The shot-peened surface of AA 5083 under the influence of elevated temperature

D. Živković[1]*, D. Bajić[1], G. Marić[2]

[1] *University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boskovica bb, 21000 Split, Republic of Croatia*
[2] *University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, I. Lucica 5, HR-10000 Zagreb, Republic of Croatia*

Received 2 May 2007, received in revised form 26 July 2007, accepted 17 September 2007

Abstract

The paper deals with the elevated temperature influence on shot-peened surface of 5083 aluminium alloy. Shot-peening introduces the compressive stress in the surface layer of the metal, changing the resulting tensile residual stresses. After the specimen had been exposed to the elevated temperature, the yield and the tensile strength were tested. The test results indicate that elevated temperature treatment is significant on the shot-peened surface of AA 5083, although the positive effect of peening is not entirely gone.

Key words: AA 5083, shot peening, elevated temperature

1. Introduction

Nowadays, the global development trends are more concentrated on the structures made from aluminium alloys. The increasing usage of Al-alloys is based upon the new technologies of treatment, good mechanical properties as well as on their excellent corrosion resistance.

In the modern engineering practice the majority of large aluminium structures are welded. The fatigue strength of welded structures follows the same general rules that apply to other types of fabricated assemblies. The fatigue strength is governed by the peak stresses at points of stress concentration rather than by nominal stresses. Anything that can be done to reduce peak stresses, by eliminating stress raiser will tend to increase the life of welded assemblies that are subjected to repeated loadings. Residual stresses in welded joints are obtained by local thermal expansion, plastic deformation and subsequent shrinkage on cooling. In the region near the weld (the heat affected zone), the resulting tensile residual stresses have a magnitude approaching the yield strength.

Welding stresses significantly reduce the fatigue strength of aluminium alloy welds, particularly butt welds [1]. As the heat treatments to relieve these stresses are impractical for many of large welded assemblies, shot-peening can and should be considered as an alternate method of improving the fatigue strength.

In one of the previous papers [2] it was pointed out that shot-peening is the most acceptable treatment for increasing the fatigue life of aluminium welded joints, especially in the case of hot crater crack appearance. Although as it is not possible to achieve the fatigue strength of weld without crater-hot cracks, the shot-peening as a method for decreasing the propagation of cracks is very acceptable. The increase of the fatigue strength at 10^5 or 10^6 cycles is 59 % or 93 % (0.9 N2 Almen) compared to unpeened specimens. The application of shot-peening is valid especially in the case of hardly accessible welded joints, where the shot-peening may be used as precaution method.

According to the literature [3], the elevated temperature exposure of aluminium alloys, prolonged heating and temperature cycling, leads to the significant changes of yield and ultimate tensile strength. For the alloys of the 5xxx series, those with magnesium con-

*Corresponding author: tel.: +385 21 305898; fax: +385 21 463788; e-mail address: Drazen.Zivkovic@fesb.hr

tents greater than 3.0 wt.%, such as 5083, contain a continuous film of anodic Al_2Mg_3 along the grain boundaries rather than in a solid solution within the grains [4]. This decreases the toughness, the ability of a material to withstand an impact, by making the alloy brittle. The most detrimental precipitates form at room temperature in heavily cold worked material. Those precipitates form over a number of years, or after prolonged exposure to slightly elevated temperatures of 65 ℃ to 180 ℃ like those found near the engine and exhaust system of ship. So, this paper deals with the elevated temperature influence on the shot-peened surface of 5083 aluminium alloy.

The AA 5xxx series are the most resistant and most widely used because of their favourable strength and good weldability.

2. Shot-peening

The fatigue strength of aluminium alloy welds can be increased by the cold working of high velocity stream of shot media upon the exposed surface layers of metallic parts under the controlled conditions [5]. When individual particles of shot in the high velocity stream contact the metal surface, they produce slightly rounded depressions in the surface. The metal beneath this first layer is not plastically deformed. The stress distribution that has developed in the metal surface, has induced residual compressive stress parallel to the surface, while the metal beneath has reaction-induced tensile stress (Fig. 1).

