Effect of Zn Content on the Mechanical Properties of Nemalloy–Al-Fe(Zn, Mg) Alloys for Automotive Applications

A. Abraham, J. Kish, S. Shankar, X. Zeng, P. Yaghi, A. Lombardi, G. Byczynski, and I. Levin

Abstract

In comparison with mainstream Al-Si alloys for structural die-casting components for automotive applications, Nemalloy HE700 (Al-Fe(Zn,Mg)) offers higher strength-to-weight ratio and elongation even without heat treatment. It is a newly developed Al-Fe hypoeutectic-based alloy with Zn and Mg additions serving as precipitation strengtheners. This study aims to determine the effect of Zn content on the microstructure and attendant mechanical properties of HE700. Alloy variations were casted as plates with three different thicknesses using high-vacuum high-pressure die casting with four different weight percentages (5%, 6.25%, 7.5%, and 8.75%) of Zn and a fixed weight percentage of Mg (1%). Mechanical properties were determined using uniaxial tensile measurements as a function of natural ageing time out to 14 days. It is observed that as zinc content increases, the electrical conductivity increases and hardness decreases. Alloy with 6.25% Zn showed better elongation (13.5%) compared to the other alloys at the end of 14 days of natural ageing but Alloy with 8.75% Zn shows better yield strength (218 MPa).

Keywords

Aluminium Alloy · Natural ageing · Mechanical Properties

1 Introduction

Aluminium (Al) alloys as the lightest structural metal material are among the most attractive candidates for the automotive applications. For automotive applications, essential properties like strength, ductility, corrosion resistance, etc., must be taken into account. The majority of these characteristics are controllable by using the appropriate alloying, processing, or a combination of these. Al alloy die-casting alloys have recently emerged as one of the key alloy groups in numerous applications in automotive industry. Since reducing CO_2 in the automotive industry has become a major goal to be accomplished, characteristics of Al alloys such as energy and fuel savings and lightweight `features were underlined. These alloys must have high elongation at fracture (EL) of approximately 10% and moderate yield strength (YS) between ~130 and -200 MPa for these applications [1, 4].

The majority of Al alloys used in the automotive industry today require heat treatment to obtain the required properties. The strength, hardness, ductility, and corrosion resistance of parts are all improved by this heat treatments. Yet, these heat treatments have an impact on cost of capital investments, lengthen the production cycle, and lower productivity. As a result, it

A. Abraham (✉) · J. Kish · S. Shankar · X. Zeng · P. Yaghi
McMaster University, Hamilton, ON, Canada
e-mail: abraha30@mcmaster.ca

A. Lombardi · G. Byczynski · I. Levin
Nemak USA/CAN, Windsor, ON, Canada

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is attractive to produce castings out of Al alloys that already have a high yield strength and a sufficient level of ductility, even without further post-processing. The development of an Al alloy suitable for use in the automotive sector without heat treatment is the primary focus of this study.

The Nemalloy HE700 alloy, a new group of cast Al-Fe-based eutectic alloy system with Zn and Mg additions for precipitation strengthening, has been established and validated for use in structural automotive components in order to keep up with the global strategy of developing Al alloys without heat treatment [3]. The HE700 offers an improved strength-to-weight ratio and elongation even without heat treatment when compared to the current structural automotive Al casting alloy [2]. Castings from this alloy do not require further heat treatment and therefore reduce production costs. The present paper describes the impact of Zinc on the microstructural and mechanical properties of HE700 after natural ageing of up to 14 days.

2 Experimental Methods

The chemical compositions of zinc-modified HE700 Al alloy used in this study are listed in Table 1. A three-step (thickness) plate casting part with nominal thicknesses of 3 mm, 2.5 mm, and 2.3 mm was fabricated, as illustrated in Fig. 1. The three-step plate castings were casted at CanmetMATERIALS using the Bühler Carat-type 1200-ton high-vacuum high-pressure die-casting press incorporating a Wohlin lubricant sprayer and ABB six axis robot. A thermotronic melting furnace, Bühler automatic ladle pouring system, and a vacuum pump with a low vacuum capability of 5 mbar were used as auxiliary equipment for casting.

A Bosello model MAX X-ray machine was used to take the images and the images were taken at 2.1 mA and 107 kV. To improve visibility of porosities, hot tearing, anomalous precipitates, and flow lines, the contrast and brightness of X-ray images (Fig. 2) were adjusted using the Fiji (ImageJ) image analysis software. An Albert Gnehm Universal Hardness Tester was used to measure the hardness and a function of natural ageing time using the Rockwell F hardness scale. An AutoSigma 3000DL machine was used to measure the electrical conductivity. A universal test machine (MTS ZZZ machine) was used to

Table 1 Nominal chemical compositions of the investigated alloys

Alloy	wt.%				
	Zn	Mg	Fe	Ti	Al
Alloy A	5	1	1	0.06	Bal.
Alloy B	6.25	1	1	0.06	Bal.
Alloy C	7.5	1	1	0.06	Bal.
Alloy D	8.75	1	1	0.06	Bal.

