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Shot peening intensity influence on the fatigue behaviour of aluminium alloy ASTM 2011

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Abstract

The aim of this study is to determine the possibilities of mass reduction of dynamically loaded aluminium alloy structures. Specimens were prepared from heat-hardened aluminium alloy ASTM 2011. In order to improve the fatigue behaviour the specimens were shot-peened. The experiment was planned using the software package Design-Expert. The research results were used to develop mathematical function among: lifetime, the level of alternating symmetric stress and Almen intensity. These results indicate the possibility of mass reduction of structural elements from ASTM 2011, according to the selected parameters.

Key words: shot peening, aluminium precipitation, Almen intensity, fatigue testing

Nomenclature

R_d – fatigue strength ($N\,m^{-2}$)
R_m – tensile strength ($N\,m^{-2}$)
N – the number of cycles
ω – angular velocity (s^{-1})
HV10 – Vickers hardness
d – specimen diameter (mm)
h – Almen intensity (mm)

1. Introduction

Permanent optimization of the structure parameters (as: mass, cost, reliability and lifetime) requires extensive research of materials. The research includes a variety of mechanical and ageing conditions for the different structure design.

The research results were used to develop mathematical function among: lifetime, the level of alternating symmetric stress and Almen intensity.

The specimens material was artificialy aged aluminium alloy ASTM 2011 bar. In order to reduce the specimens cross-section for fatigue testing, a neck was made at the middle of the specimens height. The neck areas were shot-peened by different Almen intensities.

The research was planned and conducted by software Design-Expert [1].

2. Specimens

2.1. Specimens material

The testing material was aluminium ASTM 2011 bar, 18 mm in diameter. The chemical composition is shown in Table 1 [2]. Aluminium alloy ASTM 2011 is used for its good workability properties and high ratio strength to mass (light-weight structures). It is available in the form of bars and profiles. It is used in aged hardened condition. Specimens material hardness was 130 HV10 and the ultimate strength $R_m = 480$ MPa.

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T a b l e 1. Chemical composition of aluminium alloy ASTM 2011

Symbol	Cu	Pb	Bi	Si	Fe	Zn	Al
Proportion (%)	5.5	0.4	0.4	0.40 max	0.7 max	0.3 max	rest

Specimen dimensions and shape are shown in Fig. 1.

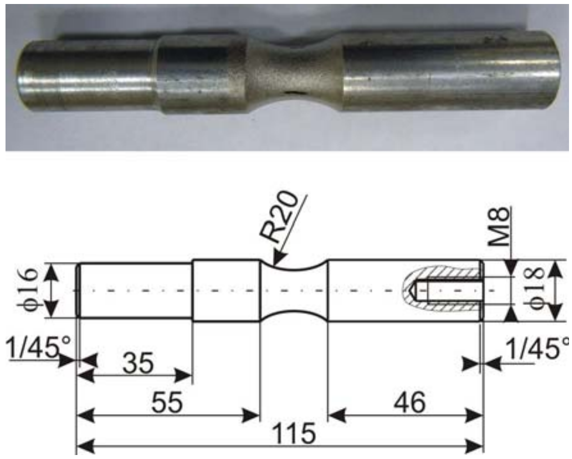

Fig. 1. Fatigue testing sample.

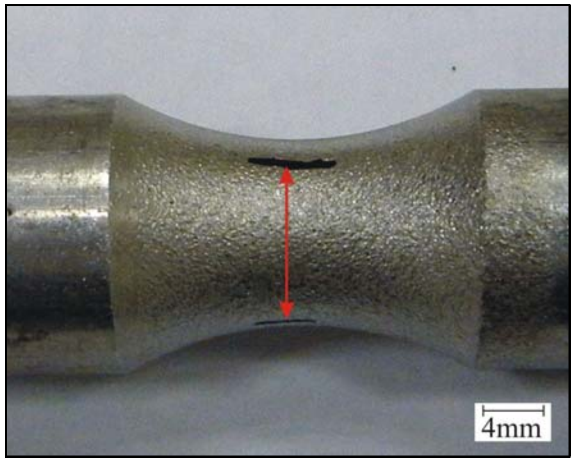

Fig. 3. Shot-peened area without specimen rotation.

