OVERAGEING CHARACTERISTICS OF ALLOY A356 AND AL-MG-SI CASTING ALLOYS

Pfarelo Daswa[1,a], Heinrich Möller[2,b] and Gonasagren Govender[1,c]

[1]Council for Scientific and Industrial Research, Pretoria 0001, South Africa

[2]Department of Materials Science and Metallurgical Engineering, University of Pretoria, Pretoria, South Africa

[a]pdaswa@csir.co.za, [b]heinrich.moller@up.ac.za, [c]sgovender@csir.co.za

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Abstract

Al-Si-Mg casting alloys, such as Al-7Si-0.3Mg alloy A356, are heat treatable and can be precipitation hardened to the T6 temper condition. However, Al-Mg-Si casting alloys (5xx series) are generally not considered to be heat treatable. These 5xx series castings are known for good castability and good resistance to corrosion, especially in marine environments. This paper investigates the extent to which 5xx series alloys could possibly be artificially aged. The influences of artificial ageing time on the overageing characteristics of both Al-Mg-Si and A356 casting alloys have been studied. A356 aluminium alloy castings were produced using the CSIR rheo-high pressure die casting process (R-HPDC). Al-Mg-Si alloys were cast using permanent mould casting. The rate of overageing of these alloys is of importance for potential higher temperature applications. The overageing characteristics of Al-Mg-Si and A356 aluminium alloys have been investigated at an artificial ageing temperature of $190^{o}C$ for ageing times up to 128 hours. It is shown that the rate of overageing of Al-Mg-Si casting alloys is lower than for alloy A356. This could possibly result in the use of these alloys in applications at temperatures that are higher than where alloy A356 can be employed. It also allows the possibility of using the 5xx series alloys as an alternative to other Al-alloys for R-HPDC applications.

Introduction

The 3xx series A356 casting alloys are popular alloys used for semi-solid metal forming due to good castability and fluidity imparted by the large volumes of the Al-Si eutectics [1, 2]. They are hypoeutectic materials that have Si and Mg as major alloying elements. They are known for their light weight and good corrosion resistance which makes them attractive to the automotive and aerospace industries [2, 3]. A356 alloys can also achieve properties such as good mechanical strength, ductility, fatigue, pressure tightness and machinability [3]. These alloys are mostly considered as being heat treatable since they have an adequate enough solubility of Mg and Si in (Al) in order to produce an age hardening effect through the precipitation of β”. However, Al-Mg-Si casting alloys are considered as being non-heat treatable since they have a low solubility of Si in (Al) [4]. This low solubility of Si results in few secondary precipitates that can be formed and most of the Si is bound in eutectic Mg_2Si particles [5]. The T6 peak hardness of alloy A356 is therefore significantly higher than what can be achieved in Al-Mg-Si alloys [2]. Al-Mg-Si alloys are also known for good corrosion resistance, good machinability, attractive appearance when anodised and are used in seawater and marine atmospheres, architectural and other decorative or building needs [3]. Their casting characteristics are less favourable than Al-Si alloys and as a group they require special care with gating and large risers and greater chilling are needed to produce good castings.

Most of these alloys are sand cast although some compositions with 7-8% Mg have limited applications for pressure die castings and permanent mould castings [3]. The purpose of this study was to investigate the overageing characteristics of alloy A356 and Al-Mg-Si aluminium casting alloys to determine whether there could be advantages for using 5xx series alloys with R-HPDC.

Experimental Procedure

In this present study the following casting aluminium alloys were investigated (Table 1):

Table 1: Chemical composition (wt%) of casting aluminium alloys used (balance Al).

