Materials Science & Engineering A 639 (2015) 288–297

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Effect of thermal exposure on the residual hardness and tensile properties of the EN AW-2618A piston alloy

Lorella Ceschini [a], Alessandro Morri [a], Andrea Morri [a,*], Marisa Di Sabatino [b]

[a] Department of Industrial Engineering (DIN), Alma Mater Studiorum-University of Bologna, V.le Risorgimento 4, 40136 Bologna, Italy
[b] Department of Materials Science and Engineering, Norwegian University of Science and Technology, Alfred Getz vei 2, 7491 Trondheim, Norway

ARTICLE INFO

Article history:
Received 3 March 2015
Received in revised form
24 April 2015
Accepted 25 April 2015
Available online 4 May 2015

Keywords:
EN AW-2618A
Thermal exposure
Tensile properties
Hardness
Microstructure

ABSTRACT

The present study was focused on the effect of temperature exposure on the hardness and tensile properties of the EN AW-2618A T6 alloy, used for forged pistons. The peak aging parameters were firstly obtained by solutioning, water quenching and aging the alloy in the range 25–220 °C. The thermal stability of the T6 heat-treated alloy was studied in the temperature range 200–300 °C for times up to a week, thus obtaining the corresponding hardness–time–temperature curves. Tensile tests and microstructural characterisation were carried out on specimens subjected to different thermal exposure and therefore characterized by different residual hardness. Proof and ultimate tensile strength decreased with decreasing the residual hardness of the alloy, while elongation to failure and strain hardening exponent increased. Empirical equations able to modelling the tensile behaviour of the alloy, based on its residual hardness, were defined. Microstructural and fractographic analyses on the thermal exposed alloy evidenced coarsening of strengthening phases, mainly at the grain boundaries, with presence of precipitate free zones and large incoherent precipitates.

1. Introduction

It is widely accepted that weight reduction is the most effective method to reduce transportation costs and to satisfy the growing demands for reducing energy consumption and gas emission. A 10 wt% reduction approximately leads to 8–10% improvement in fuel economy [1] and for this reason the use of light alloys, in particular aluminium, is the main target for automotive applications. The characteristic properties of aluminium alloys, such as high strength-to-weight ratio, good formability and castability, good thermal conductivity and corrosion resistance, as well as recycling potential, make them the ideal candidates to replace heavier materials, such as steels or cast irons. Applications of Al alloys in today's vehicles include, for example, body-in-white, closures, bumpers, wheels, heat exchangers, and also critical parts, such as engine blocks and pistons.

The piston is one of the most heavily stressed engine components. Engine combustion is inevitably linked to a very high increase in pressure and temperature, which induces severe mechanical and thermal stresses on this component. Moreover, since one of the main trends of the major automotive companies in the last years has been the engine downsizing, with a consequent increase of the specific power output, the requirements on the piston have also grown. The main property of piston alloys is therefore high static and cyclic strength, even at high temperature. As already reported by the authors in a previous paper [2], advanced CFD/FEM simulation and residual hardness measurements on Al alloy pistons for high performance motorcycle engines after service, allow the evaluation of local working temperature up to a maximum value of around 300 °C. Similar temperature can be reached in high speed diesel engines [3]. Since Al alloy pistons are generally produced by casting or forging using heat treatable alloys, high thermal loads can lead to significant reduction of their tensile and fatigue strength. High in-service temperatures (> 150 °C), in fact, induce a diffusion-controlled coarsening of the reinforcing precipitates formed by heat treatment, with a consequent loss of their effectiveness in hindering dislocations movement. Accordingly, allowable stresses for the aluminium piston alloys greatly depend on working temperature and a systematic study of the effect of thermal exposure on the specific alloy is needed.

A common alloy for high performance forged pistons is the EN AW-2618A, which belongs to the class of Al–Cu–Mg alloys and contains about 1% of Fe and Ni to retain microstructural stability at elevated temperatures. The effects of Fe and Ni on its microstructure are widely described in literature [4–8]. Moreover, several authors studied the effects of heat treatment in terms of hardness behaviour and/or microstructural evolution for this alloy

* Corresponding author. Tel.: +39 051 2093462; fax: +39 051 2093467.
E-mail address: a.morri@unibo.it (A. Morri).

http://dx.doi.org/10.1016/j.msea.2015.04.080
0921-5093/

[4,5,8–10]. However, in these previous studies the aging response was investigated in a very limited temperature range.

Another key point is the response of the peak-aged alloy to in-service high temperature exposure. Microstructural evolution due to thermal exposure was studied by TEM analyses, investigating the precipitation sequence involved during age hardening and creep tests on this [4,11] and similar alloys [12,13]. Other interesting works [14,15] were carried out to investigate the effects of temperature and time on tensile properties of EN AW-2618A. However, there is a lack of data on the relationship between microstructural evolution and tensile properties mainly in the plastic field. Based on this background, the present work aimed to study the relationship between mechanical properties and microstructural evolution due to high temperature exposure of the EN AW2618 T6 alloy. Hardness and tensile tests, coupled with OM and SEM microstructural and fractographic investigations, were carried out. Hardness–time–temperature curves were obtained, as well as empirical equations aimed to describe the tensile behaviour of the alloy as a function of its residual hardness after thermal exposure.