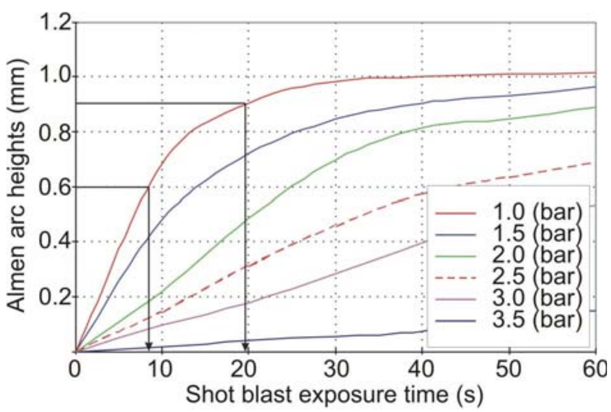

Fig. 2. Almen intensity against the shot blast exposure time.

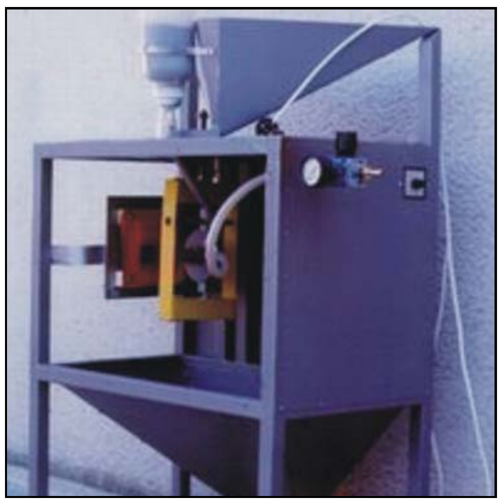

Fig. 4. Shot peening device UZK-1.

3. Testing parameters

3.1. Almen intensity

The Almen intensity was selected according to the developed diagram of Almen intensity (arc height) – shot blast exposure time. The pressure of 3.5 bar was selected, and according to the diagram in Fig. 2 it is possible to achieve Almen arc heights from 0.6 to 0.9 mm, which corresponds to the shot blast exposure time of 8–19 s. The Almen arc heights were measured on the Almen test strips [3].

The cylindrically shaped sample needs to determine the equivalent shot blast exposure time. Sample rotates during shot-peening by constant angular velocity of $\omega = 1\,s^{-1}$. The width of shot-peened area of the sample neck was approximately 11.8 mm (Fig. 3). The time correction factor ($x = 3.2$) was determined by dividing the perimeter value of the sample neck against the width of shot-peened area.

Multiplying the time correction factor by the Almen test strip, gives the new blast exposure time of the same Almen intensity for used specimens.

The specimens were shot-peened by the shot-

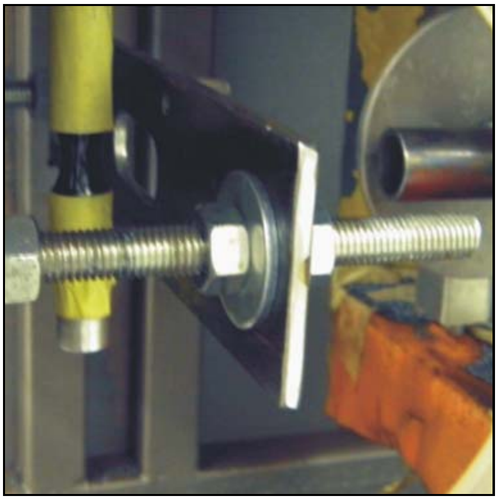

Fig. 5. Specimen fixed in shot peening device.

-peening device UZK-1, shown in Figs. 4 and 5. The pressure of inlet valve was 3.5 bar.

The coverage densities as a function of blast exposure time of 10, 20 and 30 s are shown in Fig. 6.

The achieved coverage density of nearly 100 % corresponds to the blast exposure time of 30 s. Generally, if by shot peening is not realized 100 % coverage, the expected increase of fatigue properties will not be achieved [3, 4].

Figure 7 shows the magnified photos of shot-peened surface.

3.2. Fatigue testing

Endurance limit of aluminium alloy ASTM 2011 was $R_\mathrm{d} = 124\,\mathrm{MPa}$ at 5×10^8 cycles according to R. R. Moore [2]. The experiment was performed in the range of stresses $\sigma = 140$–$155\,\mathrm{MPa}$. Selected stresses were obtained by lifting the loads on the free end of R. R. Moore testing device, shown in Fig. 8.

4. Design of experiments and testing results

The research was planned and conducted by software Design-Expert. According to the selected Central Composite Plan – CCP (with 2 variables: the maximum stress and Almen intensity), each variable was performed at 5 levels ($+\alpha$, $-\alpha$, $+1$, -1, 0).