Alloy	Mg	Si	Fe	Cu	Cr	Ti	Mn	Zr	Sr (ppm)
Al-3Mg-0.2Si	2.63	0.20	0.01	0.002	0.001	0.005	0.002	0.002	1.2
Al-5Mg-0.8Si	5.53	0.80	0.01	0.002	0.001	0.002	0.004	0.003	1.4
A356	0.36	7.14	0.10	0.01	0	0.07	0.01	0	200

Optical Emission Spectroscopy (OES) was used to determine the chemical compositions of the alloys shown in Table 1. A356 plate castings were manufactured using the CSIR rheo high pressure die casting process (CSIR-RHPDC) [6]. The alloy is melted in a tilting furnace and degassed with argon. The liquid is poured from the tilting furnace to a stainless steel processing cup, which is then transferred manually to a single coil for induction stirring and simultaneous forced air cooling. Once the desired semi-solid temperature is attained, the cup is ejected from the coil and manually transferred to a 130t LK HPDC machine for R-HPDC. The Al-Mg-Si alloys were processed using permanent mould casting. The alloys were melted in a tilting furnace at 680^{o}C and then poured manually into a quench sample mould which was at room temperature. Metallographic examination was also performed on the alloys using an optical microscope in order to investigate the difference between the permanent mould cast Al-Mg-Si alloys and R-HPDC A356 aluminium alloy. During the preparation of the samples for metallographic examination, the samples were polished using standard metallographic techniques. A356 aluminium alloy was solution heat treated at 540^{o}C for 1 hour based on the optimum T6 heat treatment of the alloy [7]. However, Al-Mg-Si alloys were solution heat treated at temperatures of 580^{o}C for 4 hours based on Differential Scanning Calorimetry (DSC). Al-Mg-Si casting alloys were used in order to compare its age-hardenability with that of A356 aluminium alloys. Immediately after the solution heat treatments and water quenching, some of the samples were kept at room temperature to naturally age for 4 days before artificial ageing and the rest of samples were immediately artificially aged at 190^{o}C for varying times of 0-128 hours. The artificial ageing curves of these alloys are presented in the paper. Hardness tests were performed using a macro Vickers Hardness tester FV-700 under a load of 5kg.

Results and Discussion

Figure 1 shows an optical micrograph of a typical as-cast (F-temper) A356 aluminium alloy microstructure after R-HPDC. The microstructure consists of globular primary α-Al and a fine eutectic with fibrous silicon particles [2].

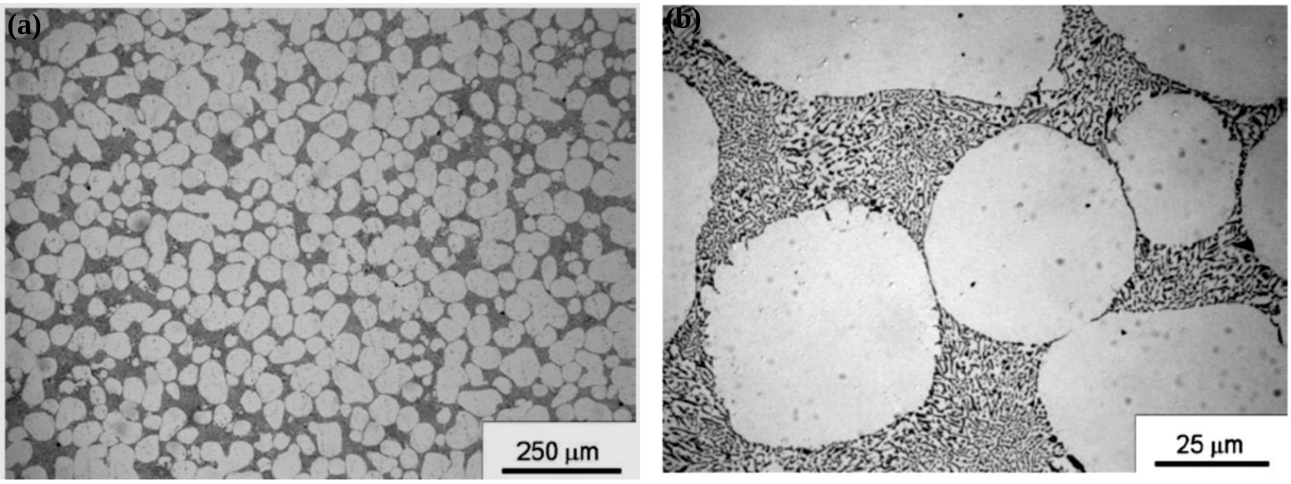

Figure 1: A356 aluminium alloy in the as-cast condition (a) lower magnification and (b) higher magnification [2].

