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Journal of Magnesium and Alloys ■■ (2018) ■■–■■
www.elsevier.com/journals/journal-of-magnesium-and-alloys/2213-9567

Full Length Article

Influence of heat treatment on the machinability and corrosion behavior of AZ91 Mg alloy

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Received 13 April 2017; revised 2 December 2017; accepted 6 December 2017
Available online

Abstract

In the present study, AZ91 Mg alloy was heat treated at 410 °C for 6, 12 and 24 h to investigate the influence of heat treatment on machinability and corrosion behavior. The effect of soaking time on the amount and distribution of $Mg_{17}Al_{12}$ (β – phase) was analyzed under the optical microscope. Microhardness measurements demonstrated the increased hardness with increased heat treatment soaking time, which can be attributed to the solid solution strengthening. The influence of super saturated α-grains on reducing the cutting force (F_z) with respect to increased cutting speed was observed as prominent. The corrosion behavior of the heat treated specimens was studied by conducting electrochemical tests. Surprisingly, corrosion rate of heat treated samples was observed as increased compared with the base material. From the results, it is evident that the machinability of AZ91 Mg alloy can be improved by producing super saturated α-grains through heat treatment but at the cost of losing corrosion resistance.

Keywords: AZ91 Mg alloy; Solid solution; Turning; Corrosion; Machinability

1. Introduction

Magnesium (Mg) alloys are now becoming attractive alternate light metals for structural applications due to low density and high specific strength compared with the aluminum alloys [1,2]. AZ (aluminium and zinc) series alloys are the most widely used group of Mg alloys in the manufacturing industry. Among them, AZ91 is a die cast Mg alloy which is widely used in automobile and aerospace industries. Basically, AZ91 Mg alloy contains two phases known as α-phase which is a solid solution of Mg and Al; and β – phase ($Mg_{17}Al_{12}$) which is a compound made of Mg and Al [3,4].

Machining is one of crucial manufacturing processes which is widely carried out to produce structural members or components. Machining of magnesium is not difficult; however a careful attention must be exercised during the machining of Mg due to its inflammability nature. Unless the temperature reaches to high enough, where the chip catches fire, the inflammable nature of Mg does not create any complexity during machining. However, the formation of flank built up edge; higher cutting forces and surface roughness are the other critical issues, which require more attention [5–8]. Birol Akyuz [9] reported lower cutting forces for AZ91 Mg alloy compared with AZ21 alloy during turning of AZ series Mg alloys. Lu et al. [10] reported the influence of cutting speed on the depth of affected layer thickness during turning of AZ31 Mg alloy. In our earlier study, a significant role of aluminium content on machining of AZ series Mg alloys during drilling was observed [11]. In AZ series Mg alloys, the presence of β – phase influences the corrosion behavior to a great extent. The machinability of Mg alloys is also influenced by the amount and distribution of the β – phase. In the materials engineering, heat treatment is a promising technique to alter the microstructure in order to achieve the desired phases, and its volume fraction to alter the bulk

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https://doi.org/10.1016/j.jma.2017.12.001

Please cite this article in press as: Swetha Chowdary V, Ravikumar Dumpala, Anand Kumar S, Kondaiah VV, Ratna Sunil B, Influence of heat treatment on the machinability and corrosion behavior of AZ91 Mg alloy, Journal of Magnesium and Alloys (2018), doi: 10.1016/j.jma.2017.12.001

behavior. Through heat treatment technique, super saturated alloys with required phase distribution and properties can be obtained. Therefore, an attempt has been made in the present study, to tailor the microstructure in order to achieve the super saturated AZ91 Mg alloy through heat treatment technique. The effect of microstructure on machining characteristics during turning and also corrosion behavior were investigated.

2. Experimental details

AZ91 Mg alloy (8.6% Al, 0.85% Zn, 0.002% Fe, 0.03% Mn and remaining being Mg by Wt.%) cast billet was obtained from Exclusive Magnesium, Hyderabad. Specimens of size 10 mm × 10 mm × 10 mm and rods of diameter 25 mm with a length of 150 mm were cut from the billet. Heat treatment was carried out at 410 °C for 6, 12 and 24 h. Initially, the specimens were placed in the furnace and slowly heated up to 410 °C with a heating rate of 5 °C/min. The samples after different intervals of time were taken out from the furnace and subsequently quenched in water. The specimens were coded as 0 h, 6 h, 12 h and 24 h for untreated, heat treated for 6, 12 and 24 h respectively. Microstructural observations were carried out (before and after heat treatment) using a polarized optical microscope (Leica DMI5000M, Germany). All the samples were metallographically polished by using different grades of emery sheets followed by alumina polishing and then finally cleaned with ethanol. Then the polished samples were etched with picric acid reagent for 20 s. Average grain sizes were measured for all the samples by linear intercept method [12]. Microhardness measurements were carried out by Vickers indentation method (MHT-Smart, Omnitech, India) by applying 100 g load for 10 s. Indents were placed across the cross section of a representative specimen cut from the rods before and after heat treatment. Measurements were obtained for every 1 mm.

