Effect of heat treatment and artificial ageing on Al-5Mg-2Zn

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Abstract

Generally, permanent mould cast Al-Mg alloys are not heat treatable, but the addition of Zn in this alloy could render it heat treatable. It could be expected that in its as-cast state (F temper condition) there should be non-equilibrium intermetallic remaining at grain boundaries after casting which could be detrimental to corrosion properties of the alloy. This study investigated the effect of heat treatment and artificial ageing of Al-5Mg-2Zn. The study showed intermetallic phases at the grain boundaries and a melting peak at about 476 °C for the F condition. Solution heat treatment at 440°C for 4 hours dissolved the intermetallic phase thus increasing the melting point of the alloy. The results further showed an appreciable increase of mechanical properties after T6 heat treatment over the F-condition.

Introduction

The marine industry aim is to reduce weight without compromising on the mechanical or desirable properties of the final product. With this in consideration aluminium and its alloys (Al-Mg) has been introduced in the marine industry. This is because aluminium has good corrosion resistance and its density (2.73g/cm3 aluminium vs 7.85g/cm3 of steel) is three times lower than that of steel, this could lead to huge weight reduction [2-3]. However, Al-Mg alloys of the 5xxx series traditionally has been regarded as non-heat treatable alloys and are used in their as fabricated condition.

Al-Mg alloys achieve its strength from magnesium solution strengthening and strain hardening [1]. To achieve a slight increase in strength one mechanism could be the addition of Zn, the addition of Zn reduces the solid solubility of aluminium in magnesium, thus increasing the amount of precipitate phase [3]. The addition of Zn could render it a heat treatable alloy. During the heat treatment and quench there is a formation of vacancy concentrations. The high concentration of quench-in vacancy has an effective role in forming solute-vacancy complexes. The formed Zn and Mg vacancy comolexes are likely to combine to form Zn-Mg vacancy clusters that act as preferable sites for nucleation [3]. The strengthening mechanism of most heat treatable aluminium alloys is due to the interference with the motion of dislocation. This is achieved through the formation/ precipitation of foreign phases. The main focus of this research is to investigate the heat treatment response of the Al-Mg alloy with the addition of small amount of Zn. Table 1 shows the typical aluminium chemical composition for marine applications aluminium alloy.

Table 1: Typical chemical composition of aluminium alloy for marine application [2].

Alloy		Mg	Zn	Fe	Cu	Cr	Ti	Mn	Zr	Si
Marine Alloy (5383 Alloy) [1]	Min	4.0	-	-	-	-	-	0.7	-	-
	Max	5.2	0.4	0.25	0.20	0.25	0.15	1.0	0.2	0.25

Experimental work

Rure aluminium (Al) was melted in an induction furnace and alloyed with pure magnesium (Mg) and zinc (Zn) the alloy was then poured into a preheated steel metal to produce a casting. The cast was characterised for chemical composition using the Optical Emission Spectroscopy (OES). Differential Scanning Calorimetry (DSC) was employed to determine if there was non-equilibrium phases formed during the casting process. Hardness was measured of the as cast and the heat treated samples using the Micro-Vickers hardness machine. The alloy was heat treated in two ways: i) 440°C for 4hours and quenched, ii) 440°C for 4hours followed by 540°C for 30 minutes and quenched. All this heat treatment processes were followed by artificial ageing at 200°C