Figure 2 shows the optical micrographs of Al-Mg-Si aluminium alloys in the as-cast condition. In Figure 2, relatively fast cooling of the Al-Mg-Si alloys resulted in microstructures with fine eutectics. The eutectics in the microstructures contain Mg_2Si and a low volume fraction of iron intermetallics.

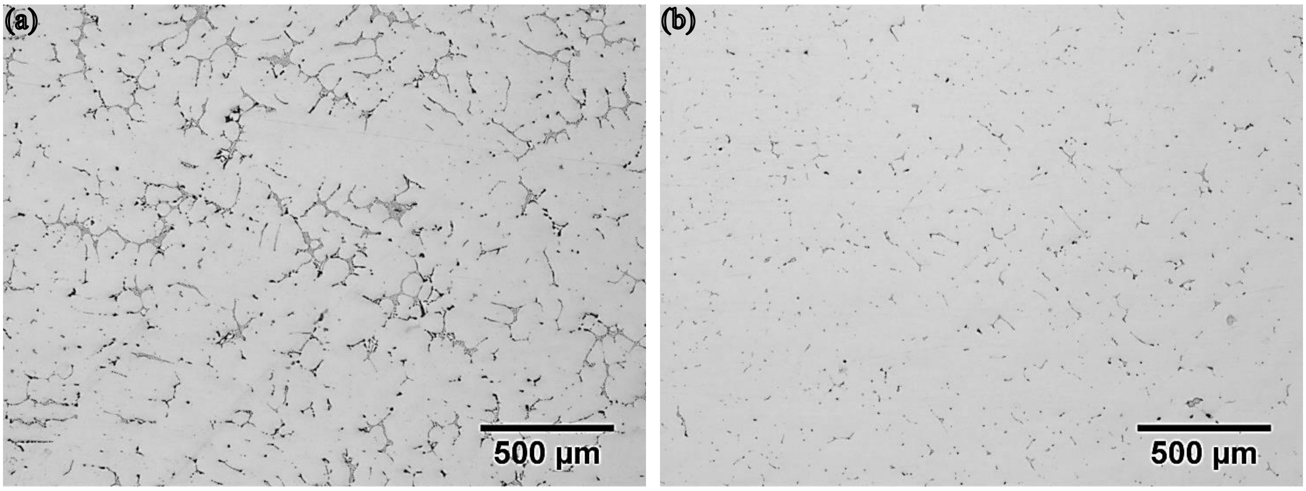

Figure 2: (a) Al-5Mg-Si and (b) Al-3Mg-Si aluminium alloy in the as-cast condition.

A356 aluminium alloy was solution heat treated at 540°C for 1 hour. After solution heat treatment and quenching, the alloys were artificially aged at 190^{o}C with and without natural pre-ageing. Al-Mg-Si alloys were also used in order to investigate the comparison in ageing response between the casting A356 and Al-Mg-Si alloys. It should be noted that it has been shown before that dendritic and globular Al-Si-Mg alloys have the same artificial ageing response [8].

Figure 3 shows the ageing curves after artificial ageing at 190°C without any natural pre-ageing. A356 aluminium alloy attains its peak hardness of 116 HV after 2 hours of artificial ageing at 190°C and overageing (softening) commences after 2 hours. However, Al-5Mg-Si alloy attains its peak hardness of 87 HV after 8 hours of artificial ageing and Al-3Mg-Si aluminium alloys attain its peak hardness of 80 HV after 16 hours of artificial ageing at the same temperature. It is also worth noting that Al-Mg-Si alloys overage after longer times of approximately ~64 hours of artificial ageing at 190^{o}C whereas aluminium alloy A356 (Figure 2) overages quicker. This is in agreement with Kores et al [9], who also did a study on Al-3Mg1Si-(Sc, Zr) and Al-Si-(Mg)-Cu alloys, where these alloys were T6 heat treated at 250^{o}C for up to 100 hours. They have shown that Al-Mg-Si alloys had higher yield strength and ductility than Al-Si-(Mg)-Cu alloys after pre-ageing for 100 hours at 250^{o}C. The slower overageing characteristics gives these Al-Mg-Si alloys new possible applications in high temperature application as it retains its strength at high temperatures better than other Al-casting alloys [9].