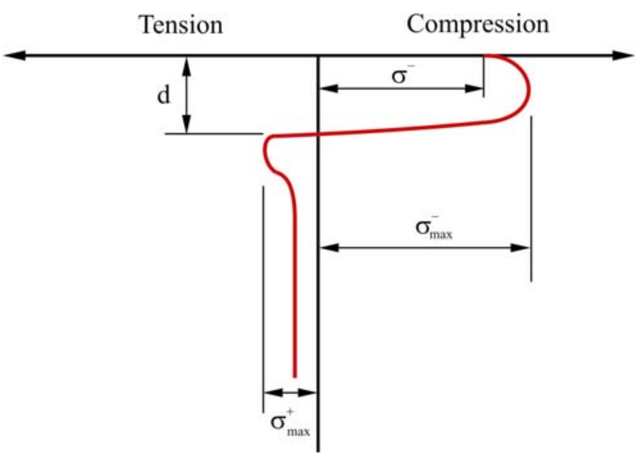

Fig. 1. Characteristic residual stress profile created by shot-peening. σ^- – the surface compressive stress, $\sigma^-_{\max}$ – the maximum compressive stress (usually found slightly below the surface – often taken to be 25 % of the thickness), d – the depth at which the residual stress becomes negative, $\sigma^+_{\max}$ – the maximum tensile stress.

3. Material and treatment

3.1. Material

The specimens were made from 5083 Al-alloy plate. This alloy is usually used as marine material, because of its excellent corrosion resistance in the sea water. Also it has good mechanical properties (R_m is from 275 to 310 MPa, $R_p0.2$ is about 200 MPa) [6]. The testing of the tensile strength was provided in the Laboratory for Mechanical Testing (LMT), Department for Materials, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb – Republic of Croatia. The testing results were: R_m = 310 MPa, $R_p0.2$ = 196 MPa.

The chemical composition of specimen metal is given in Table 1.

The table shows the weight percentage of alloying elements, and the rest is aluminium. This chemical composition control is provided by the Laboratory for Chemical Analysis – Aluminium Industry – Šibenik (Republic of Croatia).

3.2. Specimen shape

The strips from the 5083 alloy sheet were cut out. The strips were 35 mm wide and 210 mm long. After milling, the additional rasping of the specimen edges was carried out. The shape and dimensions of the specimen were defined towards possibilities of the test machine, and are shown on Fig. 2.

According to the Central Composite Design (CCD), 13 specimens for the experimental work were conducted. All the specimens had been shot-peened and exposed to elevated temperatures.

3.3. Shot-peening

The 13 specimens had been shot-peened from the both sides by Almen intensity of 1.0 N2. The shot impact angle was 90° (Fig. 3).

The shot-peening parameters were defined according to the standards SAE J422/J433, and are shown in Table 2.

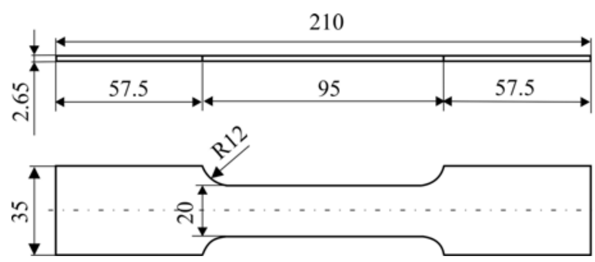

Fig. 2. The specimen shape and dimensions.

Fig. 3. The shot-peened specimen surface.

T a b l e 1. Chemical composition

Specimen metal	Chemical element (wt.%)							
	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
5083	0.11	0.02	0.38	4.75	0.58	0.17	0.021	0.01

T a b l e 2. The shot-peening parameters

The air pressure at the nozzle input	4 bars
Distance form nozzle to specimen surface	90 mm
Impact angle	90°
The time of shot exposure	60 seconds
The media type	S 390*
The obtained surface coverage	96 %

*Manufacturer Wheelabrator Corporation

T a b l e 3. Input parameters according to CCD

Input variables	Temperature X_1 (℃)	Time period X_2 (minutes)
Minimum (-1)	70	20
Medium (0)	100	40
Maximum (1)	130	60
$X^{1.2}$ kod (−1.414)	58	12
$X^{1.2}$ kod (1.414)	142	68

3.4. Elevated temperature exposure

The second level equation of CCD needs two input parameters. So, for this purpose the temperature and time were chosen as variables. The yield strength and the tensile strength were observed as output results.