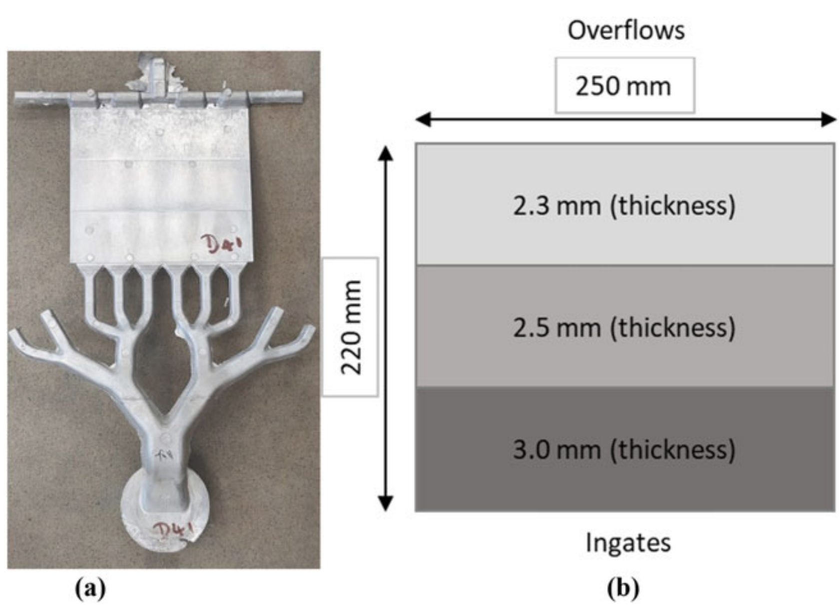

Fig. 1 (**a**) Photograph of a typical casting shot and (**b**) step plate dimension

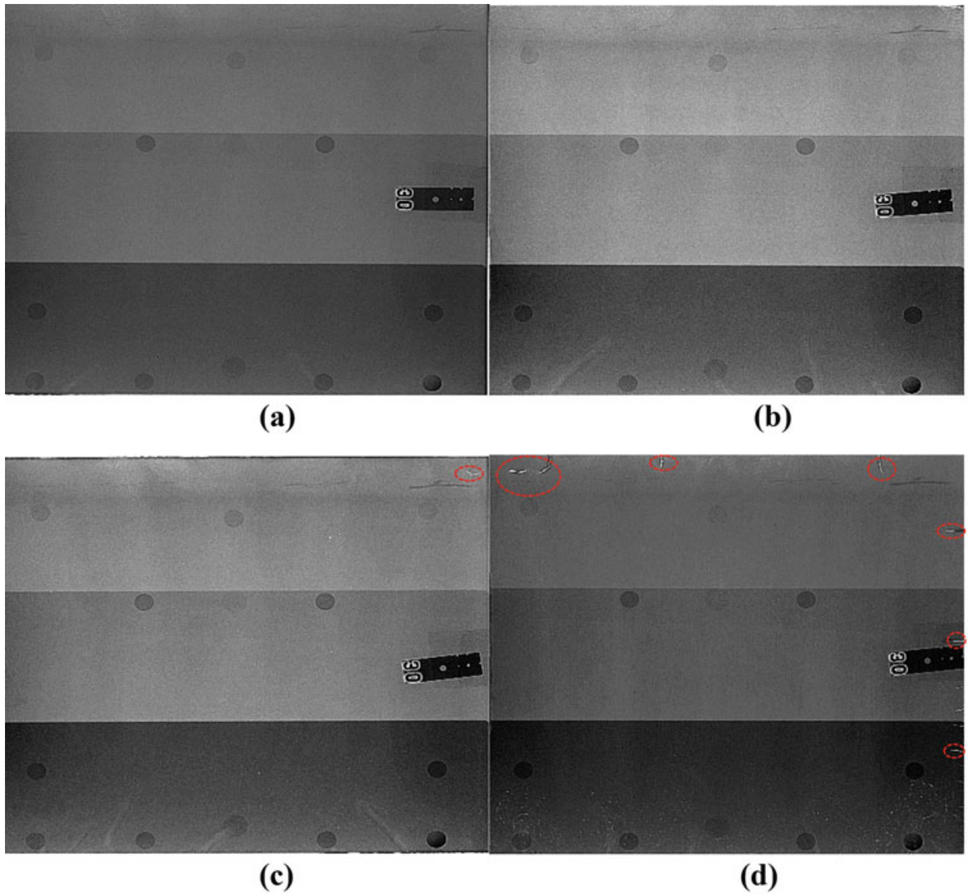

Fig. 2 X-ray image of (**a**) Alloy A, (**b**) Alloy B, (**c**) Alloy C, (**d**) Alloy D