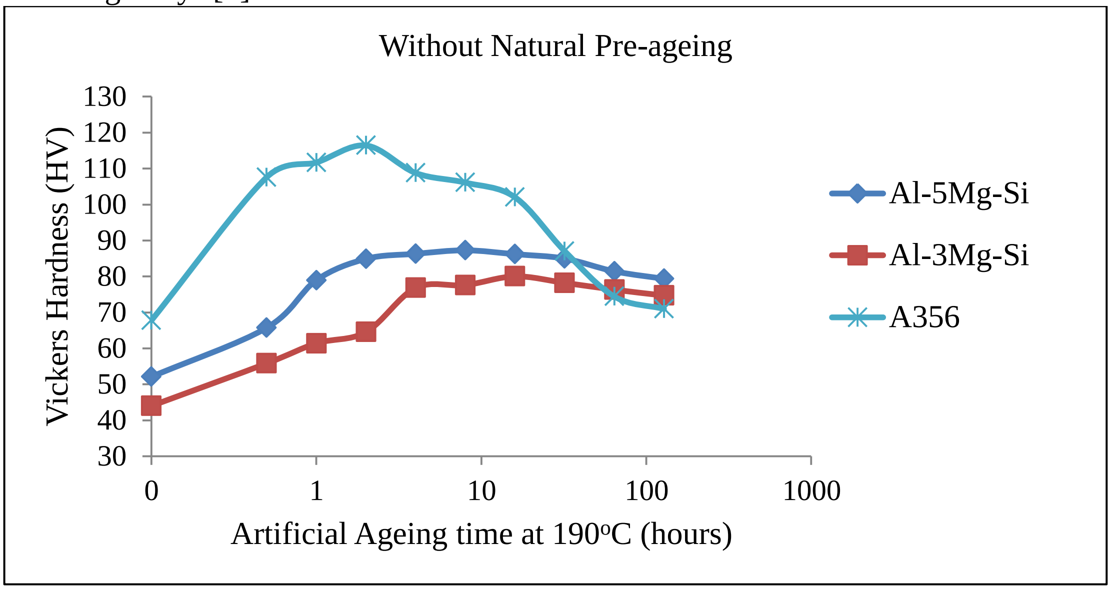

Figure 3: Artificial ageing hardness curves of Al-Mg-Si aluminium alloys without natural pre-ageing.

Figure 4 shows the artificial ageing curves after 4 days of natural pre-ageing. A356, Al-5Mg-Si and Al-3Mg-Si aluminium alloys did not show any significant difference in peak hardness with and without natural pre-ageing. From literature [4, 9], it was suggested that age-hardenable Al-Mg-Si casting alloys should have a minimum Mg-content of 2.5% and a maximum of about 5%. This would still give a lower solid solubility of Si in (Al) than in A356 Al-Si casting alloy. The lower response to age hardening is therefore expected for the Al-Mg-Si casting alloys. In addition, levels of excess Si above that required to form stoichiometric equilibrium β-Mg_2Si are known to result in increased strength in 3xx (A356) and 6xxx series alloys [2]. The lack of excess Si in the Al-Mg-Si casting alloys also contributes to a lower age hardening response as compared to the A356 aluminium alloys. It is believed that excess Si causes a higher volume fraction of strengthening precipitates, as well as a finer particle size from the higher driving force for nucleation giving higher strength [10]. A moderate increase in strength in Al-Mg-Si casting alloys could still be useful in certain applications and the good high temperature strength of these alloys is also of interest [9].