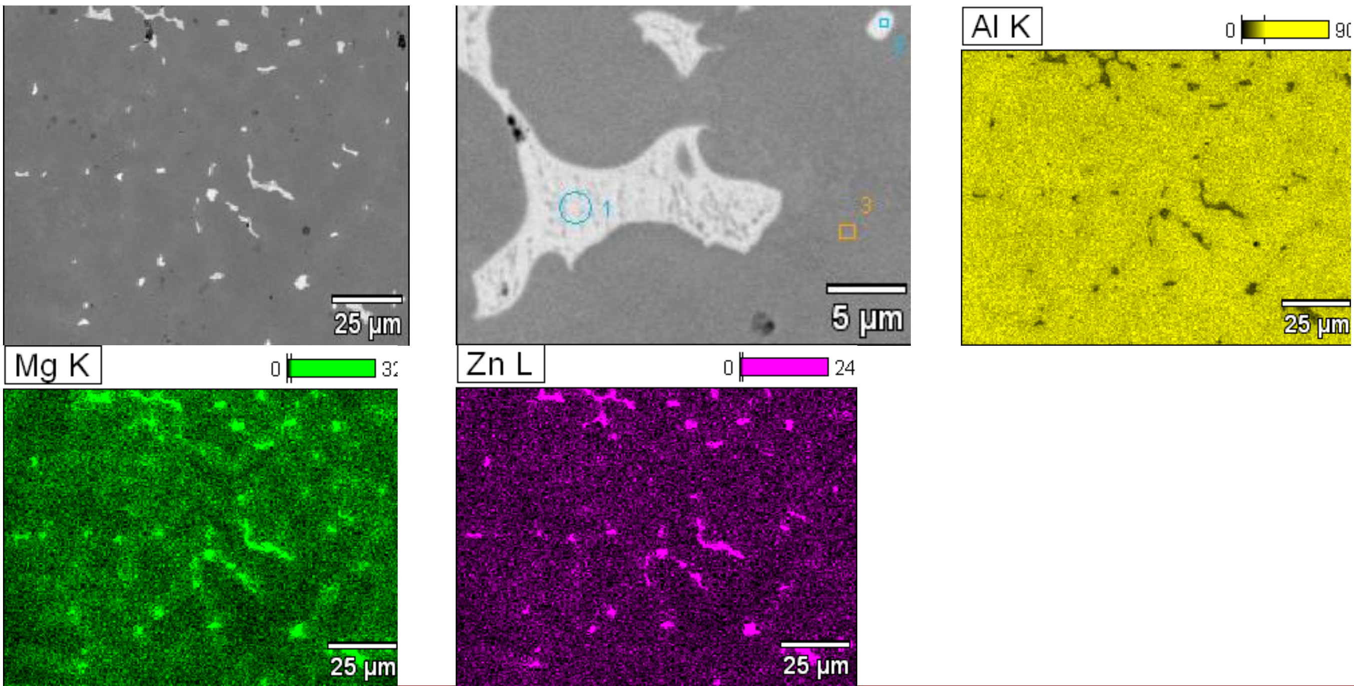
Results and Discussion

Table 2 below shows the OES results of the as cast Al-xMg-xZn alloy. As shown in Table 2, the magnesium content is within the specification of the aluminium alloys used in the marine industries as it was stated in Table 1. However the Zn content is significantly high. The hardness of the as cast was 82.1HV and after homogenisation at 440°C and 540°C the hardness was 52.1HV and 63.9HV respectively.

Table2: Chemical composition (wt %) of the Al-Mg-Zn aluminium alloys used (balance Al).

Alloy		Mg	Zn	Fe	Cu	Cr	Ti	Mn	Zr	Si
Al-Mg-Zn		5.2	2.33	0.01	0	0.001	0.004	0.004	0.003	-

Figure 1, shows the eutectic phase that is formed during the casting of the Al-Mg alloy. Point 1 and Point 2 according to EDX analysis shows that the eutectic phase contains high levels of Al, Zn, and Mg and Point 3 is the Al-matrix.



	C-K	O-K	Mg-K	Al-K	Zn-L
pt1			25.5	46.3	28.2
pt2	4.0	1.0	23.2	43.7	28.0
pt3	2.3	0.4	4.9	90.0	2.4

Figure 1: SEM micrographs at low and high magnification showing the eutectic phase.

The Differential scanning Calorimetry results are shown in Figure 2. The DSC results shows a peak at about 460°C, however after homogenisation at 440°C the peak disappeared as shown in Figure 2. This shows that the homogenisation at 440°C is adequate to dissolve the second phase and distribute them homogeneously in the matrix. The homogenised samples were artificial aged at 200°C for different time. Figure 2 shows the artificial ageing curves at different homogenisation temperature.

