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Fatigue life of AW 7075 aluminium alloy after severe shot peening treatment with different intensities

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Abstract

Fatigue life of AW 7075 aluminium alloy in the high and ultra-high cycle region was tested after application of severe shot peening surface treatment with different peening intensities. Severe shot peening with 9.6N Almen intensity and coverage of 650 % provides increase of the fatigue life up-to 9 %. However, using more severe peening parameters, 14.9A Almen intensity and coverage of 650 %, significantly decreases the fatigue life up-to 21 %. Study of the surface layer character showed a damage of the surface integrity by shot peening treatment with the more severe parameters. According to fracture surface analysis, in both cases shot peening caused increase of the number of initiated fatigue cracks. The fatigue crack propagation in the strengthened surface layer after treatment with 9.6N/650 % parameter has a different orientation and character when compared to not-treated specimens. After treatment with 14.9A/650 % parameters, due very strong work hardening, the surface layer started to peel off during propagation of fatigue crack.

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Keywords: AW 7075 aluminium alloy; severe shot peening; fatigue strength; fatigue crack initiation

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1. Introduction

Positive effect of shot peening and severe shot peening was proven by many works of researchers all over the world [1-6]. The increase of fatigue strength after application of conventional shot peening is commonly accredited to introduction of compression residual stresses in the subsurface layers of material. Another effect to be considered when using severe shot peening, which differs from conventional shot peening by using unconventional high peening parameters (high intensities and coverage) is that, besides the introduction of compression residual stresses, grain refinement of the treated material surface layer is induced. It is proved that severe shot peening, when using optimized parameters, can provide even a higher improvement of fatigue strength. However, using extremely severe shot peening parameters can significantly damage the surface integrity. This is usually considered as the "overpeening" and has a strong negative influence on the materials fatigue strength [7].

In this article are shown results of fatigue tests in the high and ultra-high cycle regime of AW 7075 aluminium alloy subjected to two severe shot peening intensities together with corresponding fracture surface analysis.

Nomenclature

σ_a	stress amplitude
$\Delta\sigma_a$	difference in stress amplitudes
σ'_f	coefficient of fatigue toughness
b	exponent of fatigue life curve
N	number of cycles
N_f	number of cycles to fracture
NP	not peened
Ra	arithmetic mean surface roughness
Rz	surface roughness depth
UTS	ultimate tensile strength

2. Experimental material and surface treatment

As experimental material was used AW 7075 – T6511 aluminium alloy in form of extruded bars (diameter of 15 mm), with chemical composition given in Table 1. The mechanical properties obtained in standard tensile test (displacement rate 2 mm/min) are presented in Table 2. The microstructure of extruded bars (Figure 1) has a strong deformation (row-kind) texture caused by the extrusion process. It is formed by solid solution of zinc in aluminium and a great number of large or fine intermetallic phases.

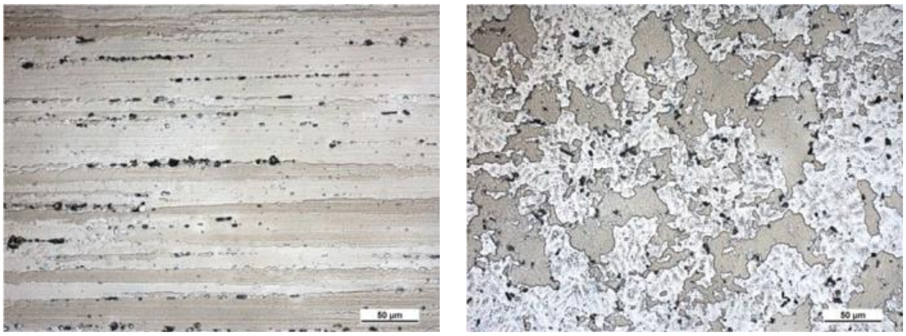
Table 1. Nominal chemical composition of AW 7075 aluminium alloy in wt. % [8].

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.

UTS (MPa)	Elongation (%)	Reduction of area (%)	Hardness HV10
631	4.9	15.7	175

Two sets of specimens (10 PCS each) were treated with severe air blast shot peening with two increasing peening parameters (SP1 and SP2). To provide comparison to material without strengthened surface layer was used a set of specimens (14 PCS) with mechanically polished surface (NP). Mechanical polishing was carried out with use of metallography diamond emulsions. The surface treatment parameters are listed in Table 3 together with the resulting surface roughness.



(a) (b)

Fig. 1. Microstructure of the AW 7075 extruded bars longitudinal cut (a) transversal cut (b), etch. Fuss.

Table 3. Aspects of surface treatment of fatigue specimens.