Thirteen specimens were tested (Fig. 9). The number of cycles to fracture represents the response of system obtained by experiments. Design of experiments and results obtained from tests are shown in Table 2.

Statistical analysis of test results was also carried out using the Design-Expert. Results after analysis of variance are presented in Table 3 (A refers to stress, B refers to Almen intensity).

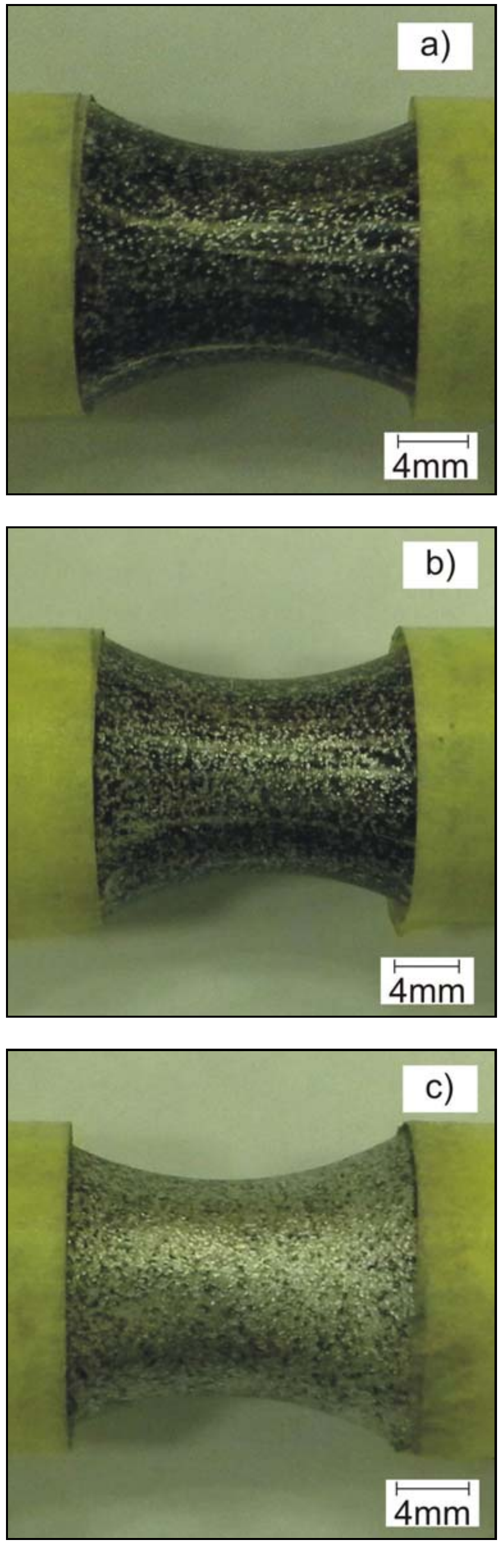

Fig. 6a,b,c. The covering density for the specimens exposed to shot blast for 10, 20 and 30 s, corresponding to Almen intensity 0.7, 0.9 and 0.97.

The model F-value of 6.83 implies the model is significant. There is only a 1.28 % chance that a model F-value this large could occur due to noise. Values of