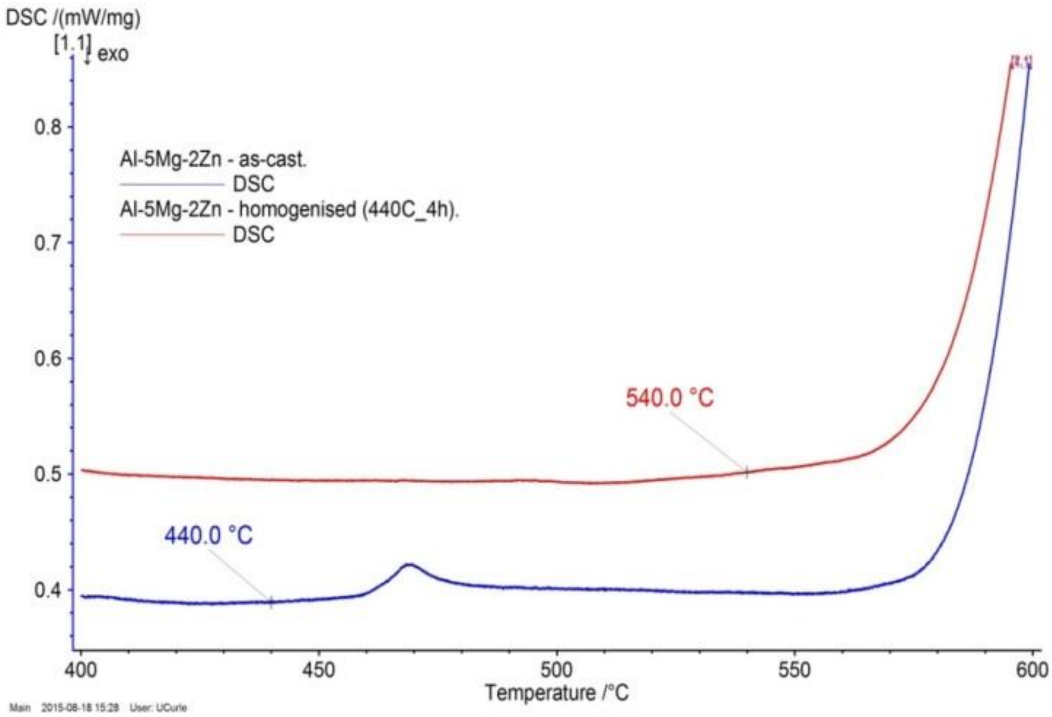


Figure 2: Differential Scanning Calorimetry results of Al-5Mg-2Zn aluminium alloys in the as-cast condition

There are two important factors to note from Figure 3: (i) homogenisation temperature and (ii) the effect of ageing time. It is seen from Figure 2 that homogenising at 540°C has superior hardness results than at 440°C until after 210 minutes. This could be possible due to quick formation of the Zn-Mg vacancy clusters that allows the quick impediment of dislocation during artificial ageing. And during the artificial ageing the τ phase was precipitated. In both homogenisation temperatures the peak hardness was attained after 180 minutes.

