

Industrial heat treatment of R-HPDC A356 automotive brake callipers

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Abstract:

Heat treatment of rheo-high pressure die cast (R-HPDC) A356 brake callipers has produced good mechanical properties on the laboratory scale. An industrial heat treatment is required to evaluate the applicability and conformance of the R-HPDC A356 brake callipers to the automotive industry. This research studied A356 brake callipers heat treated on the industrial scale with particular emphasis on the resulting microstructure, hardness and tensile properties. The eutectic Si-particle spheroidisation after solution heat treatment was achieved and observed with optical microscopy. A hardness increase from 64 to 100 Vickers was achieved from the as-cast condition to the industrially heat treated T6 condition. The heat treatment caused no significant variation in hardness and tensile properties from brake callipers within the same batch or from different batches. The yield and ultimate strengths of the industrial heat treated brake callipers were lower compared to the laboratory scale heat treatment properties, while the ductility increased, mainly due to quenching effects. Even though the industrial heat treated A356 brake callipers resulted in yield and ultimate tensile strengths lower than those achieved on a laboratory scale, they still exceeded the minimum specifications for gravity die cast A356 brake callipers.

Keywords: Heat treatment, automotive, brake calliper, alloy A356, rheocasting

1. Introduction

In recent years, efforts to improve fuel efficiency in the automotive industry have triggered the use of mass production capable, low cost, aluminium castings as part of weight reduction strategies [1]. High volume automotive parts are extensively produced using the high pressure casting (HPDC) methods [1]. However, due to turbulent die filling the HPDC process has problems of oxide entrapment, porosity and blistering during heat treatment [1,2].

Semi-Solid Metal (SSM) processes can be used to fulfil the needs of the automotive industry. During the SSM process, the alloy is stirred in the liquid-solid region during solidification, thus forming a globular structure rather than a dendritic structure [3]. Thixocasting and rheocasting are the two different SSM processes. Thixocasting involves the reheating of solid material with a globular microstructure into the semi-solid range, while rheocasting involves preparation of SSM slurry directly from the liquid followed by a forming process such as high pressure die casting (HPDC) [4]. The SSM material has a laminar flow during the die filling, hence it can overcome the problems of oxide and gas entrapment and lowers the shrinkage problems during solidification [5].

The SSM-high pressure die casting parts (such as A356 brake callipers) have found possible application in the automotive industry [2]. The heat treatment of SSM-processed alloy A356 has been studied in great detail before [2,5]. In these studies, small laboratory furnaces were used to investigate the heat treatment response of the alloy. The aim of this study is to characterise the industrial heat treatment of A356 automotive brake callipers and compare the results with those obtained from the laboratory scale heat treatment cycles.

2. Experimental

The details of the R-HPDC automotive brake callipers can be found in a paper by Curle et al [6]. In brief, batches of automotive brake callipers were cast on five different days. The chemical

composition of these brake callipers is 7.14wt% Si, 0.36wt% Mg, 0.14wt% Fe, 0.13wt% Ti, and 105ppm Sr with the balance of Al.

The brake callipers from different batches were taken to a local heat treater for industrial heat treatment. Industrial size electrical furnaces were used for both solution heat treatment and age hardening. The furnace capacities are 0.25m³, 610mm width, 914mm length and 457mm height for both solution heat treatment and age hardening furnaces. The two furnaces have a maximum temperature limit of 750°C and have temperature uniformity within 5°C with air circulation. All the programmes are computer controlled. The water quench tank employed has a size of approximately 2500 litres. The water is electrically heated and the maximum temperature limit for the water in the water tank is 90°C. The water is circulated by stirring for temperature uniformity. The furnace was fired to the solution treatment temperature of 540°C before loading the brake callipers. The solution heat treatment was done at 540°C for 1 hour, based on previous studies [2,5]. A total of 88 brake callipers were heat treated simultaneously. After the heat treatment, the brake callipers were transferred to the quenching tank. The transfer took approximately 20s. The quenching water temperature used was 70°C. The heat treated brake callipers were stored for 24 hours at room temperature (natural ageing) before artificial ageing. Artificial ageing was performed at 180°C for 4 hours based on previous studies [2,5]. Vickers-hardness measurements (VHN) were performed on selected heat treated brake callipers using a 10 kg load. Tensile specimens were taken from the positions shown in Figure 1. Figure 1 shows the non-heat treated (as-cast) and the industrially heat treated brake callipers.

