Materials Science Forum
ISSN: 1662-9752, Vol. 930, pp 507-512
doi:10.4028/www.scientific.net/MSF.930.507
© 2018 Trans Tech Publications, Switzerland

Submitted: 2018-01-29
Accepted: 2018-02-08
Online: 2018-09-14

Evaluation of the Residual Stress and Microstructure of Extruded and Shot Peened Aluminum Alloy 6082

Arnaldo Augusto Ciquielo Borges[1,2,a*], Mayara Cardoso de Araújo[1,b]
Antonio Augusto Couto[1,3,c], Nelson Batista de Lima[1,d], Chester Contatori[1,2,e]

[1]Instituto de Pesquisas Energéticas e Nucleares (IPEN), 05508-000, São Paulo, SP, Brasil

[2]Instituto Federal de São Paulo (IFSP), 01109-010, São Paulo, SP, Brasil

[3]Universidade Presbiteriana Mackenzie (UPM), 01239-010, São Paulo, SP, Brasil

[a]arnaldo.ifsp@gmail.com,[b]mayaraujo@yahoo.com.br, [c]acouto@ipen.br, [d]nblima@ipen.br,
[e]chester.contatori@gmail.com

Keywords: aluminum alloy, residual stress, shot peening, crystallographic texture

Abstract: Aluminum-magnesium-silicon alloys have been widely used as extruded products due to its mechanical strength and high ductility. The effects induced by shot peening has been extensively used in materials that have potential for structural applications. In this context, the purpose of this study was to evaluate the residual stress induced by shot peening of extruded aluminum alloy 6082. Initially, the effect of heat treatments such as solution treatment and ageing of this alloy was studied. The residual stress measurements were carried out using x-ray diffraction. The microstructure of the alloy was studied by optical microscopy. The crystallographic texture was determined using x-ray diffraction and back-scattered electron diffraction. The heat treatment sequence that resulted in the highest hardness of Al alloy 6082 was solution treatment at 560ºC for 30 min, followed by ageing at 185ºC for 5 h. The residual stress in compression of the extruded alloy's surface increased by 87.38%, from -66.6 to -124.8 MPa, caused by shot peening. The residual stress profile indicated an increase in its value up to a depth of 86 µm, beyond which the values obtained were unreliable. The extruded section revealed accentuated crystallographic texture in the (111) plane parallel to the cross-section and in the (200) and (220) planes oriented preferentially in the longitudinal direction to extrusion and perpendicular to the (111) plane.

Introduction

The motivation purpose for using aluminum and its alloys in structural applications is mainly related to its low density. The versatility in fabrication using extruded components makes these alloys potential substitutes for materials with higher density, mainly as structures. The Al-Mg-Si (AA 6XXX) alloys are considered to be of medium strength and constitute the largest amount among extruded aluminum alloys.

In metallic components, residual stresses are introduced either intentionally by shot peening or unintentionally during manufacture. In the case of shot peening, the introduction of compressive residual stresses in the surface layers results in a marked increase in fatigue life of the component. Shot peening is nothing more than high velocity bombardment of the surface with hard spherical particles that could be metallic, ceramic or glass. This process creates a plastically deformed layer on the surface of the material. A region with residual stress in compression is produced when the elastically deformed material, just below the plastically deformed surface layer, tries to recover its original geometric form [1-5].

Many studies have been carried out to understand better the role of residual stress in improving the fatigue resistance of aluminum alloys [6-12]. This study was carried out to contribute further towards understanding the residual stress generated by shot peening of aluminum alloy 6082. The microstructure of the extruded section of this alloy has been examined, having observed the effect of the presence of large grains and crystallographic texture in the determination of residual stress.

Materials and Methods

Extruded bars of aluminum alloy AA 6082 with a circular section 13 mm in diameter were used in this study. Specimens 20 mm in length were cut from the extruded bars for solution and ageing heat treatments. The solution treatment was done at temperatures of 545ºC and 560ºC for 30 min followed by quenching in water. Ageing was done at 175ºC and 185ºC for 0.5, 1, 2, 3, 4, 5, 6, 7, 8 and 24 hours followed by air cooling. On cross-sections of the heat treated specimens, Rockwell B hardness measurements were carried out, and hardness curves as a function of ageing times for both solution treatment temperatures were determined. On each specimen, 5 random measurements were made.