2. Experimental

2.1. Material

The experimental activity was carried out on the EN AW-2618A aluminium alloy, whose chemical composition, obtained by spectrometric analyses, is reported in Table 1. Samples for the experimental analyses were taken from forged pistons. The forging process is carried out on a hydraulic machine after heating up to 400 °C and holding for 3 h. Average deformation rate during this process is 1 mm/s with a maximum reduction of 50% along the forging axis.

2.2. Heat treatment and thermal stability

Differential scanning calorimetry (DSC) analyses were performed to optimise the solution treatment. The alloy was studied as-forged (untreated) and after a solution treatment at 525 °C for 8 h. The samples, about 40 mg in weight, were heated at 10 °C/min from room temperature to 700 °C, under a protective Ar atmosphere, on a TA2920 scanning calorimetry instrument.

For the study of the aging treatment, several specimens ($6\times5\times3$ mm^3) cut from the pistons, were solutioned (slow heating to 525 °C and 8 h soaking), quenched in hot water (60–90 °C) and aged at different temperatures (in the range 25–220 °C) for times up to 50 h. After that, samples were ground to obtain a suitable surface finishing for Brinell hardness tests, carried out according ASTM E 10-08 standard (2.5 mm diameter indenter and 62.5 kg load). For each aging condition at least three measurements on two identical samples were taken.

A similar procedure was used to study the thermal stability of the T6 heat-treated alloy. Several specimens ($12\times4\times6$ mm^3) were heat treated according to the previously optimised parameters (8 h at 525 °C, 60÷90 °C water quench and 20 h at 200 °C) and then exposed to different temperatures, from 200 °C to 305 °C (typical values of maximum temperatures reached in pistons), for holding times ranging from 5 min to 1 week. Brinell hardness tests were carried out on the thermally exposed specimens, as described above for aging optimisation, and the hardness–time curves at fixed temperatures were obtained by non-linear regression analyses. These data were used to derive the temperature–time–hardness (or constant-hardness) curves of the T6 heat treated alloy.

2.3. Tensile tests

In order to further investigate the effect of high thermal exposure on the T6 heat-treated EN AW-2618 alloy, seven classes of tensile specimens (with five specimens for each class) were defined. Each class of tensile specimens was subjected, after the heat treatment (8 h at 525 °C, 60–90 °C water quench and 20 h at 200 °C), to different thermal exposure resulting in different expected hardness values. Flat tensile specimens, whose geometry and dimensions are shown in Fig. 1, were cut from the crown of the forged pistons. Tensile tests were carried out at room temperature, using a screw tensile testing machine, according to EN ISO 6892-1:2009 standard, at a strain rate of 3.3×10^{-3} s^{-1}. Elastic modulus (E), yield strength (YS), ultimate tensile strength (UTS) and elongation to failure (E%) were evaluated. The behaviour of the alloy in the plastic field was modelled through the Hollomon's equation [16]: strength index (K) and strain hardening exponent (n) were evaluated through a non-linear regression analysis of the true stress–true strain curves in the plastic portion (by excluding the data before the 0.2% proof strength).

2.4. Microstructural and fractographic characterisation

Samples for microstructural characterisation were cut from the tensile specimens close to the fracture surfaces. The samples were cold embedded in resin, ground and polished according to ASTM E3 standard. Microstructural analyses were carried out both by optical (OM) and scanning electron microscopy, equipped with an energy dispersive spectroscopy (SEM-EDS). Optical microscopy analyses were carried out by a *Zeiss Axio*® optical microscope before and after electrochemical etching (12 V tension, using a solution of 5% HBF_4 in water for 30–45 s, according to ASTM E 407 standard). A *Zeiss Supra*® *55VP* field emission gun (FEG) SEM was used. The analysis was carried out both with secondary electrons (acceleration voltage 10 kV, aperture size 30 μm, working distance 10 mm) and back scattered electrons (acceleration voltage 15 kV, aperture size 120 μm, working distance 10 mm). EDS of selected points (acceleration voltage 15 kV, aperture size 120 μm, working distance 10 mm, counting time 1 min) was used to verify the chemical composition of the phases observed with both secondary and back scattered electrons.

A *Zeiss EVO*® *MA 50* scanning electron microscope was finally used to study the fracture surfaces and analyse the changes in the fracture pattern due to different thermal exposure.

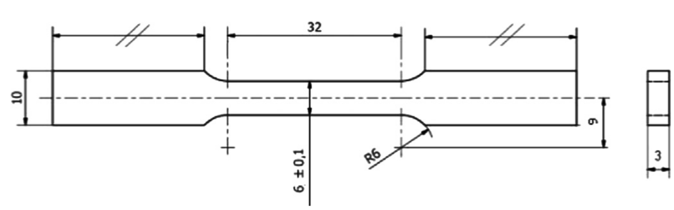

Fig. 1. Geometry and dimensions (mm) of the tensile specimens.

Table 1
Chemical composition of the EN AW-2618A alloy (wt%).

Si	Fe	Cu	Mn	Mg	Zn	Ti	Ni	Zr	Pb	Sn	Cr
0.2294	1.0831	2.6116	0.112	1.5206	0.0393	0.0308	1.2229	0.1243	0.0016	0.0036	0.0003