For the purpose of this study three different batches (A, B, C) were selected and three brake callipers from each batch were used for tensile testing. Two tensile specimens were machined from each brake calliper, giving a total of 6 tensile specimens from each batch. Tensile specimen dimensions can be found in the paper by Möller et al [2].

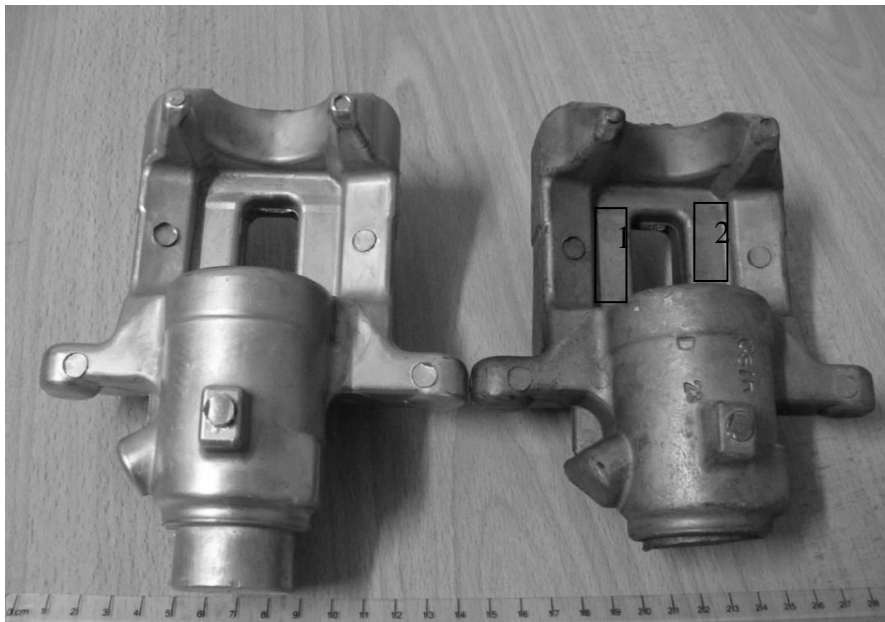


Figure 1: The rheocast A356 brake callipers in the as cast condition (left) and after industrial T6 heat treatment (right) showing the tensile specimen positions (1 and 2).

3. Results and Discussion

Figure 3 shows typical optical micrographs of the A356 in the as-cast condition as well as the microstructural changes due to the influence of the solution heat treatment.