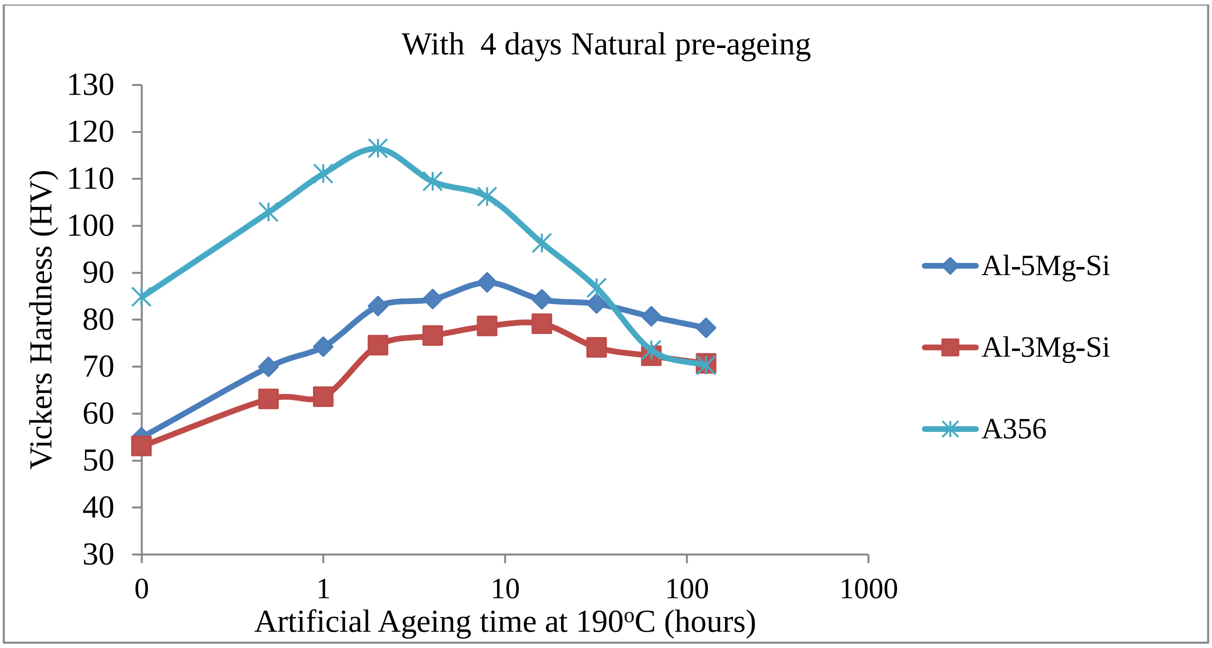

Figure 4: Artificial ageing hardness curves of Al-Mg-Si aluminium alloys with natural pre-ageing.

In Figure 4, it should also be noted that the A356 aluminium alloy shows a higher hardness value than Al-Mg-Si alloys after 4 days of natural pre-ageing (at time = 0h in Figure 4). Natural ageing is due to the formation of Si-rich clusters in Al-Mg-Si alloys [10]. A356 has excess Si, so it is expected to have more Si-rich clusters and this will result in higher hardness values as compared to Al-Mg-Si alloys in the T4 condition [10]. The increase in hardness during 4 days of natural ageing after quenching is from 68 HV to 85 HV for alloy A356, whereas it is only from 44 HV to 53 HV and 52 HV to 55 HV for alloys Al-3Mg-Si and Al-5Mg-Si respectively (Figures 3 and 4).

A356 aluminium alloy had the highest T4 and T6 peak hardness of the three alloys. However, Al-Mg-Si alloys had slightly higher hardness values than A356 after 128 hours of artificial ageing at 190°C (T7). This is in agreement with Kores et al [9], who did a study on aluminium alloys for cylinder heads that were T6 heat treated at 250°C. They have shown that Al-3Mg1Si-(Sc, Zr) alloy had the best compromise of strength even after artificial ageing at 250°C for 100 hours. This strength compromise could serve as an advantage to Al-Mg-Si alloys for higher temperature application in the production of components such as aluminium cylinder heads for instance [9].

Conclusions

Even though Al-Mg-Si casting alloys are considered non-heat treatable, they still show a positive heat treatment response such that an increase in strength is noted in the T6 condition. A356 aluminium alloy has higher T4 and T6 strength as compared to Al-Mg-Si alloys. However, A356 alloy overages quickly as compared to Al-Mg-Si alloys. Therefore, Al-Mg-Si alloys can be used at higher temperatures for longer time periods with lower loss in strength as compared to A356. This opens up the possibility of using another casting series of Al-alloys (5xx), in addition to the well-studied 3xx and 2xx series alloys, specifically for R-HPDC. The castability of these 5xx (Al-Mg-Si) series aluminium alloy using rheo-high pressure die casting will be investigated in future work.

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