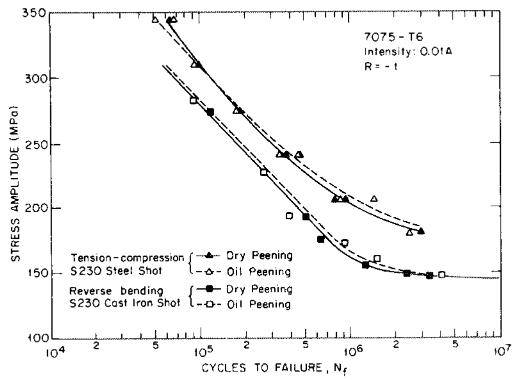

Fig. 2. Fatigue behavior of oil peened vs dry peened 7075-T6 in reverse bending and tension-compression.

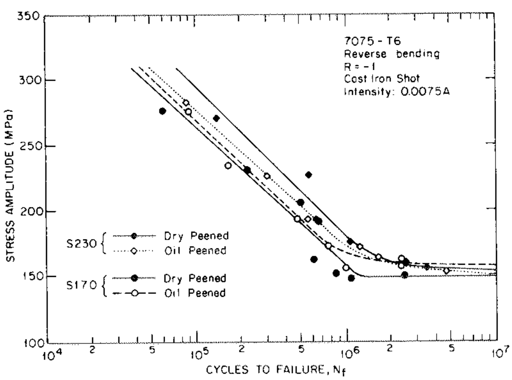

Fig. 3. Reverse bending fatigue of 7075-T6 specimens, oil peened and dry peened with S170 and S230 shot.

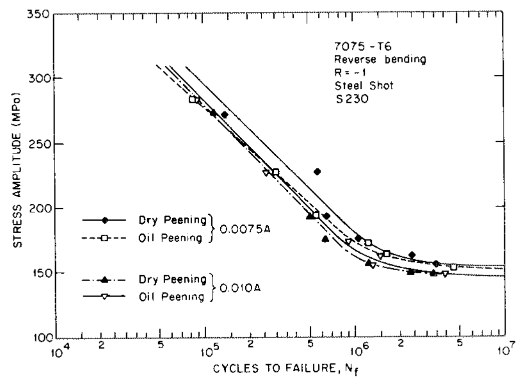

Fig. 4. Reverse bending fatigue of 7075-T6 specimens, oil peened and dry peened to 0.0075 A and 0.01 A.

The residual compressive stress induced by shot peening was measured for the various peening conditions. Figure 5 shows the residual stress distribution due to peening with size S230 cast iron shot. The maximum residual stress lies between 250 and 350 MPa with a compressive stress layer 200 μm deep in this and subsequent figures. These results are in agreement with those obtained by Hawkes (1968), and Hospers and Vogelsang (1975) for other high strength aluminum alloys. It is clear from Fig. 5 that as the intensity increases from 0.0075 A to 0.01 A, the maximum residual compressive stress increases and its position is displaced away from the specimen surface. An increase in the thickness of the compressive layer is also observed. These results are in good agreement with those obtained by Coombs (1956) for steel. Figure 5 also shows that the softer stainless steel shot produces a lower maximum residual compressive stress while the compressive layer increases in thickness. Figure 6 shows that a larger shot size creates a higher maximum compressive stress farther below the surface and a thicker compressive stress layer. From Figs. 5 and 6, it is evident that the major effect of wet peening is to decrease the maximum residual compressive stress, displace it to a position farther from the surface and increase the depth of the compressive layer. Figure 7 gives the microhardness distribution of a Phase II specimen as a function of distance from the surface. The cold worked layer resulting from the shot peening operation extends to a depth of 350 μm below the specimen surface.

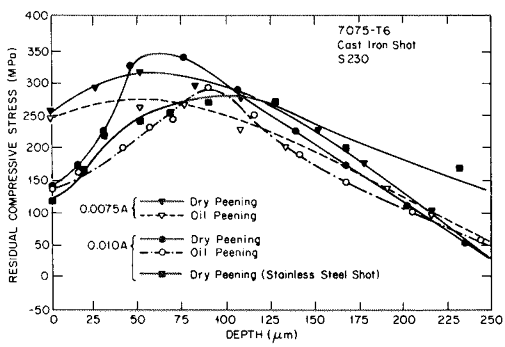

Fig. 5. Residual stress distributions in 7075-T6 specimens peened with S230 cast iron shot.