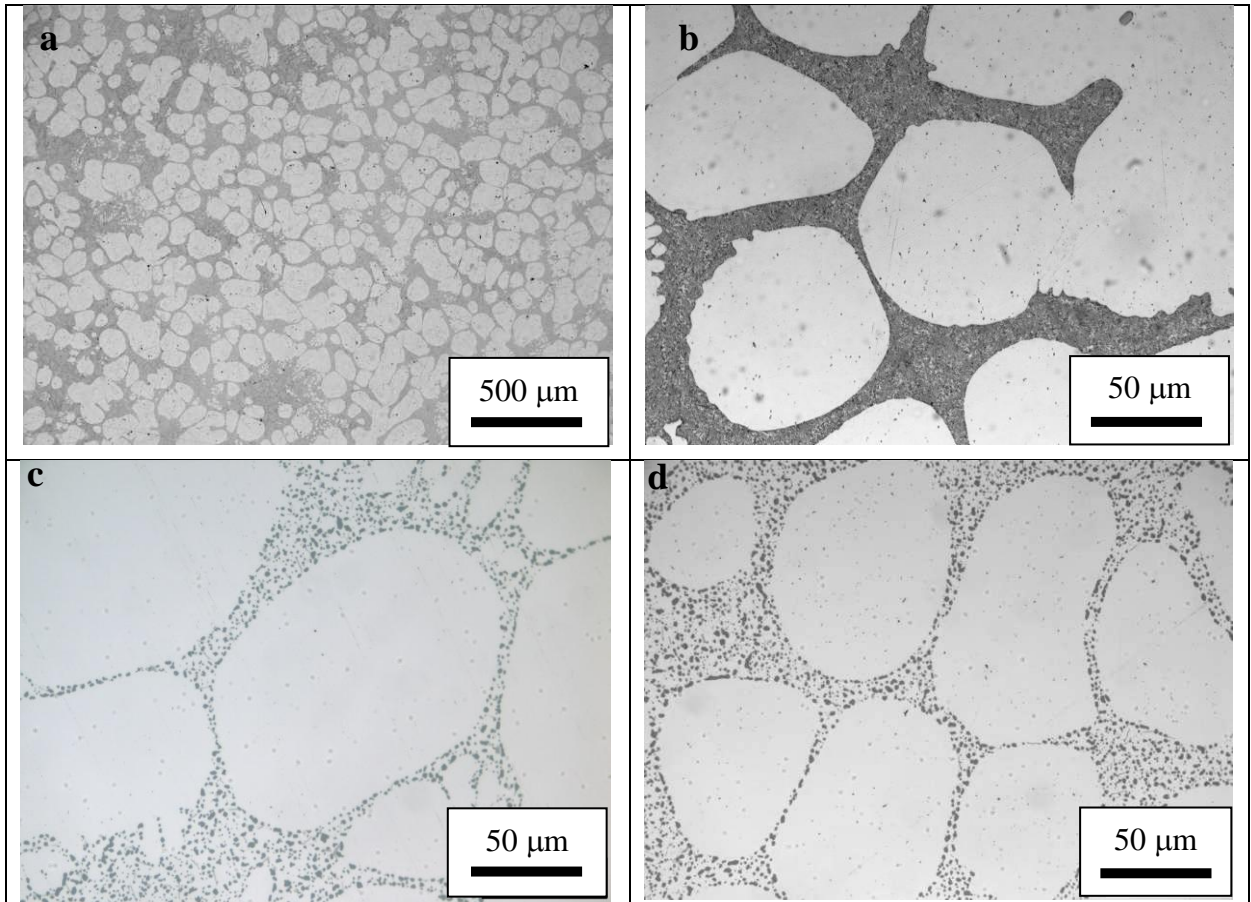


Figure 2: Optical micrographs of rheo-high pressure die cast A356 brake callipers (a) in the as-cast condition showing globular primary α -Al surrounded by eutectic, (b) higher magnification image showing fibrous Si in the eutectic in the as-cast condition, (c) higher magnification image after laboratory T6 heat treatment and (d) higher magnification image after industrial T6 heat treatment.

Globular primary α -Al with fibrous Si in the eutectic in the as-cast condition can be observed in Figures 2 (a) and (b). Figures 2 (c) and (d) show that spheroidising of the eutectic Si-particles occurred during the solution heat treatment. It is observed from Figures 2 (c) and (d) that there are no significant differences in microstructure of the sample heat treated in the laboratory and industrially in terms of spheroidised eutectic Si-particles in particular. It has been shown before [5] that spheroidising of the eutectic Si occurs within minutes at 540°C. The other main purpose of the solution treatment i.e. the dissolution of Mg_2Si and homogenisation also occurs rapidly in alloy A356. According to Taylor et al [7], the Mg_2Si dissolves within 5 minutes for alloy A356 during solution treatment at 540°C. Homogenisation of the concentration profiles also occurs rapidly – approximately 8-15 minutes for alloy A356 [7].

The average hardness value for the as-cast brake callipers is 64 VHN₁₀. The hardness values of the industrially T6 heat treated brake callipers from the different batches are shown in Table 1. It is seen that there are insignificant differences in T6 hardness between the different batches.