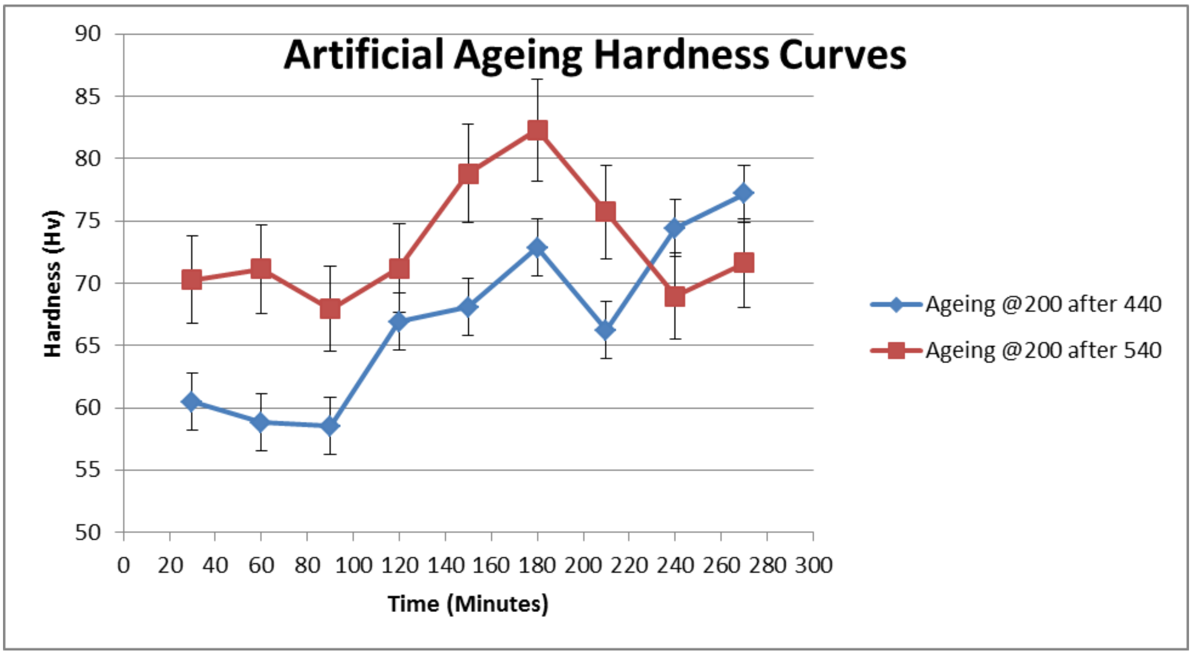


Figure 3: Artificial ageing curves of Al-5Mg-2Zn aluminium alloy.

Figure 4, the two step heat treatment ageing curve shows a rapid increase during the first 360 minutes of ageing. An increase in hardness could be the results of hindrance of dislocation by the precipitation of the second phase, this is because after quenching the material at high temperatures (440°C and 540°C) it will possible have excessive vacancy concentration. However after peak hardness the material shows hardness decreasing trend. It further shows that after peak hardness (after 360 minutes) the increase in ageing time results in the decrease in hardness, this could be due to coarsening (fine particle joining together) of the second phase that could result in less hindrance of the dislocation movement.