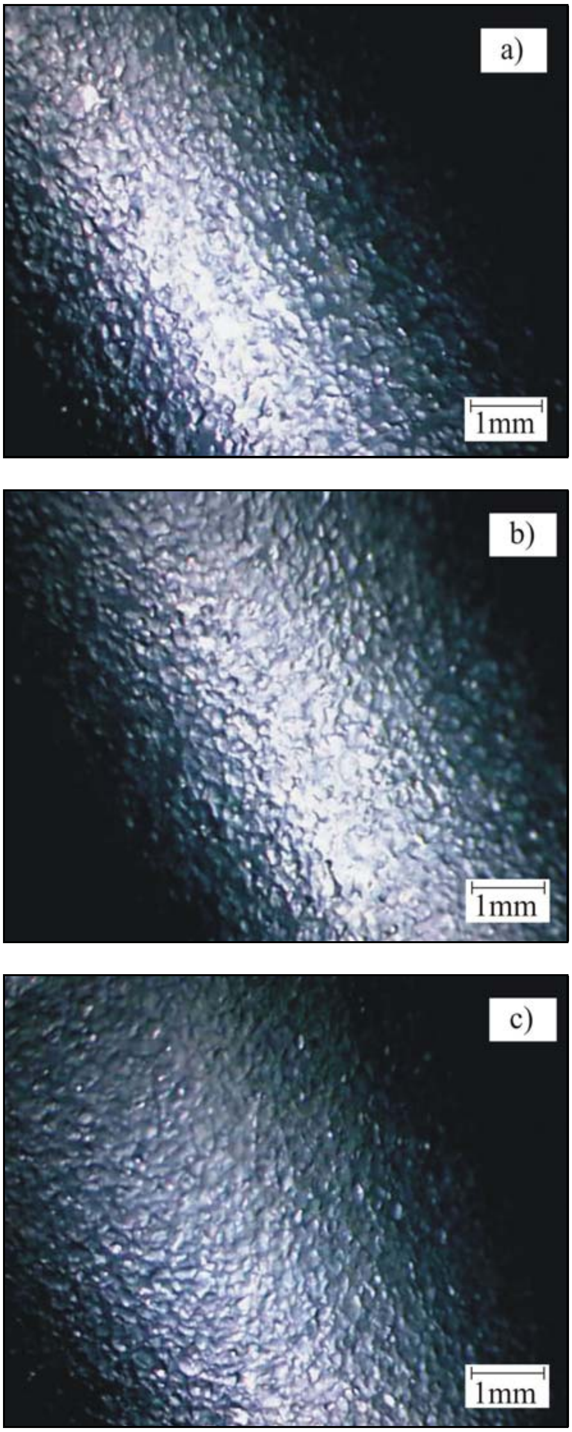

Fig. 7. Shot-peened specimens surfaces with various Almen intensity: a) $h = 0.60$ mm, b) $h = 0.5$ mm, c) $h = 0.90$ mm.

prob $> F$ less than 0.0500 indicate model terms are significant. In this case, $A \cdot B^2$ are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The final model equation is:

$$\log N = 5.0976 + 0.0401A - 0.5115B - 0.0006A^2 - 13.6421B^2 + 0.1432AB. \quad (1)$$

Fig. 8. R. R. Moore fatigue testing device.

Fig. 9. Specimens after experiment.

The obtained final model is shown in the 2D and 3D diagrams in Figs. 10 and 11.

The diagram Stress against Almen intensity in Fig. 10 shows the curves of constant values of the logarithm number of cycles to the specimen fracture.

It is obvious that each level of stress corresponds to an Almen intensity that may result with maximum fatigue life. Red (thick) line represents the combination of stress and Almen intensity that the maximum fatigue life is obtained.

5. Conclusion

This study leads to the conclusion that the intensity of shot peening has to be chosen against to designed stress level.

Table 2. Design of experiments (CCP)

Samples No.	Run	Stress (N mm^{-2})	Almen intensity (mm)	Number of cycles
5	1	136.9	0.75	1068780
4	2	155.0	0.90	104340
13	3	147.5	0.75	270720
1	4	140.0	0.60	217140
11	5	147.5	0.75	321480
3	6	140.0	0.90	107160
9	7	147.5	0.75	301740
2	8	155.0	0.60	47940
12	9	147.5	0.75	476580
6	10	158.1	0.75	126900
7	11	147.5	0.54	93060
8	12	147.5	0.96	118440
10	13	147.5	0.75	242520

Table 3. Analysis of variance

Source	Sum of squares	Mean square	F-value	Prob > F	
Model	1.251743	0.250349	6.826415	0.0128	significant
A	0.488257	0.488257	13.31362	0.0082	
B	0.004012	0.004012	0.109410	0.7505	
A^2	0.008244	0.008244	0.224792	0.6498	
B^2	0.655418	0.655418	17.87171	0.0039	
AB	0.103832	0.103832	2.831258	0.1363	
Residual	0.256715	0.036674			
Lack of fit	0.206743	0.068914	5.516283	0.0663	not significant