Table 1: Average Vickers-hardness of industrially T6 heat treated A356 brake callipers (standard deviation of 5 values is shown in brackets for each batch)

Brake calliper batch	VHN ₁₀
A	101 (1.3)
B	100 (2.2)
C	100 (1.5)
Average of the 3 batches	100 (1.7)

The tensile properties of the industrially heat treated brake callipers are shown in Table 2. It is seen that the variations in properties are small within the brake callipers from the same batch, as well as with brake callipers from different batches. High ductility of approximately 10% elongation is achieved with brake callipers from all batches. This is due to a large extent on the spheroidisation of the eutectic Si-particles that occurred during the solution treatment (Figure 2(d)) [10]. The minimum tensile properties specifications required by a local gravity die casting (GDC) supplier of A356 automotive brake callipers are all exceeded (Table 2), especially the ductility.

Table 2: Tensile properties of industrially T6 heat treated A356 brake callipers (standard deviations in brackets) in comparison with laboratory heat treated brake callipers.

Batch	0.2% YS (MPa)	UTS (MPa)	% Elongation
A	223 (5.4)	287 (1.3)	10.9 (1.2)
B	226 (1.9)	292 (4.7)	11.9 (2.8)
C	233 (2.2)	297 (2.4)	9.7 (0.7)
All batches combined	227 (5.5)	292 (5.1)	10.8 (1.9)
Minimum Specs (GDC brake callipers)	215	260	3.0
Laboratory heat treated brake callipers [2]	261	317	6.7

The tensile properties of industrially and laboratory heat treated brake callipers are also compared in Table 2. Higher strength values and lower ductility were achieved with the laboratory heat treatment. This is mainly due to the lower water quench temperature (25°C) used with the laboratory heat treatments [2].

In a previous study [5], R-HPDC A356 plates with 0.40wt % Mg were also quenched in 70°C water and the following tensile properties were obtained after laboratory solution treatment at 540°C for 1 h and artificial ageing at 180°C for 4 h: 0.2% YS = 265 MPa, UTS = 327 MPa and % Elongation = 8.6. Comparing these properties with those achieved for the industrial heat treatment in Table 2, it can be seen that the industrial heat treatment again resulted in lower strength values and higher ductility. With the industrial heat treatment, a transfer time of 20s elapsed between the solution treatment furnace and the quench tank. This was significantly longer than with the laboratory heat treatments. It has been shown before [8,9,11] that the A356/7 casting alloys are relatively quench sensitive and the long transfer time during the industrial heat treatment most likely resulted in the lower strengths achieved in T6 than with the laboratory heat treatments. Microstructural analysis using transmission electron microscopy (TEM) by Zhang and Zheng [8] revealed β' -quench precipitates in slowly cooled A356 specimens. The high quench sensitivity of Al-7Si-Mg casting alloys has been attributed to the presence of Si particles in the microstructure [8,9]. It is believed that Si in solid solution diffuses to these particles and that the Si-particles serve as heterogeneous nucleation sites for β -Mg₂Si. In this study, optical microscopy (Fig. 2(d)) did not reveal β' nor β -Mg₂Si precipitates.

The 0.2% yield strength and Vickers hardness values of the industrially heat treated A356 brake callipers are compared with previous results for A356/7 in Figure 3 [12]. The data point for the industrially heat treated brake callipers fits well within the data points previously obtained.

The predicted YS in Fig. 3 (b) was calculated using an equation proposed in a previous study [12], namely

$$YS = 3.03 \times VHN \times [0.055]^n \quad (\text{Eq. 1})$$

Where n is the strain hardening exponent = 0.091 in this case. This was estimated by assuming that the strain hardening exponent is constant over the plastic strain range up to the point of necking

during tensile testing of these alloys. An expression for the ratio of YS to UTS in terms of n alone may be found (eq. 2).

$$YS_{0.2\%}/UTS \approx \{(0.002)^n (\exp n)\} / (n)^n \quad \text{(Eq. 2)}$$

This Equation is derived from the Hollomon equation ($\sigma = K\varepsilon^n$), as well as from the conversion equations for engineering strain (e) to true strain ($\varepsilon = \ln(e+1)$), engineering stress (s) to true stress ($\sigma = s(e+1)$) and the equivalence of true strain at necking = n. [12]

Note that the n value in this case (0.091) is slightly higher than achieved with immediate cold water quenching (0.072) [8]. This is most likely due to quench precipitates that most likely formed during the delayed warm water quench. For example, the n-value for A356-T5 is even higher at 0.125 [12]. The predicted YS using eq. 1 for the industrially heat treated brake callipers is in good agreement with the measured value (Fig. 3(b)).