There were three chosen basic temperatures: 70 ℃, 100 ℃ and 130 ℃. The temperature range was determined according to possible working conditions [3]. The additional two temperatures (58 ℃ and 142 ℃) were calculated according to the CCD. Similarly there were three exposure time periods chosen: 20, 40 and 60 minutes. The additional two time periods (12 and 68 min) were calculated according to the CCD. The input parameters are shown in the Table 3.

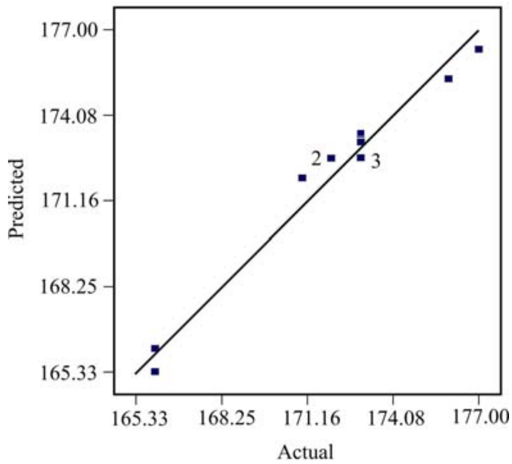

Fig. 4. Predicted vs. actual values.

4. Tensile testing

The tensile strength tests were conducted in the Laboratory for Mechanical Testing in the Aluminium Industry – Šibenik. The tensile testing machine was 60 kN measuring range.

Thirteen peened and heated specimens were tested. Additional two specimens were also tested. One of them was only shoot-peened, and the other was completely untreated.

5. Results and discusion

As it is previously stated the test results are analysed according to the CCD. The test results of interaction between mechanical properties ($R_p0.2$, R_m), temperature T and time exposure t are shown in Table 4.

Based on the variance and the regression analysis, with reference to regression coefficients, the functional interaction between yield strength, temperature and time exposure may be expressed:

$$R_p0.2 = 181.464 + 0.113 \cdot T - 0.519 \cdot t - 1.792 \cdot 10^{-3} \cdot T^2 + 2.219 \cdot t^2 + 3.75 \cdot 10^{-3} \cdot T \cdot t. \quad (1)$$

According to the model F-value of 42.23 and R-squared equal 0.9679, it may be concluded that all examined factors and their interactions are significant, so they are included in the Eq. (1). The difference between actual and predicted values is shown on Fig. 4. Good correspondence of monitored values is obvious.

The yield strength results indicate differences between the shot-peened specimens and specimens that were additionally heat-treated. By the second level CCD the test results are mathematically ana-

Table 4. Test results

Treatment	Specimen	Cross section A (mm^2)	Temperature T (°C)	Time exposure t (min)	Yield strength $R_p0.2$ (MPa)	Tensile strength R_m (MPa)
SP+HT	1	52.22	70	20	177	309
SP+HT	2	53.53	70	60	173	307
SP+HT	3	54.15	130	20	166	307
SP+HT	4	54.11	130	60	171	306
SP+HT	5	54.81	58	40	173	307
SP+HT	6	54.52	142	40	166	305
SP+HT	7	54.60	100	12	173	310
SP+HT	8	54.99	100	68	176	310
SP+HT	9	54.44	100	40	172	309
SP+HT	10	54.82	100	40	173	307
SP+HT	11	52.54	100	40	172	311
SP+HT	12	53.41	100	40	173	309
SP+HT	13	53.75	100	40	173	307
/	14	52.48	Room temp.	/	195	310
SP	15	55.33	Room temp.	/	210	309