carry out the uniaxial tensile test according to ASTM B557M-15 at a constant strain rate of $1 \times 10^{-3}\ s^{-1}$ coupled with an online digital extensometer to measure transient elongation. All the testings were done using samples from each of the three thicknesses casted for each alloy composition.

3 Results and Discussion

3.1 Electrical Conductivity

Figure 3 shows the variation in electrical conductivity (in %IACS) with natural ageing time out to 14 days for the four model alloys of 2.3 mm, 2.5 mm, and 3 mm thickness. From the curves, it can be seen that there is a sharp decrease in the value for all the alloys after 7–8 days of natural ageing. With increasing Zn content, the electrical conductivity decreases significantly but alloys A and B showed similar conductivity values throughout the 14 days of natural ageing.

3.2 Hardness

Figure 4 shows the progressive increase in the Rockwell hardness (HRF) of the four alloys of 2.3 mm, 2.5 mm, and 3 mm thickness when it was naturally aged from 0 to 14 days. With increasing Zn content, the hardness increases significantly. Alloy D gives the highest hardness and the hardness value increased by ~23% when measured after 14 days of natural ageing compared to the as-cast condition (no natural ageing).

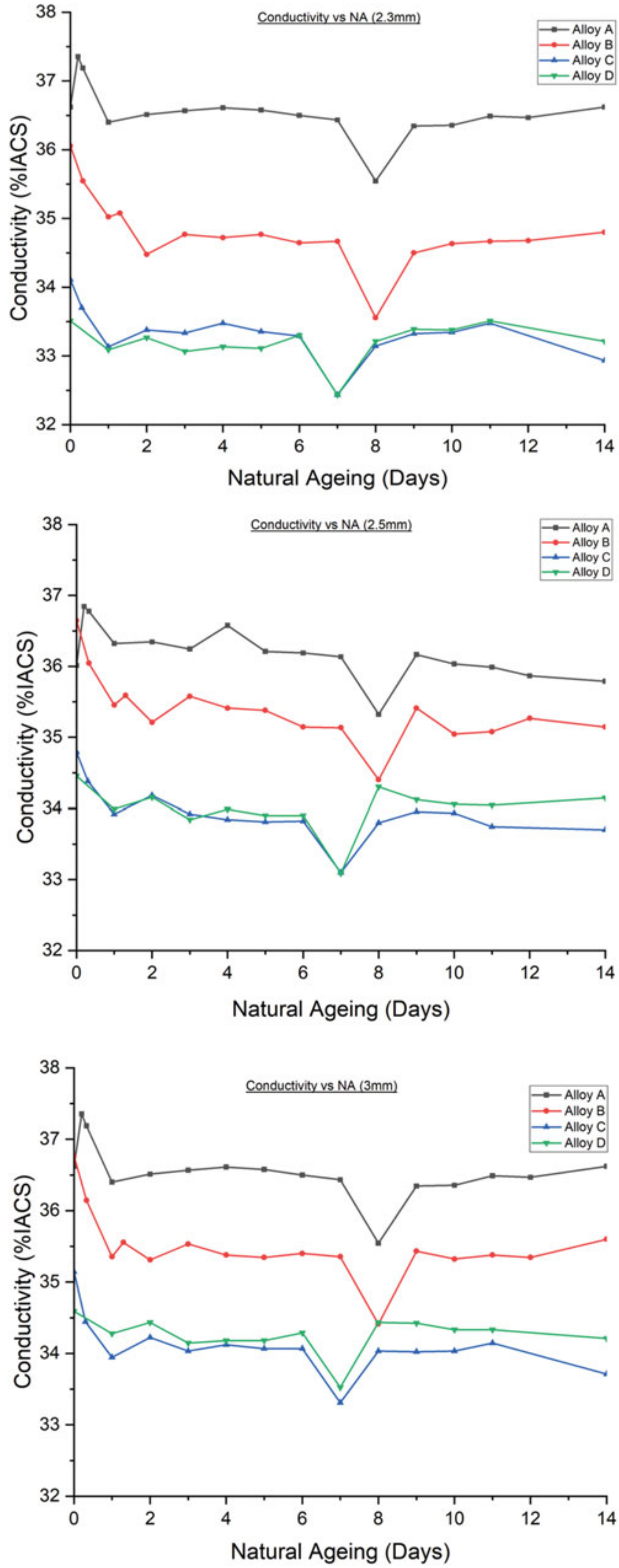

Fig. 3 Electrical conductivity of 2.3-mm-, 2.5-mm-, and 3-mm-thickness plates of four alloys as a function of natural ageing time

