



THE EFFECT OF DIFFERENT SHOT PEENING INTENSITIES ON FATIGUE LIFE OF AW 7075 ALUMINIUM ALLOY

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Resume

In this study the effect of different shot peening intensities, from very light peening with ceramic beads to severe shot peening with high coverage, on the fatigue life of aircraft AW 7075 aluminium alloy was investigated. Results were discussed in means of surface roughness, character of deformed surface layer and residual stress profile measured by XRD methods. Light peening intensity creates high and shallow compression residual stress field in the subsurface layers of material and increases the fatigue life of studied alloy. Increasing the peening intensity increases the depth of residual stress field, however the surface damage created by impact of shots at high velocity causes significant surface damage and rapidly degrade the fatigue properties of AW 7075 aluminium alloy.

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1. Introduction

Air blast shot peening (ABSP) is a widely used surface strengthening method which is used to increase fatigue life of components usually up to 20 % [1-5]. The main advantage of this technology is the possibility of peening components with almost any shape and dimensions, what is not possible with other surface strengthening technologies like deep rolling or ultrasonic surface attrition. Air blast shot peening is often mistaken with sand blasting, used for surface cleaning. Even if these technologies have something in common, the air blast shot peening is a very sophisticated technology with possibility of repeating the process with exactly the same results. The peening process is characterized mainly by four basic factors and that is the type of peening media, angle between the shot stream and

the peened surface, Almen intensity [6] and coverage [7].

The intensities of shot peening vary from very light (designated by the N Almen strips) to medium (designated by the A Almen strips) and very high intensities (designated by the C Almen strips). Special type is a so called “severe shot peening” for which is used medium and high Almen intensities and high values of coverage (usually from 500 up to 1000 %). When performing shot peening, the question is, what intensity and coverage should be used to obtain best performance because higher peening intensities do not assure higher fatigue life of a component and in many cases may lead to surface damage and significant decrease of fatigue life [8, 9].

In this study, the effect of four shot peening intensities on the character of deformed

surface layer, subsurface microhardness and residual stress profile was evaluated on aircraft AW 7075 aluminium alloy with aim to increase the fatigue life in the high and ultra-high cycle region.

2. Experimental material and surface treatment

As an experimental material was used aircraft aluminium alloy AW 7075 with nominal chemical composition and mechanical properties obtained by tensile test according to Table 1 and Table 2, respectively. Due to its very high strength, alloy 7075 is used for highly stressed structural parts. Applications include aircraft fittings, gears and shafts, fuse parts, missile parts, regulating valve parts, worm gears, and various other commercial aircraft, aerospace and defense equipment.

Fatigue test specimens (Fig. 1) were treated with air blast shot peening with four different intensity parameters (Table 3) increasing from light peening to severe shot peening. As initial state of material were used not peened (NP) fatigue specimens, which surface was mechanically polished by metallography diamond paste of 0.7 μm grain size.

To study the surface layer character was made a longitudinal cut of one half of fractured fatigue specimen and prepared by standard metallographic procedure. Increasing the

Almen intensity of shot peening caused increasing of the surface roughness (Table 3). Also the increase of peening intensity causes creation of more deep and visible deformed surface layer (Fig. 2). For SP1 specimen (Fig. 2b), the deformed surface layer is barely visible, when compared to NP specimen (Fig. 2a), but it is possible to see the increasing character of surface roughness. In contrary, the plastically deformed layer after SP4 treatment (Fig. 2e) is very deep with large dimples caused by multiple impacts of large peening media at high velocity. The small crack visible in Fig. 2e is a non-propagated fatigue crack and it is not a result of the peening treatment.

3. Experimental results

First provement of shot peening work hardening effect is the hardness increase of the subsurface layers of material. On the cross section of threaded specimens was performed microhardness measurement according to EN ISO 6507-1: 2005. The first measurement was performed in the distance of 0.05 mm, what is more than double of the indentation size, so the result was not affected by the free surface. According to microhardness results (Fig. 3), after the SP1 treatment (8.3 N) the subsurface microhardness slightly increased from the value of 179 HV0.05 for the polished specimen to 182 HV0.05.

Table 1

Nominal chemical composition of AW 7075 aluminium alloy in wt. % [10].

Al	Cr	Cu	Zn	Mg	Fe
87.1 ÷ 91.4	0.18 ÷ 0.28	1.2 ÷ 2.0	5.1 ÷ 6.1	2.1 ÷ 2.9	max. 0.5
Mn	Si	Ti	Zr + Ti	Other - each	Other - total
max. 0.3	max. 0.4	max. 0.2	max. 0.25	max. 0.05	max. 0.15

Table 2

Mechanical properties of AW 7075 aluminium alloy.