Shot peening was carried out with a METALCYM/METALBLAST Turnblast equipment. The nominal distance between the turbine and the specimen was 600 mm. The turbines of this equipment was set to operate at 2500 rpm and for 1 min. Spherical S170 steel shots manufactured as per SAE J-444 standard, with diameter of 0.42 mm and minimum hardness of 57 HRC were used. To measure the residual stress a Rigaku x-ray diffraction equipment was used with a chromium tube, voltage of 40 kV and current of 20 mA. The method used was sen$^2\psi$, with variation in ψ from +50º to -50º and intervals of 10º in the diffraction angle with respect to (311) plane.

The residual stress curve as a function of depth was determined in the radial direction of the cross-section, starting from the circular surface of the specimen. This depth profiling was done by etching the surface of the specimen with concentrated HCl followed by measurement of the residual stress. To measure the depth after etching, a setup consisting of a Mitutoyo base and a PUY 220 comparator watch with sensitivity of 1 μm was used.

To carry out optical metallographic measurements, specimens from longitudinal section and the cross-section, with respect to the extrusion direction, were prepared using conventional procedures consisting of cutting, mounting, grinding, polishing and etching with HF. The optical measurements were made with an Olympus optical microscope using polarized light. To carry out crystallographic texture measurements, a Rigaku x-ray diffraction equipment was used. The pole figures were obtained for the crystallographic planes (111), (200), (220) and (311). To examine the crystallographic orientation, a scanning electron microscope coupled to an electron backscattered diffraction equipment was used.

Results and Discussion

Figure 1 shows the hardness versus ageing time curves. The highest hardness (89 HRB) was exhibited by the specimen that was solution treated at 560ºC and aged for 5 h at 185ºC. These conditions were chosen to heat treat other specimens prior to shot peening and measurement of their residual stresses. Shot peening was carried out on specimens with two parallel longitudinal chamfers 0.6 mm deep along its whole length. These chamfers were introduced mainly to serve as reference while positioning the specimen to carry out subsequent measurement of residual stress and depth after chemical etching. Measurement of residual stress on the specimen surfaces was done at 4 positions at 90°, 2 in the chamfered region and 2 in the curved region, before and after shot peening. The shot peening showed more than 100% coverage. Regardless of the position, the 4 measurements revealed similar values for both, the specimen before and after shot peening, indicating thus that the shot peening process was homogeneous. The specimens, prior to and after shot peening, revealed values of residual stress in compression. The average residual stress value on the surface of the specimen that was not shot peened was -66.6 MPa, whereas it was -124.8 MPa on the surface of the shot peened specimen.

The average residual stress curve as a function of depth from the curved surface is shown in figure 2. It can be seen that the residual stress values increase with depth up to 86 μm. Beyond 86 μm, the measurements showed no statistical consistency and after 166 μm, measurements could not be made with the technique used in this investigation. These results indicate the presence of very large grains and/or highly oriented crystallography.

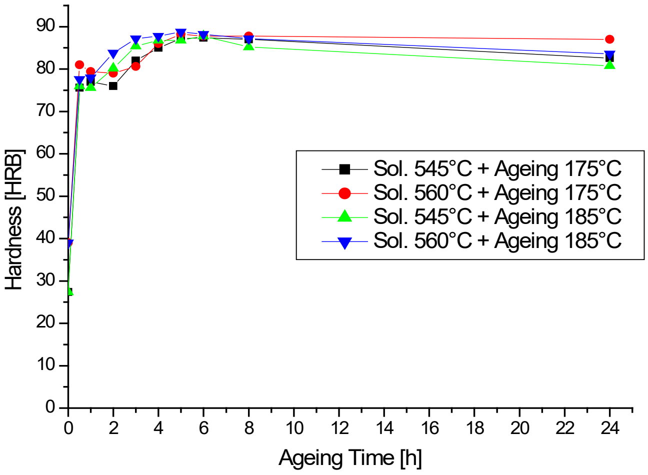

Fig. 1: Rockwell B hardness curves as a function of ageing time.