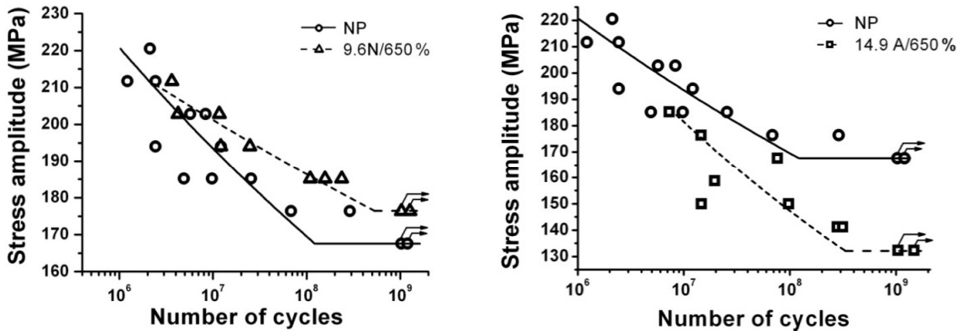
Label	Shot type	Almen intensity (0.001 inch)	Coverage (%)	Roughness Ra (μm)	Roughness Rz (μm)
NP	-	-	-	0.125	0.913
SP1	CEZ 100	9.6 N	650	3.493	20.767
SP2	S170	14.9 A	650	7.971	35.793

3. Fatigue tests

Fatigue tests were carried out with use of ultrasonic fatigue testing device with aim to analyze the fatigue strength in high and ultra-high cycle region. Specimens were loaded in tension-compression loading mode at room temperature, cycle asymmetry ratio R = -1 and frequency f ≈ 20 kHz. In general, fatigue life curve of AW 7075 in high and ultra-high cycle region has a “flat” character, where the difference in loading stress amplitude only of $\Delta\sigma_a = 50$ MPa provides increase of fatigue lifetime from $N = 10^6$ cycles to $N = 10^9$ cycles (Figure 2).

Application of severe shot peening with 9.6N intensity and coverage of 650 % had a positive effect on the fatigue life of AW 7075 aluminum alloy and the fatigue strength in the high and ultra-high cycle fatigue region was significantly increased (Figure 2a), corresponding regression parameters of the Basquin function are provided in Table 4. The decreasing line of the S – N curve again tends to converge near $N = 2 \times 10^6$ cycles and it seems that the fatigue life at higher stress amplitudes will be lower than for NP specimens. The fatigue strength difference increases with increasing number of cycles (Table 5). The run-out number of cycles was determined as $N = 10^9$ cycles and the fatigue limit was determined as $\sigma_a = 168$ MPa for NP specimens and $\sigma_a = 176$ MPa for severely shot peened specimens (9.6N/650 %), so the increase of the fatigue limit is only $\Delta\sigma_a = 8$ MPa. Unfortunately, the increase of fatigue strength for $N = 10^8$ is $\Delta\sigma_a = 16$ MPa what is double than the increase of fatigue life for $N = 10^9$ cycles (Table 5). This difference is caused by the termination of the running fatigue test at run-out number of cycles and these points, due their different character of the test result, can’t be considered in the evaluation of the regression curves with the Basquin function.

After treating the surface of specimens with severe shot peening with more intensive parameters with Almen intensity of 14.9A and coverage of 650 %, the fatigue life of experimental material rapidly decreased in the whole measured region (Figure 2b, corresponding regression parameters are in Table 4). With decreasing loading stress amplitude, the decrease of fatigue life is even more significant (Table 6) and the fatigue limit for $N = 10^9$ cycles decreased from $\sigma_a = 168$ MPa (for NP specimens) to $\sigma_a = 132$ MPa (for SSP 14.9A/650 % specimens), what is a drop of $\Delta\sigma_a = 32$ MPa.



(a) (b)

Fig. 2. S – N curves of AW 7075 aluminium alloy after mechanical polishing (NP) and severe shot peening with 9.6N/650 % (a) and 14.9A/650 % (b) parameters.

Table 4. Aluminium alloy AW 7075 regression curve coefficients.

Surface treatment	σ'$_f$ (MPa)	b
NP	488	-0.0574
9.6N/650 %	342	-0.0330
14.9A/650 %	782	-0.0906

Table 5. Fatigue strength for $N = 10^7$, $N = 10^8$, $N = 10^9$ cycles according to regression curves.