Ultimate tensile strength (MPa)	Elongation (%)	Reduction of area (%)	Hardness HV10
631	4.9	15.7	175

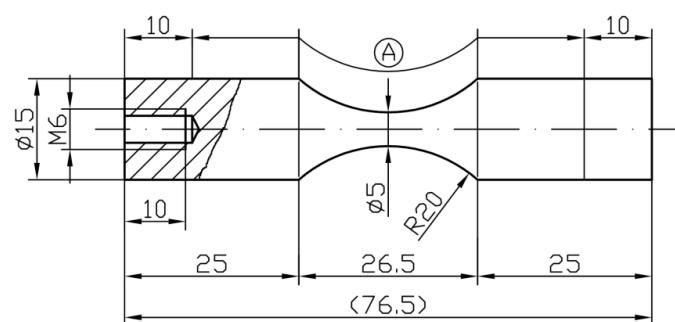
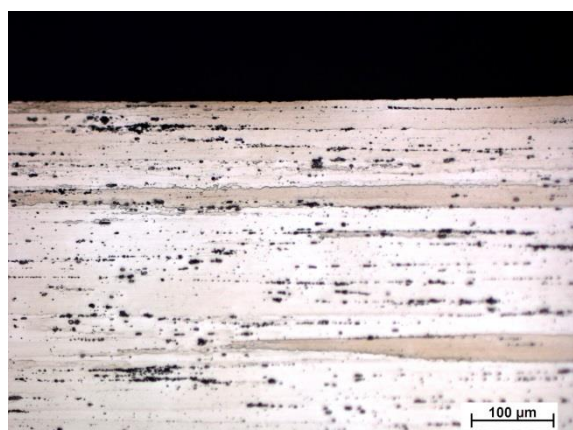


Fig. 1. Shape and dimension of fatigue specimens. Dimension marked A is the length of treated surface.

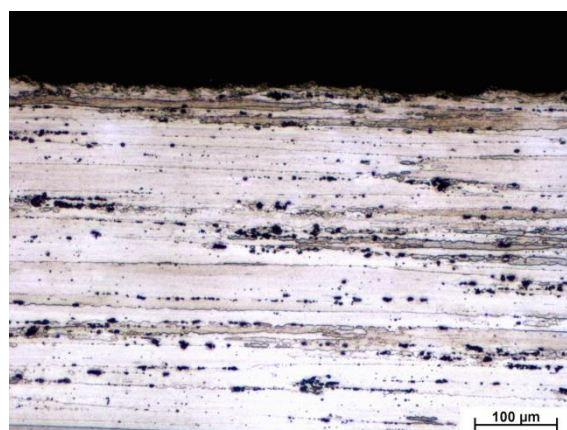
Table 3

Aspects of surface treatment of fatigue specimens

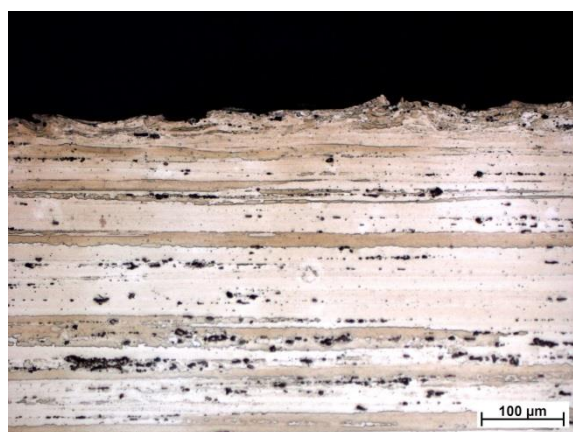
Label	Shot type	Almen intensity (0.001 inch)	Coverage (%)	Roughness Ra (μm)	Roughness Rz (μm)
NP	-	-	-	0.125	0.913
SP1	CEZ 100	8.3 N	100	2.614	14.304
SP2	S110	6.9 A	100	3.849	20.712
SP3	S170	14.4 A	100	7.553	34.217
SP4	S170	14.9 A	650	7.971	35.793



a) NP



b) SP1 - 8.3N/100 %

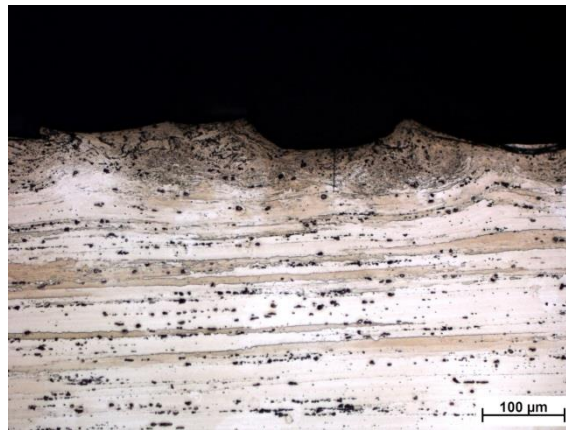


c) SP2 - 6.9A/100 %



d) SP3 - 14.3A/100 %

Fig. 2. Longitudinal cut of fractured fatigue specimens showing the character of the surface layer, etch. Fuss.



e) SP4 - 14.9A / 650 %

continue of Fig. 2. Longitudinal cut of fractured fatigue specimens showing the character of the surface layer, etch. Fuss.