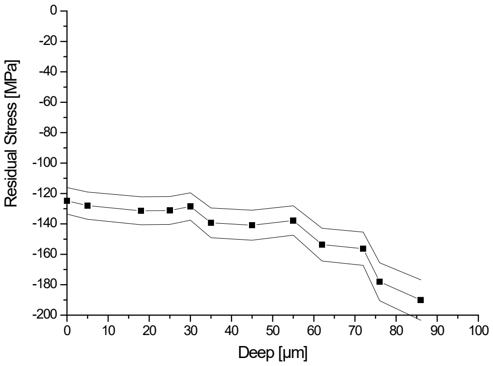

Fig. 2: Residual stress values as a function of distance from the surface on extruded AA 6082 alloy that was solution treated, aged and shot peened.

The microstructure was examined to identify the reason for the results of the residual stress measurements. Figures 3 and 4 show optical micrographs of the cross-section (figure 3) and the longitudinal section (figure 4), obtained using polarized light. The microstructure of the cross-section (figure 3) shows large grains at the edge of the extruded section. This may have resulted during solution treatment of the material while exiting the extruder. Nevertheless in the central region of the micrograph the presence of a large grain and with a slight variation in its color can be seen. The micrograph of the longitudinally cut specimen (figure 4) confirms the presence of large grains at the edge. In the central region, fine grains elongated in the extrusion direction can be observed, with predominantly two colors, suggesting preferential orientation.

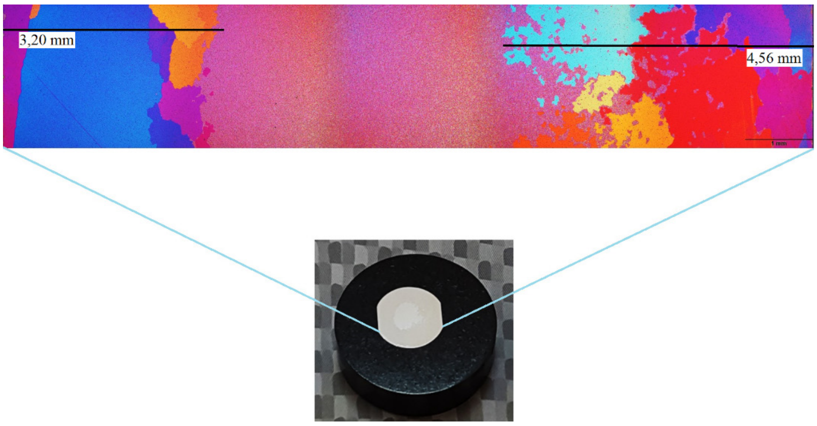

Fig. 3: Micrograph of cross-section of the extruded specimen.

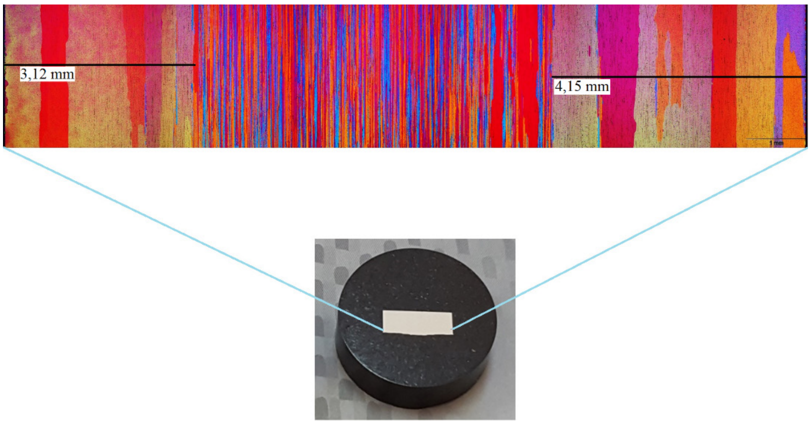

Fig. 4: Micrograph of longitudinally cut extruded specimen.