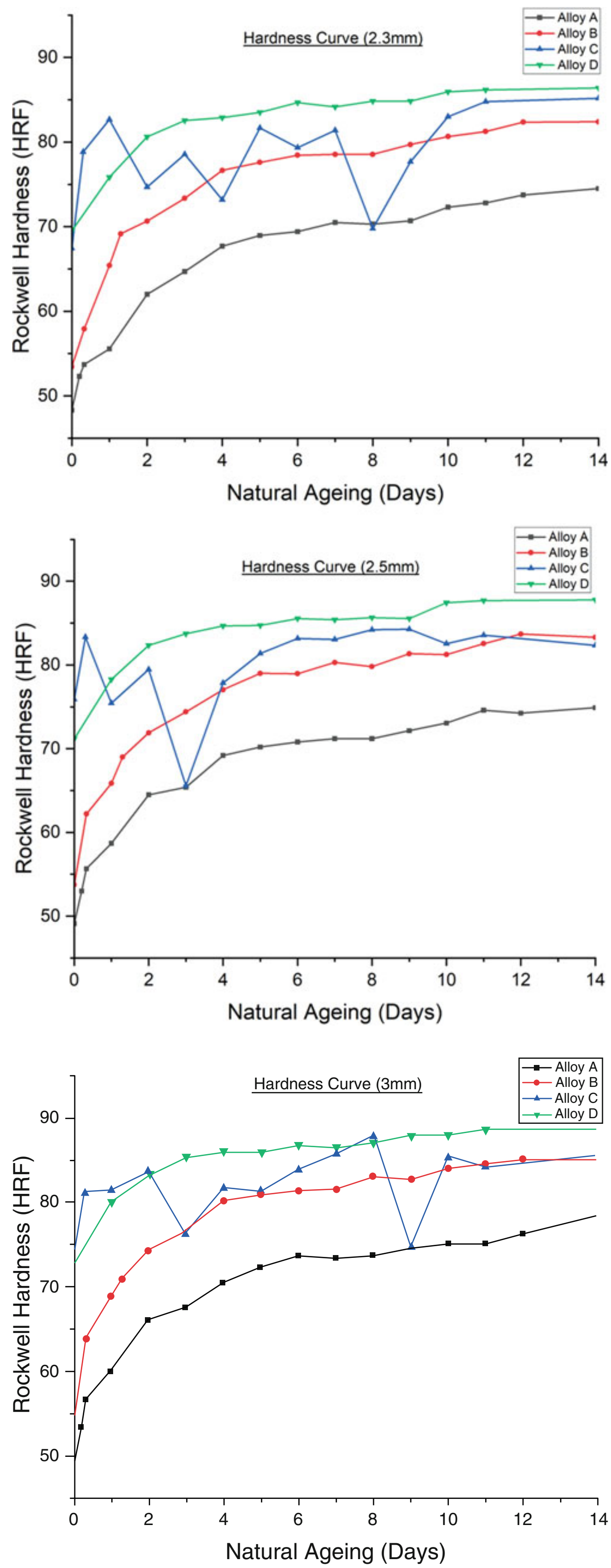

Fig. 4 Hardness plot for 2.3-mm, 2.5-mm, and 3-mm-thickness plates of four alloys