Surface treatment	Fatigue strength for $N = 10^7$ (MPa)	Fatigue strength for $N = 5\times10^7$ (MPa)	Fatigue strength for $N = 10^8$ (MPa)
NP	193	176	170
9.6N/650 %	200	190	186
Increase $\Delta\sigma_a$	7	14	16

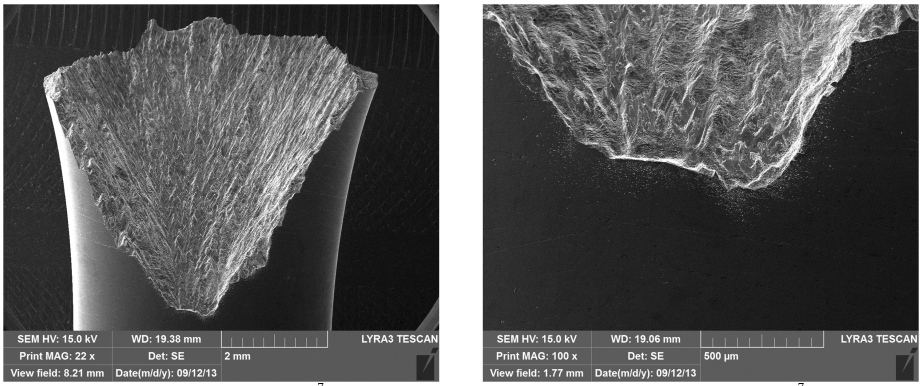
Table 6. Fatigue strength for N = 107, N = 108, N = 109 cycles according to regression curves.

Surface treatment	Fatigue strength for $N = 10^7$ (MPa)	Fatigue strength for $N = 5\times10^7$ (MPa)	Fatigue strength for $N = 10^8$ (MPa)
NP	193	176	170
14.9A/650 %	182	157	147
Decrease $\Delta\sigma_a$	11	19	23

4. Fracture surface analysis

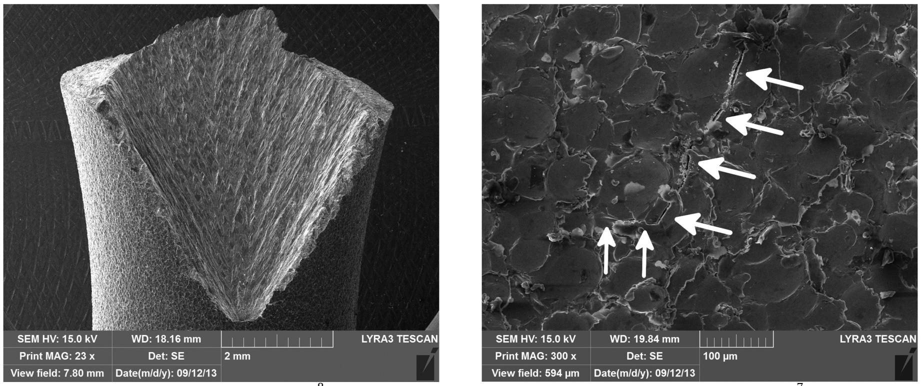
In all AW 7075 aluminium alloy specimens fatigue cracks initiated on a free surface of the specimen and in the beginning, the crack propagated almost perpendicularly to the direction of loading force. After reaching several tenths of micrometers the orientation of the crack propagation started changing to angle of 45° up-to 60° to the vector of loading force (Figure 3a, Figure 4a, Figure 5a).

In the NP specimen only one crack initiated in the gauge length (Figure 3b) which propagated through the cross section. In the severely shot peened specimens, under the initiation side of the main crack which caused the fracture, were found multiple initiated fatigue cracks (Figure 4b and Figure 5b). Due the effect of closing of the crack with the compressive residual stresses introduced by shot peening, these cracks are very narrow and barely visible. The work hardened surface layer after shot peening treatment with 9.6N/650 % parameters has a different appearance and the crack propagated in a different orientation than in the core of the material (Figure 6a). After increasing the peening parameters to 14.9A/650 %, the work hardened surface layer peeled-off during the crack propagation (Figure 6b).



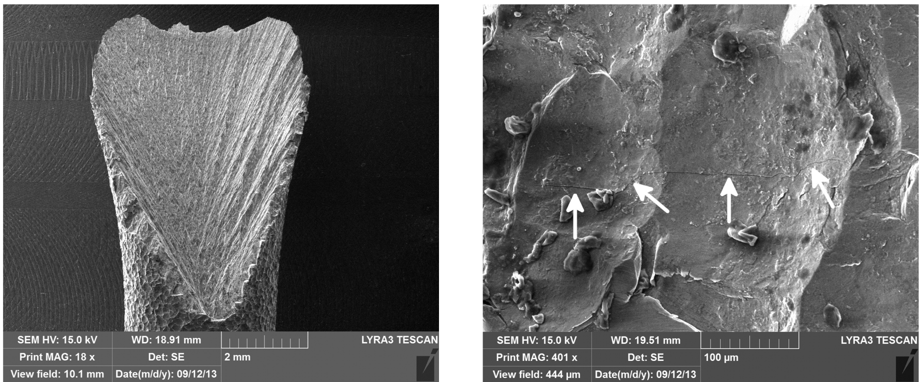
(a) σ_a = 185 MPa, N_f = 2.6 ×10^7 cycles (b) σ_a = 185 MPa, N_f = 2.6 ×10^7 cycles

Fig. 3. Fracture surface of NP specimen in macro view (a) and detail of the area under the crack initiation site (b).