SP – Shot peened, HT – Heat treated

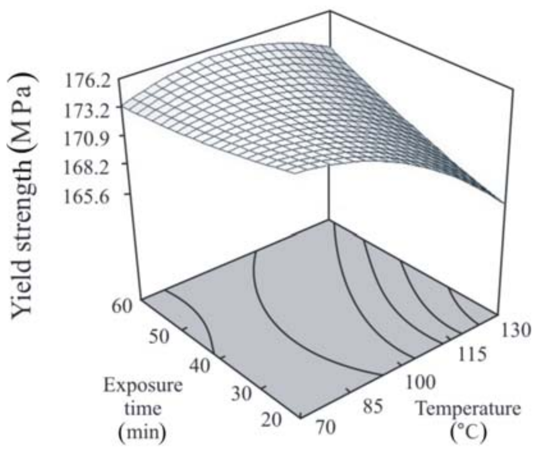

Fig. 5. 3D plot of yield strength vs. exposure time vs. temperature.

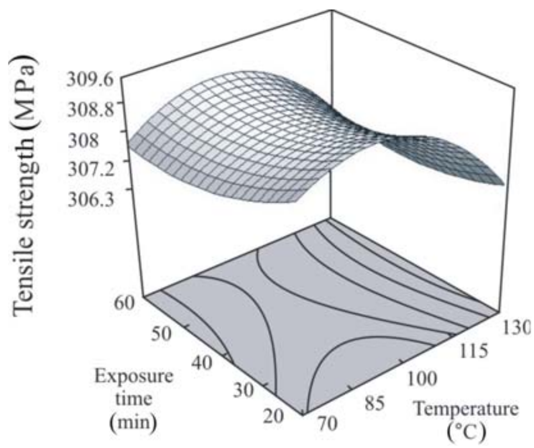

Fig. 6. 3D plot of tensile strength vs. exposure time vs. temperature.

lysed and associated with two input variables (temperature and exposure time). The shot-peened specimen has nearly 30 MPa higher yield strength compared with the unpeened specimen.

The plots of interaction between yield strength, temperature and exposure time is shown on Fig. 5.

Additional thermal treatment decreased the yield strength of the specimen, but it is also obvious that thermal treatment had not set aside all shot-peened effects. The most significant effect of elevated temperature is registered with the specimen that was 40 minutes exposed to temperature of 142 °C. But, in this case also the benefits of shot-peening are not entirely gone.

The tensile strength results indicate that there are no significant effects caused by shot-peening and elevated temperature on AA 5083 test specimens. By CCD the obtained results are calculated and plotted on Fig. 6.

6. Conclusion

The goal of this work was the analysis of the mechanical properties of the shot-peened AA 5083 specimen, after it had been exposed to elevated temperatures. At the end of experimental work and result analysis, it may be concluded:

– the exposure to the elevated temperature decreased the yield strength of shot-peened AA 5083, but it had not set aside all shot-peened effects;

– the elevated temperature is more influential than time exposure;

– time exposure has major influence at the higher temperature;

– shot-peening and elevated temperature exposure did not affect the tensile strength of AA 5083 specimens. Achieved deformations, during tensile test, were in the plastic area, so the advantageous effects of shot-peening had entirely gone.

References

[1] TABAN, E.—KALUC, E.: Kovove Mater., *44*, 2006, p. 25.
[2] ŽIVKOVIĆ, D.—ANZULOVIĆ, B.: In: Proceedings MATRIB '02. Ed.: Ivušić, V. Vela Luka, Croatia 2002, p. 253.
[3] BROWN, S.: Feasibility of Replacing Structural Steel with Aluminium Alloys in the Shipbuilding Industry. University of Wisconsin at Madison, 1999, p. 1, www.elvis.engr.wisc.edu:16080/UER/uer99/author1/content.html
[4] KENT, R. K.—BAGGERLY, R.: MDE Engineers, Inc., Intergranular Corrosion, USA, 2000, p. 777.
[5] ŽIVKOVIĆ, D.—ANZULOVIĆ, B.—GABRIĆ, I.: In: Proceedings MED '06. Ed.: Kennedy, D. International conference on materials energy and design. Dublin, Dublin Institute of Technology 2006, p. 18.
[6] www.aluminium.matter.org.uk/aluselect/