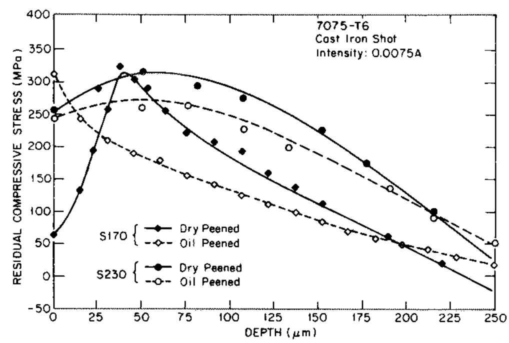

Fig. 6. Residual stress distributions in 7075-T6 specimens peened with cast iron shot to 0.0075 A.

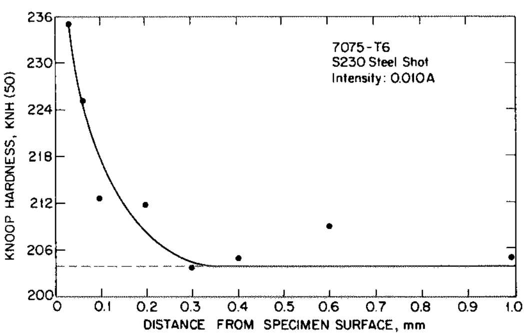

Fig. 7. Knoop hardness distribution in a 7075-T6 specimen dry peened with S230 steel shot to 0.01 A.

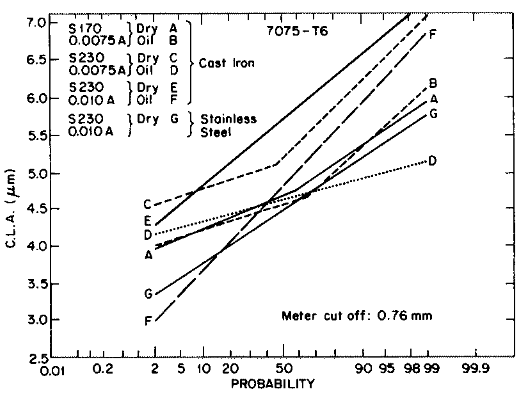

Fig. 8. Centerline average distribution for oil peened and dry peened specimens.

The integrated CLA probability distribution for a cut-off value of 0.76 mm in Phase I is given in Fig. 8. For cast iron shot, as the shot size increases, the CLA increases, demonstrating that the larger the shot and the greater the intensity, the deeper the shot penetrates the surface. The beneficial effect of wet peening is evident in 2 of the 3 cases shown. However, a consistently significant improvement is lacking. CLA values for the ground, dry peened and wet peened surfaces of Phase II specimens showed insignificant differences, indicating that the oil had little effect in reducing surface roughness.

DISCUSSION

Shot peening increases the fatigue life of alloy 7075-T6 in reverse bending by creating a residual compressive stress near the specimen surface thus reducing the effective tensile stress, Fig. 9. Since the maximum tensile stress due to an applied load, σ^{a}_{max}, normally occurs at the specimen surface, shot peening reduces this stress by the value of the residual compressive stress, $\sigma_{eff}=\sigma^{a}_{max} - \sigma^{R}_{comp}$.

Fatigue life also depends on the position and magnitude of the maximum compressive stress and the thickness of the compressive layer. If the maximum stress is near the specimen surface, a crack initiated at the surface will propagate very slowly through this region. The crack growth rate will be less affected by the residual stress field when the maximum compressive stress is located far below the surface. Hence, as shown in Table 2, it is desirable to have a high compressive surface stress, a high maximum stress located near the surface and a thick compressive stress layer.

TABLE 2 Effect of Shot Peening Variables on Surface Roughness, Residual Stress and Fatigue Life

An increase in \ Produces the following effect on:	Compressive surface stress (σ_s)	Max compressive stress (σ_m)	Depth of σ_m	Thickness of compressive layer	Surface roughness	Fatigue life
Shot size	increase	-	increase	increase	increase	increase
Shot hardness	-	increase	decrease	decrease	increase	increase at low stress
Intensity	decrease	increase	-	-	increase	increase then decrease
Oil film	-	decrease	increase	increase	decrease	small increase

In the presence of a thin liquid film on a free surface, the collision of the shot with the surface creates plastic flow of the specimen through the liquid film without the occurrence of metallic contact. This is because the hydrodynamic pressure developed in the liquid film exceeds the yield pressure of the base metal and the collision time is shorter than the time necessary to squeeze out the oil film between the shot and the base metal surface (defined as the squeezing time). The result is a smoother surface which has a lower number of fatigue crack initiation sites. Below a critical shot velocity, v_c, the shot-metal contact time is larger than the squeezing time. At these velocities, the fluid film has a negative effect since metallic contact occurs between the shot and specimen surface, and the oil absorbs some energy during shearing leaving less energy for plastic deformation, hence, a rough surface and low residual compressive stress. This explains why the S230 shot degraded fatigue life compared to dry peening while the S170 shot increased fatigue life. For a given force, the S170 shot velocity is higher, resulting in less metal surface contact and a smoother finish.