After SP2 (6.9A), SP3 (14.4A) and SP4 (14.9A) treatment the subsurface hardness significantly increased to values close to 185 HV0.05. Approximately same value of the subsurface hardness for all these three treatments show, that the maximum deformation strengthening possible by shot peening was achieved, but after increasing the intensity higher microhardness is achieved deeper from the material surface.

To obtain quantitative values of the residual stresses in the material X-ray diffraction (XRD) measurement were carried out by means of X-Stress 3000 StressTech device (Cr radiation $K\alpha$, irradiated area of 1 mm^2 diameter, $\sin 2\psi$ method, diffraction angles (2θ) scanned at 11 different ψ angles ranging from -45° and 45°). Due the curvature of the specimen, the measurement could only be carried out at angle $\phi = 90^\circ$, what means that the collimator was perpendicular to the specimen axis, and only the circumference residual stresses were evaluated (Fig. 4).

Machining and polishing created in the NP specimens small compression residual stress which disappears in the depth of 0.04 mm. SP1 treatment created high and shallow compression residual stress field with maximum of $\sigma \approx -380\text{ MPa}$ which completely disappears in depth of 0.1 mm. Increasing of the peening

intensity in SP2, SP3 and SP4 treatment created more deeper residual stress field up to maximal depth of 0.4 mm. Unfortunately, the maximum of the compression residual stress of these treatments did not reached the maximum value of SP1.

Fatigue tests were carried out on two specimens from each treatment at two different loading amplitudes $\sigma_a = 185.2\text{ MPa}$ and $\sigma_a = 176.4\text{ MPa}$ with use of ultrasonic fatigue testing device. Specimens were loaded in tension-compression loading mode at room temperature, cycle asymmetry ratio $R = -1$ and frequency $f \approx 20\text{ kHz}$. According to the fatigue test results (Fig. 5), the SP1 treatment increased the fatigue life of AW 7075 alloy, but the shot peening with higher intensities had a strong negative influence and decreased the fatigue life in the high and ultra-high cycle region.

4. Discussion

The tension plastic deformation created when a peening media hits the surface and creates a dimple causes increase of the dislocation density in the subsurface layers of material. Increasing of the dislocation density is the basic deformation strengthening mechanism and causes increase of the subsurface microhardness.

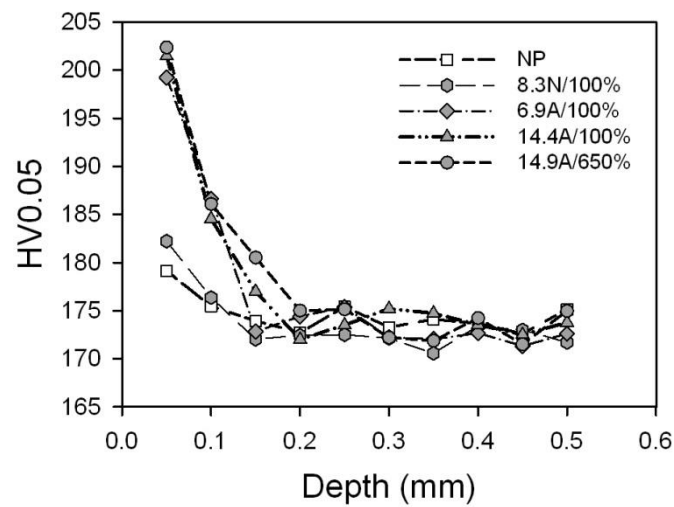


Fig. 3. Microhardness of the surface layer before and after surface treatment with different intensities.

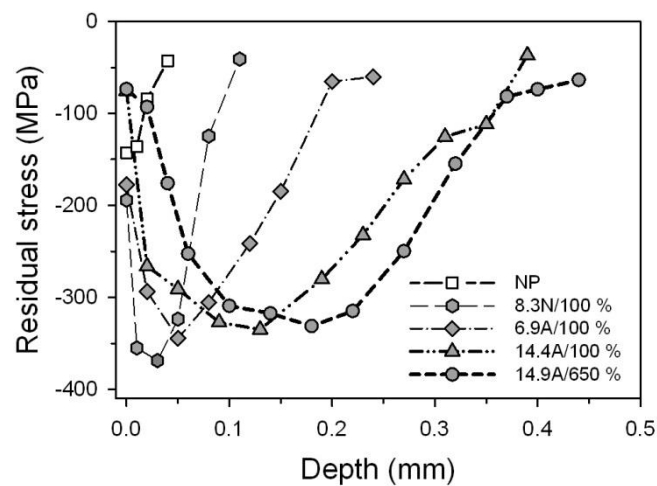


Fig. 4. Residual stress profile of the surface layer before and after surface treatment with different intensities.