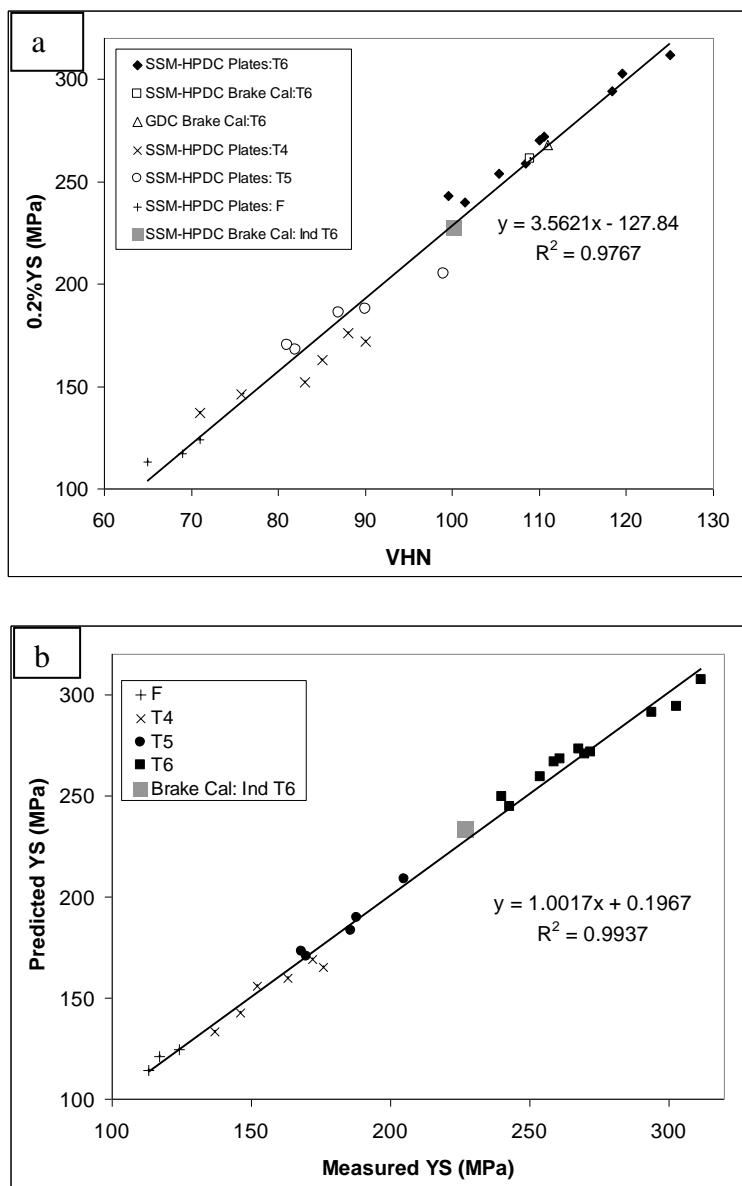


Figure 3: (a) Correlation between the VHN and YS in different heat treatment conditions (b) Correlation between the measured and predicted YS (MPa) values

4. Conclusions

The following conclusions were reached in this study:

- There is no significant difference (variation) in properties of the brake callipers produced on the same day (same batch).
- There is no significant difference (variation) in properties of the brake callipers produced on different days (different batches).
- The yield strength and ultimate tensile strength of the industrially heat treated brake callipers are lower than for the laboratory heat treated brake callipers. This is most likely due to the difference in quenching procedures used.
- The tensile properties of the industrially heat treated brake callipers exceed the minimum specifications of GDC A356 brake callipers.

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