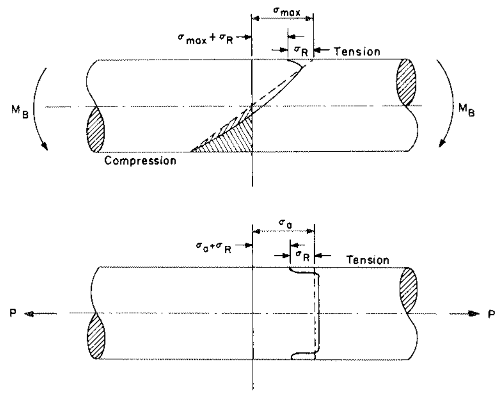

Fig. 9. Superposition of applied and residual stresses in bending and tension-compression.

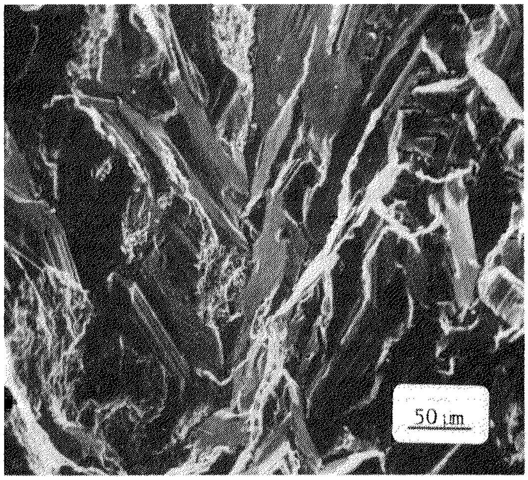

Fig. 10. SEM fractograph of the crack initiation region in a tension-compression fatigue failure.

Fatigue testing of shot peened parts in fully reversed tension-compression does not result in the same increase in life as testing in reverse bending. Figure 9 shows that the effect of a residual surface compressive stress on the fatigue life is not nearly as dramatic since the applied stress is uniform over the cross-section of the specimen. Examination of failed specimens revealed two distinct fracture modes. Tensile mode type failures occured in all control specimens. This type of failure initiated at the specimen surface at all values of stress amplitude. Stage II fatigue crack growth occured early in the propagation stage and it was present up to fast fracture. A shear type failure occured in most shot peened specimens with the fracture surfaces at oblique angles to the specimen axis. These cracks initiated at subsurface sites in all but one shot peened specimen. The initiation site is identified by a large region of state I crystallographic crack growth prior to the transition to stage II growth, Fig. 10. For the shot peened tests with sub-surface crack initiation, nucleation and initial growth of the internal fatigue crack occur in a vacuum. In vacuum, the absence of air and water vapor results in slow crack growth along oblique angles to the main principal stress (Vogelsang, 1975, 1976; Schijve, 1977). At high stresses, crack nucleation is rapid and most of the specimen's life is spent in crack propagation. Since the environment affects crack propagation rather than crack initiation (Tetelman and McEvily, 1967), the crack growth in vacuum leads to an increase in life by as much as a factor of 3.0. However, at low stresses, 95% of the life is spent in crack nucleation with crack propagation occurring quickly and accounting for a small fraction of the life. The nearly equal lives of control and peened specimens at low stress levels implies equal time to initiation despite the difference in initiation sites.

CONCLUSIONS

Shot peening by either method is only effective near the fatigue limit in parts to be used in reverse bending. Shot peening of parts used in tension-compression at stresses near the fatigue limit produces no improvement over the unpeened parts. Improvement of the fatigue strength of shot peened 7075-T6 is due mainly to the residual compressive stresses developed at and below the surface. The improvement increases with increasing surface and maximum stresses, a decrease in the depth of the maximum stress and a thicker compressive stress layer. The residual stress distribution depends strongly on the shot velocity (intensity) and to a lesser extent, on the shot size and hardness.

The presence of a surface oil film during peening affects fatigue life mainly through its viscosity. The oil film prevents contact between the shot and workpiece, minimizing the surface roughness and creating a hydrodynamic pressure in the film which results in an increased residual compressive stress. However, the "improved process" does not show any systematic improvements of the fatigue properties beyond the improvements obtained by the dry peening process.

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