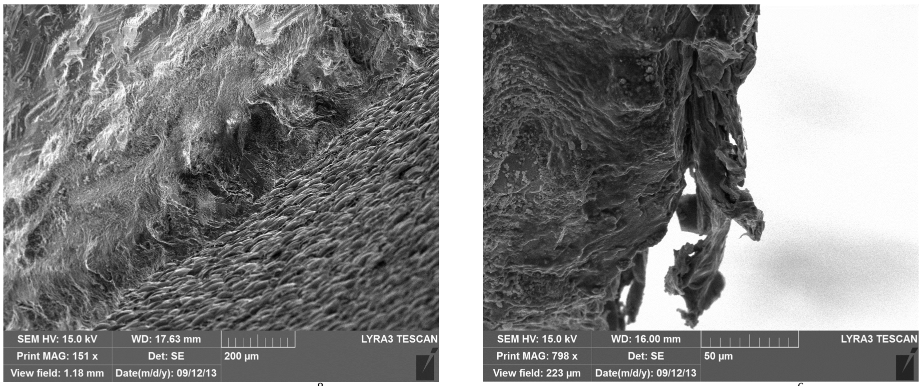
(a) σ_a = 185 MPa, N_f = 1.6 ×10^8 cycles (b) σ_a = 194 MPa, N_f = 2.5 ×10^7 cycles

Fig. 4 Fracture surface of 9.6N/650 % shot peened specimen in macro view (a) and detail of another initiated fatigue crack under the main crack initiation site (b).



(a) σ_a = 185 MPa, N_f = 7.3 ×10^6 cycles (b) σ_a = 141 MPa, N_f = 3.1 × 10^8 cycles

Fig. 5 Fracture surface of 14.9A/650 % shot peened specimen in macro view (a) and detail of another initiated fatigue crack under the main crack initiation site (b).



(a) σ_a = 185 MPa, N_f = 1.6 ×10^8 cycles (b) σ_a = 185 MPa, N_f = 7.3 ×10^6 cycles

Fig. 6 Different fracture character of the work hardened surface layer in 9.6N/650 % shot peened specimen (a) and peeling off surface in 14.9A/650 % shot peened specimen.

5. Discussion

Even when plastic deformation of AW 7075 aluminium alloy, due the precipitation hardening, is very limited (ductility under 5 %), surface strengthening by severe shot peening can still increase the fatigue life of this alloy. Peening with 9.6N intensity and coverage of 650 % was able to increase the fatigue strength up-to $\Delta\sigma_a$ = 16 MPa (9 %). These results correspond with the different appearance of the surface layer on the fracture surface (Figure 6a). The work hardened surface layer is more resistive to crack initiation and propagation, so it slows down the fatigue crack initiation process. However, increasing the peening intensity to 14.9A with coverage of 650 % had an opposite effect and decreased the fatigue strength up to $\Delta\sigma_a$ = 23 MPa (21 %). To create a balanced stress field, the compression residual stress zone created by shot peening has to be followed by a zone with tension residual stress [9,10]. When too intensive peening parameters are used, this tension stress exceeds the local ultimate tensile strength and a layer of material is separated from the surface and a crack is created. These cracks represent places with strong stress concentration and serve as points for fatigue crack initiation. This is also confirmed by the fracture surface (Figure 6b) where can be seen that a large part of the surface layer peeled off.

Because the fatigue crack initiates always in a place with highest stress concentration, on the polished specimen was an initiation place probably a scratch or intrusions on the surface (Figure 3b). Shot peening treatment created dimples on the surface with very similar geometry, what means that they presented notches with very similar stress concentration intensity. Due the multiple notches on the surface, fatigue cracks were able to initiate after a very similar number of cycles and that is the reason why multiple initiated fatigue cracks could be observed on the gauge length of a specimen (Figure 4b and Figure 5b).

6. Conclusions

According to experimental works carried out on AW 7075 aluminium alloy treated with two different shot peening parameters can be concluded:

- Work hardening effect of shot peening performed with 9.6N/650 % parameters was able to improve the fatigue strength up-to 9 %.
- Damage of surface integrity which occurred when shot peening treatment was performed with 14.9A/650 % parameters decreased the fatigue strength up-to 21 %.

- Symmetrical notch distribution on the surface created by shot peening treatment increases the number of initiated fatigue cracks.
- Fracture surface of the work hardened layer created by shot peening with 9.6N/650 % parameters has a different appearance, when compared to the NP specimen, what corresponds to a layer with higher resistance to crack initiation and propagation.
- The work hardened surface layer created by shot peening with very high intensity of 14.9A and coverage of 650 % was peeling off during the crack propagation.

Acknowledgements

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