The x-ray diffraction spectra of the cross-section and longitudinal section of the specimens are shown in figures 5 and 6 respectively. The spectrum of the cross-section (figure 5) reveals marked crystallographic orientation in the (111) plane and, to a lesser extent, in the (200) and (220) planes. Other crystallographic planes are not seen. The spectrum of the longitudinally cut specimen (figure 6) reveals only peaks related to the (200) and (220) planes. Conjoint evaluation of these x-ray spectra along with the observations from optical microscopy suggest accentuated texture in the (111) plane and, to a lesser extent, in the (200) plane, both parallel to the cross-section of the extruded section. The (002) and (220) planes are preferentially oriented in the longitudinal direction of extrusion and perpendicular to the (200) and (111) planes, respectively.

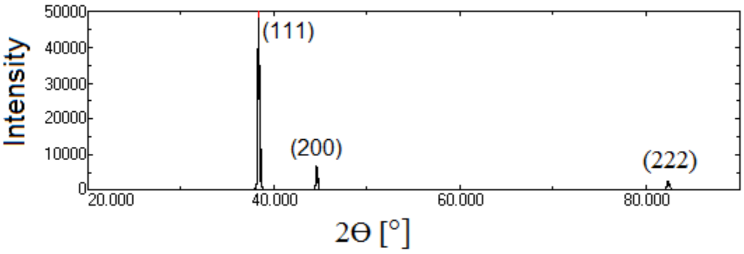

Fig. 5: X-ray diffraction spectrum of the cross-section of extruded specimen.

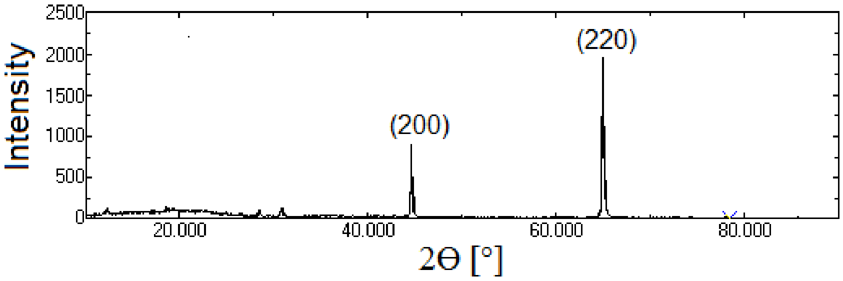

Fig. 6: X-ray diffraction spectrum of the longitudinally cut specimen from the extruded section.

To confirm crystallographic texture in the alloy, pole figures were obtained by x-ray diffraction and electron backscatter diffraction (EBSD) images using a scanning electron microscope. The pole figures related to the (111), (200), (220) and (311) planes of the specimen cross-section can be seen in figure 7. These confirm strong crystallographic orientation in the (111) plane, parallel to the cross-section of the extruded section. Besides this, the specimen revealed radial symmetry. In the ESBD image of the central region of the same section (figure 8), only two colors related to orientation can be observed. As seen in the orientation standard of this image, the blue color represents predominantly the (111) direction and the red color the (200) direction. These observations are consistent with those made based on the results of optical microscopy, the x-ray diffraction spectra and the pole figures.

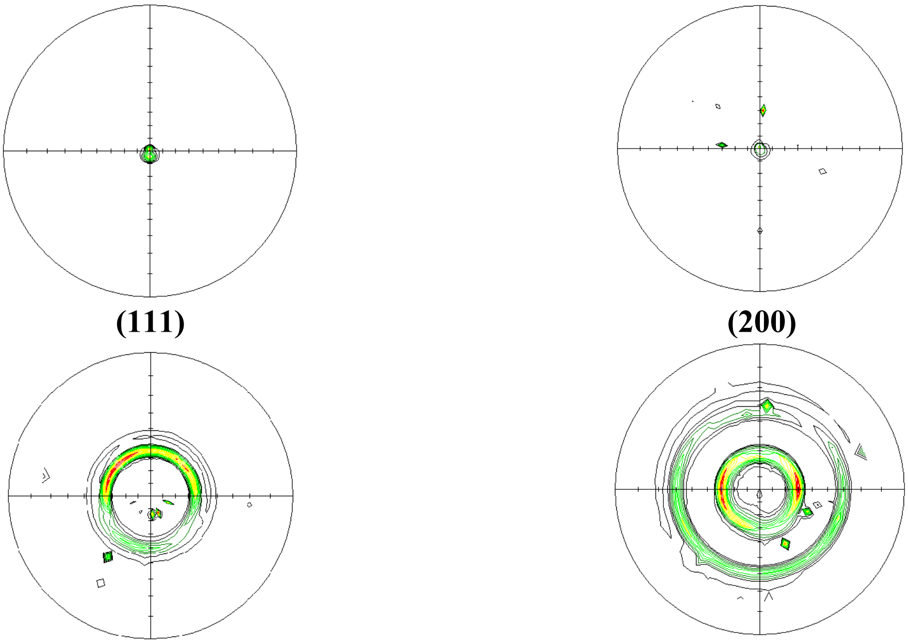
(111) (200)
(220) (311)