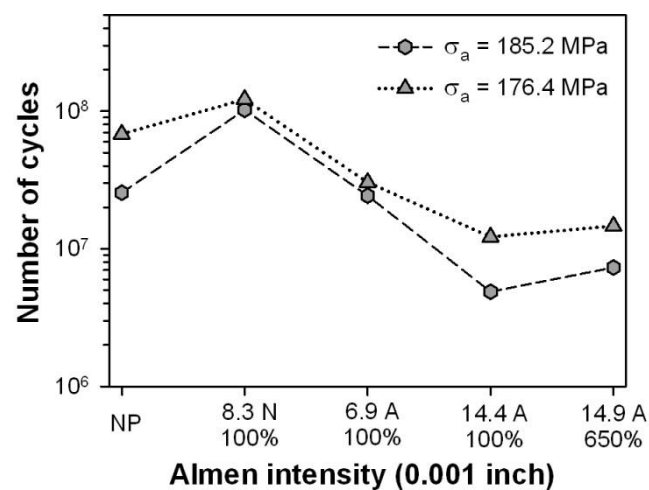


Fig.5. Dependence of fatigue life on shot peening intensity at two stress levels.

After saturation of the dislocation density, the hardness on the surface stops increasing, what is the reason that the three highest peening intensities (SP2, SP3 and SP4) have the same value of surface microhardness, but further increase of the peening intensity increases the dislocation density deeper under the surface and the microhardness is higher deeper under the free surface (Fig. 3).

Surface plastic deformation accumulates energy in the material what causes changes of the distance between atoms in crystallographic lattice. This distance can be measured in means of X-ray diffraction and when the distance is shorter (when compared to no-stress state), it means that in the material is accumulated compression residual stress. According to residual stress profiles of experimental material after shot peening with increasing peening intensity it can be seen an increase of the depth of accumulated compression residual stresses. The highest value of compression residual stress ($\sigma \approx -380$ MPa) was measured after the lightest SP1 treatment, but it reaches zero in a very short distance from the surface and this was probably the reason why the microhardness value is lower than for the higher intensities. None of the higher intensities did not reach the maximum value of compression residual stress obtained by SP1 treatment and it also can be seen a decreasing character of the maximal value with increasing peening energy. This was probably again caused by the saturation of the plastic deformation of the material surface and by partial relaxation of the residual stresses by the small component of tensile deformation which occurs during the shot impact. The value of this tensile deformation gets more important at higher peening intensities. In many studies [11-13] was proven, that the severe plastic deformation created by severe shot peening (intensity SP4) causes grain fragmentation and can result in creation of nano-graind surface layer, but in this work this influence was not studied so far.

The compression residual stress field often positively increases the fatigue life of components because it increases the number of cycles needed for nucleation of fatigue crack and slows down the propagation of short fatigue cracks [7, 14, 15]. After performed fatigue test (Fig. 5) can be seen that in this case only the SP1 treatment, even due the lowest depth of residual stresses, had a positive influence on fatigue life. The higher intensities (SP2, SP3 and SP4) even when they created deep compression residual stresses in the subsurface material layers caused significant decrease of fatigue life of the studied aluminium alloy. This means, that the negative influence of increasing surface roughness and the surface damage caused by impact of peening media at high velocity had the determining influence of the fatigue life and the residual stresses played only the second role. This is often referred to so called “overpeening” effect [7] which can be sometimes reduced by removing the damaged surface layer by additional machining operation such as grinding might again increase the fatigue life of AW 7075 aluminium alloy shot peened at high intensities [16].

5. Conclusions

According to experimental works performed on AW 7075 aluminium alloy after air blast shot peening treatment at gradually increasing intensities it can be concluded:

- shot peening creates a deformed surface layer and the deformation is more intensive after increasing the peening parameters,
- the plastic deformation has its saturation point and after reaching this point, the microhardness and compression residual stress values do not further increase,
- increasing peening intensity causes deeper microhardness increase and creates deeper compression residual stress field,

- only the light peening intensity (SP1) had a positive influence on the fatigue life and the more severe shot peening (SP2, SP3 and SP4) resulted in strong overpeening and rapidly decreased the fatigue life.

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