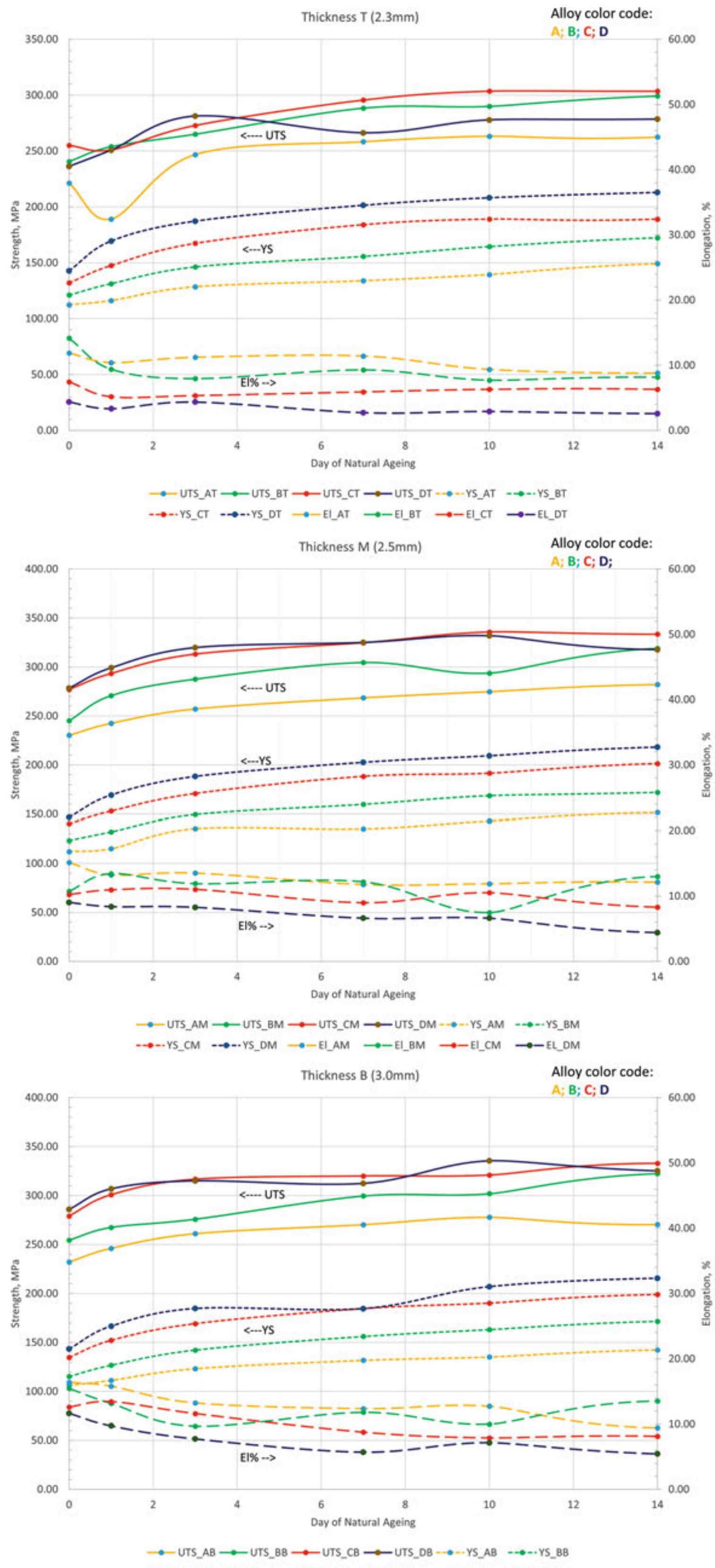

Fig. 5 Tensile properties of 2.3-mm, 2.5-mm, and 3-mm-thickness plate of four alloys as a function of natural ageing time

3.3 Tensile Properties

The four different as-cast alloy exhibit good mechanical properties in all three thicknesses (Fig. 5). As the natural ageing time increases, the elongation decreases and the strength increases for all three thicknesses. The largest averaged ultimate tensile strength (UTS) of 303 MPa, 333 MPa, 333 MPa for the 2.3 mm, 2.5 mm, and 3 mm thick plates, respectively, was acquired from alloy C after 14 days of natural ageing. But the averaged yield strength (YS) of 213 MPa, 218 MPa, 215 MPa for the 2.3-mm, 2.5-mm, and 3-mm-thick plates, respectively, was acquired from alloy D. All four alloys showed a good elongation (EL) as a function of natural ageing out to 14 days. Alloy B shows better El compared to others at the end of 14 days of natural ageing, which is 8.2%, 13%, and 13.5% for 2.3-mm, 2.5-mm, and 3-mm-thick plates, respectively. The tested samples exhibited a good consistency in the UTS, YS, and EL.

4 Conclusion

1. As Zn content increases, the electrical conductivity decreases significantly but alloys A and B showed similar conductivity values throughout the 14 days of natural ageing, and it was observed that there is a decrease in the electrical conductivity at 7–8 days of natural ageing. For the same alloy composition, conductivity values did not change much with natural ageing.

2. As Zn content increases, the hardness increases significantly. Alloy D gives the highest hardness and the hardness value increased by 23% at 14 days of natural ageing compared to the initial.
3. Alloy B showed better elongation (13.5%) compared to the other alloys at the end of 14 days of natural ageing but alloy D shows better yield strength (218 MPa). These properties meet the specifications of many automotive structural components enabling the potential use of this alloy without heat treatment.

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