Fig. 7: Pole figures of the cross-section of the extruded aluminum alloy 6082.

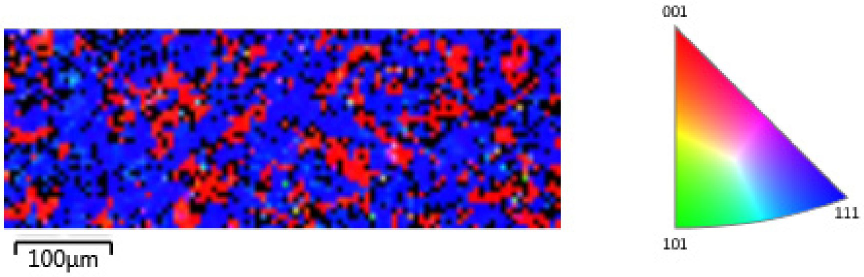

Fig. 8: ESBD image of the central region of the cross-section of the extruded aluminum alloy 6082.

Conclusions

The heat treatment sequence that resulted in highest hardness of the aluminum alloy 6082 was solution treatment at 560ºC for 30 min followed by ageing at 185ºC for 5 h. The shot peening and fatigue tests were carried out after extrusion and heat treatment for maximum hardness. The residual stress in compression of the surface of the extruded aluminum alloy increased by 87.38 % from -66.6 to -124.8 MPa as a result of shot peening. The residual stress profile revealed an increase with depth. However, measurements could not be made beyond a depth of 86 µm due to the grain size being very large in the subsurface region of the extruded section and crystallographic texture. The extruded section showed marked crystallographic texture in the (111) plane, parallel to the cross-section and the (200) and (220) planes that were oriented preferentially in the longitudinal direction of extrusion and perpendicular to the (111) plane.

References

[1] J.O. Almen, P.H. Black: *Residual Stresses and Fatigue in Metals*. (MacGraw Hill, Book Company, New York 1963).

[2] M.A.G. Calle: Análise Numérico-Computacional das Tensões Residuais Induzidas pelo Jateamento com Granalha. Doutorado (Tese). São Paulo, 2004. Escola Politécnica Universidade de São Paulo (USP).

[3] A. Ezeilo: *Analysis of Residual Stress by Diffraction using Nêutron and Synchroton Radiantion*. (Taylor & Francis, 2003).

[4] P. Juijerm, I. Altenberger: Scripta Materialia Vol. 56 (2007), p. 745.

[5] R.R. Oliveira: Avaliação da tensão residual em alumínio 7050 conformado pelo processo de peen forming. Dissertação (Mestrado). São Paulo, 2011. Instituto de Pesquisas Energéticas e Nucleares (IPEN/USP).

[6] D. Azzam, C.C. Menzemera, T.S. Srivatsanb: Materials Science and Engineering A Vol. 527 (2010), p. 5341.

[7] D.B. Barrios, M.A.G. Calle, E. Angelo, E. Gonçalves,A.H.P. Andrade:Soldagem Insp. Vol. 12 (1) (2007).

[8] P. Juijerm, I. Altenberger, B. Scholtes: Materials Science and Engineering A Vol. 426 (2006), p. 4.

[9] H. Luong, M.R. Hill: Materials Science and Engineering A Vol. 527 (2010), p. 699.

[10] K. Oguri: Journal of Materials Processing Technology Vol. 211(2011), p. 1395.

[11] M.A.S. Torres, H.J.C.Voorewald: International Journal of Fatigue Vol. 24 (2002), p. 866.

[12] O.S. Zaroog, A. Ali, B.B. Sahari, R. Zahari: International Journal of Fatigue Vol. 33 (2011), p. 279.