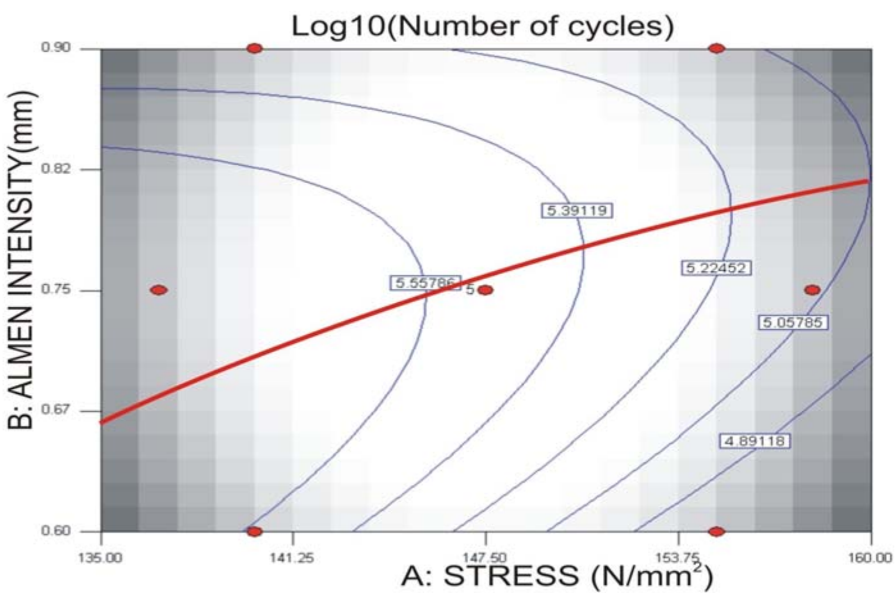

Fig. 10. Final model in 2D diagram.

Shot peening intensity selected according to the obtained model results in a fatigue life increase of structures made from aluminium alloy ASTM 2011.

The tests carried out in this study may be the basics for extended research of fatigue life in real ASTM 2011 alloy structures.

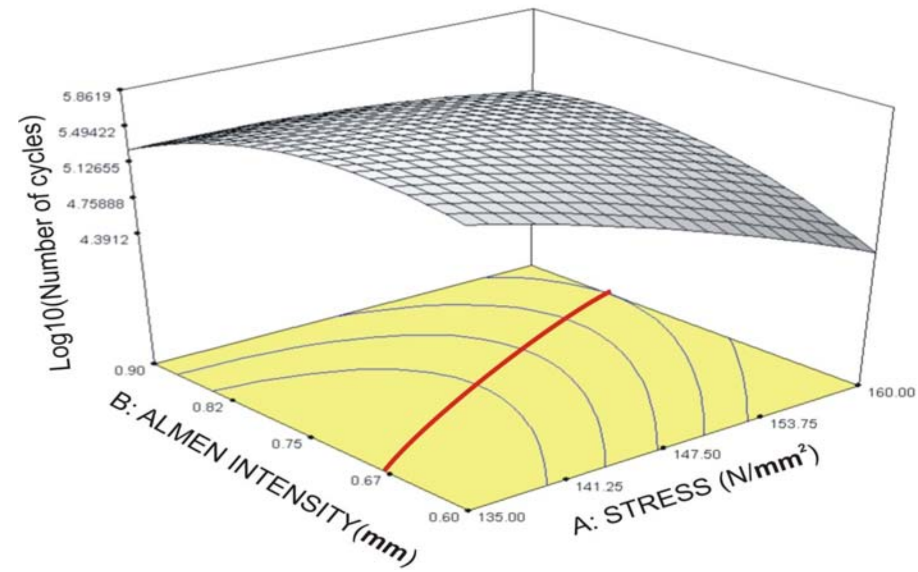

Fig. 11. Final model in 3D diagram.

References

[1] STAT EASE. Inc.: DESIGN – EXPERT v.6.0.10. Minneapolis. MN 55413.

[2] ASM INTERNATIONAL: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials. Materials Park, Ohio, ASM International Handbook Committee 2005.

[3] Živković, D.: Influence of hot-crack and shot-peening on fatigue strength of welded aluminium constructions. [Doctoral thesis]. Split, University of Split, Faculty of Electrical Engineering 1999.

[4] Živković, D., Bajić, D., Marić, G.: Kovove Mater., *45*, 2007, p. 263.

[5] Totten, G. E., MacKenzie, D. S.: Handbook of Aluminum – Physical Metallurgy and Processes. New York, Basel, Marcel Dekker, Inc. 2003.

[6] Wagner, L.: Materials Science and Engineering, *A263*, 1999, p. 210. doi:10.1016/S0921-5093(98)01168-X

[7] Rodopoulos, C. A., Curtis, S. A., De Los Rios, E. R., Solis Romero, J.: International Journal of Fatigue, *26*, 2004, p. 849. doi:10.1016/j.ijfatigue.2004.01.003