Machining experiments on the specimens were conducted using a lathe machine (HMT, India) mounted with tungsten carbide cutting tool. The workpiece was fixed in the three jaw chuck and the cutting tool was fixed on a dynamometer (Kistler 9403, Switzerland), which was fixed on the tool post of the lathe machine. Tailstock was used to give support to the workpiece with the help of dead centre. Fig. 1 (a) shows the photograph obtained during the machining and Fig. 1 (b) shows the photograph of the rods after machining. The cutting parameters (speed in rpm, feed rate in mm/r and depth of cut (DOC) in mm) were selected in such a way that one is lower value and the other is higher value. Turning operations were carried out at two different cutting speeds (325 and 715 rpm), two different feed rates (0.16 and 0.04 mm/r) and two DOCs (0.1 and 0.4 mm). Turning experiments were done on dry condition and cutting forces were recorded with the help of the dynamometer. The measurement of cutting forces was started a few seconds before the cutting tool touched the workpiece and continued up to a few seconds of machining for all the samples. After machining, chips were carefully collected and morphology of the chips was observed for every set of cutting parameters.

Electrochemical tests were carried out using 3.5% NaCl solution as the electrolyte (IVIUM Soft, Netherlands). During the experiments, platinum rod was used as a counter electrode and a saturated calomel electrode (SCE) was used as a reference electrode with the specimen (area 1 cm^2) as working electrode. All the specimens were polished using emery papers up to 2000 grade to obtain the same level of surface roughness before the experiments. Open circuit potential (OCP) was established for 30 min and then with the reference to OCP, the potential scanning range was fixed for all the specimens. The experiments were conducted at a scan rate of 5 mVs^{-1}. Corrosion current density (i_{corr}) and corrosion potential (E_{corr}) were obtained from the polarization plots using Tafel extrapolation method [13]. The corrosion rate (CR) was calculated using the Eq. (1) [13].

$$CR\,(mils/year) = 0.129 \times a \times i_{corr} / n\ D \tag{1}$$

where CR is the corrosion rate, a is the Molar mass (for magnesium 24.3 g/mol), i_{corr} is the corrosion current density in $\mu A/cm^2$, n is the valance and D is the density (1.74 gm/cm^3). The obtained CR was converted into mm/year by considering 1 mils/year equal to 0.0254 mm/year.

3. Results and discussion

The optical micrographs of the specimens as shown in Fig. 2 clearly demonstrate the effect of heat treatment on altering the microstructure. Usually in AZ series Mg alloys, solid solution of magnesium and aluminum is formed, when the aluminum content is less than 1%. $Mg_{17}Al_{12}$ (β – phase) appears at the grain boundaries if the aluminum content is more than 1% at room temperature. The solubility of aluminum can be increased

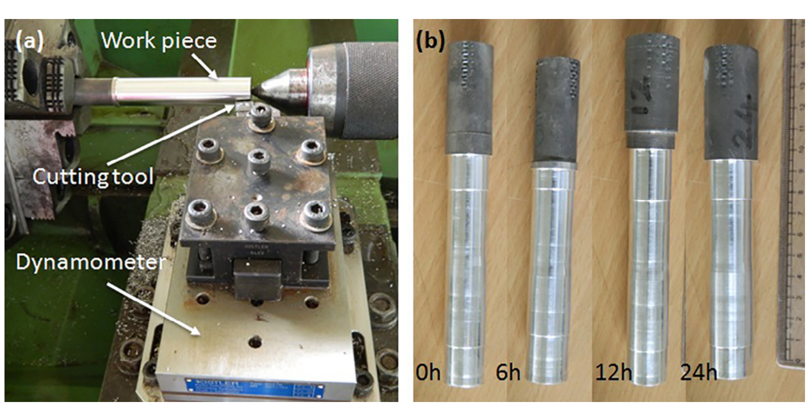

Fig. 1. a) Photograph showing the workpiece during turning operation and b) photographs of machined specimens.

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