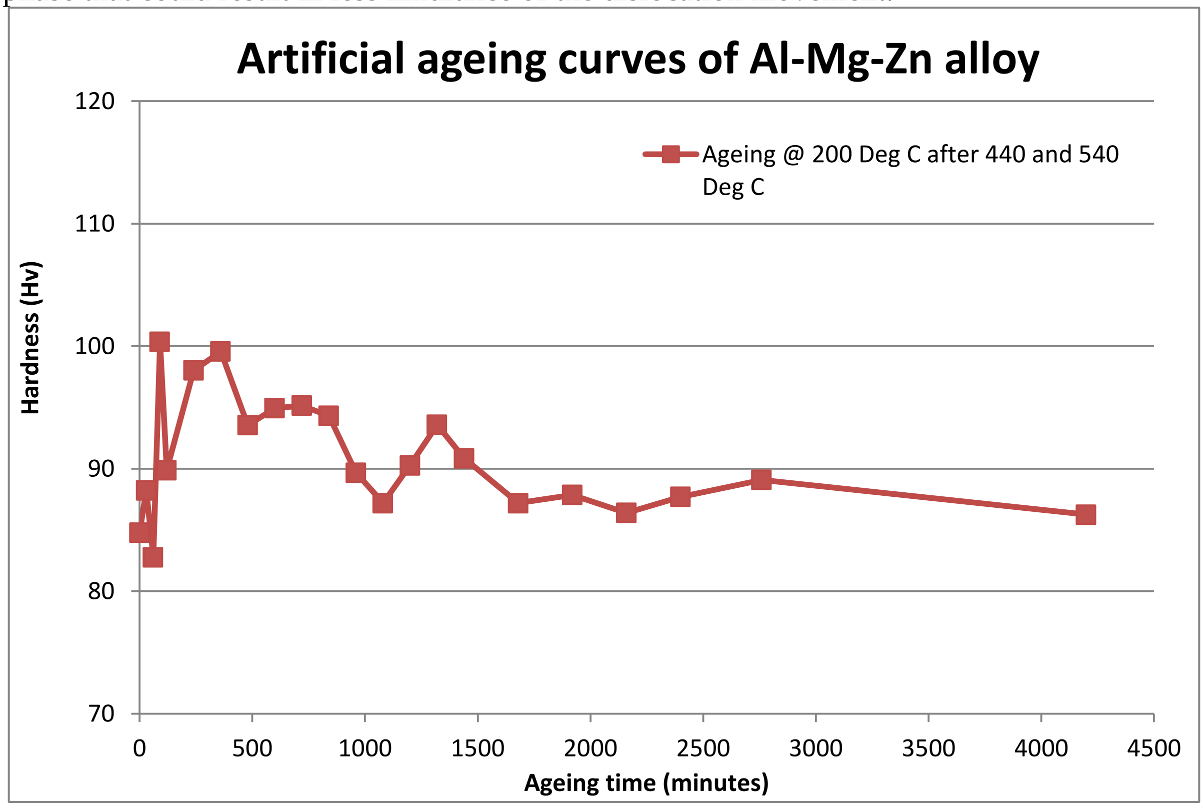


Figure 4: Artificial ageing curves at 200°C for the Al-5Mg-2Zn aluminium alloy after two step heat treatment.

Tensile properties of the Al-Mg-Zn alloy were measured and are given in Table 2. Table 2 shows the tensile properties of the Al-5Mg-2Zn as well as the typically aluminium alloy tensile property specification for marine applications. The Al-5Mg-2Zn alloy shows very low tensile properties as compared to current commercial marine aluminium alloy, It could be seen from Table 2 that there is a marginal increase in tensile properties after heat treatment as compared to the as cast except for the % elongation for the Al-5Mg-2Zn alloy.

Table 2: Tensile properties of Al-5Mg-2Zn aluminium alloy.

Sample	Temp (Deg C)	Time (hrs)	Temp (Deg C)	Time (min)	Tensile properties		
					Ys (MPa)	UTS (MPa)	% Elongation
As cast	N/A	N/A	N/A	N/A	121.74	218.14	9.74
One step	440	4	N/A	0	138.25	226.42	3.75
Two Step	440	4	540	40	139.80	245.68	6.89
Marine Alloy (5383 Alloy) [1]	Temper						
	H116/H321	-	-	-	220	305	10

*H116 Work hardened for special corrosion resistance

*H321 Work hardened then stabilised by low temperature heat treatment to quarter hard

Conclusions

The fundamental aim of this research was to investigate the heat treatment response of the Al-5Mg-2Zn. From the results obtained during the investigation, the following conclusions can be made.

- Because of the marginally increase in mechanical properties the alloy could not be said it was successfully heat treated to T6 temper condition.
- The addition of Zn could not render the alloy heat treatable.
- The heat treatment at 440°C dissolved the eutectic phase.
- The alloy showed an increase in properties after heat treatment except for % elongation that is lower than the as cast.
- Regardless of heat treatment, the alloy still shows inferior properties as compared to the typical aluminium alloy for marine application.

Though the alloy has low strength, due to its good ageing response it could be applied to areas of lower strength that need lower thermal ageing response.

References

1. Chunang Meng, Di Zhang, Ciu Hua, Linzhing Zhuang and Jishan Zhang, “Mechanical properties, intergranular corrosion behaviour and microstructure of Zn modified Al-Mg alloys”, Journal of Alloy and Compounds, 617 (2014) 925-932.
2. Endre Romhanji and Miljana Popovic, “Problems and prospects of Al-Mg alloys application in marine construction”, Association of Metallurgical Engineers of Serbia, AME, Journal of Metallurgy, Pp297-307.
3. Nasser Afify, Abdel-Fattah Gaber and Ghada Abbady, “Fine scale Precipitate in Al-Mg-Zn alloys after various Aging Temperatures”, Materials Science and Applications, Vol 2, (2011) pp427-434.