THE T5 HEAT TREATMENT OF SEMI-SOLID METAL PROCESSED ALUMINIUM ALLOY F357

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Abstract

The T5 heat treatment of semi-solid metal (SSM) processed alloy F357 was investigated by considering the effects of cooling rate and natural aging after casting, as well as artificial aging parameters on tensile properties. In addition, the tensile properties of SSM-HPDC F357 in different temper conditions (F, T4, T5 and T6) are compared. The Quality Index (QI) is used to compare the influence of different T5 heat treatment parameters and different temper conditions.

Introduction

Semi-solid metal (SSM) processing is an effective near-net-shape manufacturing method in which the metal is formed in the semi-solid state [1]. The conventional casting alloys A356 and F357 are probably the most popular alloys used for semi-solid metal forming. This is due to their high fluidity and good “castability” [2]. The chemical composition limits of alloy F357 (the Be-free variant of A357) are shown in Table 1 [3]. Alloy A357 is gradually being phased out in many applications due to the carcinogenic effects of beryllium, particularly at higher concentrations used during make-up of the alloy. In Al-Si-Mg alloys containing an excess of silicon, the decomposition of the supersaturated solid solution (SSS) is believed to occur as follows [2]:

$$SSS \rightarrow (Mg + Si)_{clusters} / GP(I)_{spherical} \rightarrow \beta'' / GP\ (II)_{needles} \rightarrow \beta'_{rods} + Si + others \rightarrow \beta_{plates} + Si$$

where GP = Guinier-Preston zones, β = equilibrium Mg_2Si, β' and β'' = metastable precursors of β.

The natural aging response of these alloys is considered to be due to (Mg+Si) clusters and GP zones. The precipitation hardening which results from natural aging alone produces the useful T4 temper. Peak hardening with artificial aging results from the precipitation of the metastable and coherent β' and β''.

Alloy F357 can be heat treated alternatively to the T4, T5 and T6 temper conditions. The T5 temper is achieved by artificially aging the as-cast material without a solution treatment (as opposed to the T4 and T6 temper conditions where a solution heat treatment is used). The advantages of not using a solution treatment include significant energy savings and less distortion of the components. However, spheroidisation of the silicon particles [2] is not achieved in A356-T5 with deleterious effects on ductility and lower strength obtained in A356-T5 if compared to A356-T6 due to less supersaturation of strengthening solutes before artificial aging. The aim of this paper is to characterise the influence of different variables on the T5 properties of semi-solid metal high pressure die cast (SSM-HPDC) alloy F357. In addition, the T5 properties are compared with the F (as-cast), T4 and T6 properties of the alloy.

Experimental

Semi-solid metal slurries of alloy F357 (chemical composition given in Table 1) were prepared using the CSIR rheocasting process [1]. Plates (4 mm × 80 mm × 100 mm) were cast in steel moulds with a 50 ton high pressure die casting machine. For the T4 and T6 temper conditions, the material was solution treated at 540°C for 1 h, before quenching in water at 25°C [4,5]. To study the T4 temper, the material was allowed to age at room temperature (25°C) for at least 120 hours [2,5]. For the T6 temper, the samples were firstly naturally aged (NA) for 20 h before artificial aging (AA) at 180°C for 4 hours [2,4,5]. Table 2 shows details of the variables that were used to test the SSM-HPDC F357 in the as-cast (F temper) and T5 temper conditions. The tensile properties of the differently heat treated samples were determined using sub-standard size specimens that were machined from the plates [2,5]. A total of 12 tensile samples/heat treatment condition were used.

Table 1. Chemical composition limits (wt%) of alloy F357 [3] as well as the composition of the alloy used in this study.

Alloy		Si	Mg	Fe	Cu	Mn	Zn	Ti	Be	Other
F357	Min	6.5	0.40	-	-	-	-	0.10	-	-
	Max	7.5	0.70	0.20	0.20	0.10	0.10	0.20	-	0.05
This study		7.1	0.63	0.09	0.01	0.01	0.01	0.14	-	0.02Sr

Results and discussion

The tensile properties of the SSM-HPDC alloy F357 in different temper conditions are shown in Table 2.

Table 2. Yield strength (YS), ultimate tensile strength (UTS) and % elongation (%A) of SSM-HPDC F357. The standard deviation from 12 values for tensile properties is also indicated in brackets.

Quench after SSM-HPDC	Natural Aging (NA)	Artificial aging (AA)	YS (MPa)	UTS (MPa)	% A
As-cast (F)					
Air (AQ)	25°C-120 h	-	117 (2.2)	229 (4.9)	9.9 (1.7)
Water (WQ)	25°C-120 h	-	124 (2.7)	241 (6.1)	9.4 (1.7)
T5					
Air (AQ)	25°C-120 h	180°C-4 h	170 (9.9)	256 (10.9)	7.2 (1.5)
Water (WQ)	-	180°C-4 h	186 (3.6)	273 (3.8)	6.6 (1.1)
Water (WQ)	25°C-120 h	180°C-4 h	188 (1.9)	278 (4.9)	6.4 (1.0)
Water (WQ)	25°C-120 h	160°C-28 h	205 (3.1)	290 (4.9)	6.1 (1.3)
T4 and T6					
T4	540-1		174 (2.7)	298 (2.8)	12.5 (1.9)
T6	540-1,20NA,180-4		308 (6.2)	359 (2.8)	6.1 (1.0)

The tensile properties of the differently T5-treated F357 are compared in Table 2. As expected, higher tensile properties are obtained by water quenching the material after SSM-HPDC rather than cooling in air. However, the difference is lower than was expected. Also, it can be seen from Table 2 that there is a significant difference in tensile properties between the as-cast material that was cooled in air [F357-F(AQ)] and the F357-T5(AQ). This implies that most of the elements are actually placed in solution during cooling with SSM-HPDC, rather than with the quench after SSM-HPDC. Less distortion can be achieved by cooling the castings in air, however, the much larger variation in properties achieved by this method (see the standard deviations in Table 2) might be a disadvantage. Furthermore, it is seen that natural aging after the quench (0 or 120 h) does not have a meaningful influence on the T5 properties. Finally, a lower artificial aging temperature (160 vs 180^{o}C) results in better mechanical properties. This is most likely due to a higher volume fraction of β″ as a result of the lower solubility of strengthening phases at lower temperatures. It might likely also be due to a higher thermodynamic driving force for nucleation of the second phases, leading to a finer size distribution. Unfortunately, due to the lower diffusion rates at 160^{o}C, the time to attain these properties is reached after much longer times than with artificial aging at 180^{o}C [2].

The quality index (QI) can be used to allow comparison of different heat treatment cycles. The quality index relates the ductility and strength (ultimate tensile strength or UTS) into a single term. The quality index is given by equation 1 [2]:

$$QI\ (MPa) = UTS\ (MPa) + 150\log(\%\ A) \qquad (1)$$

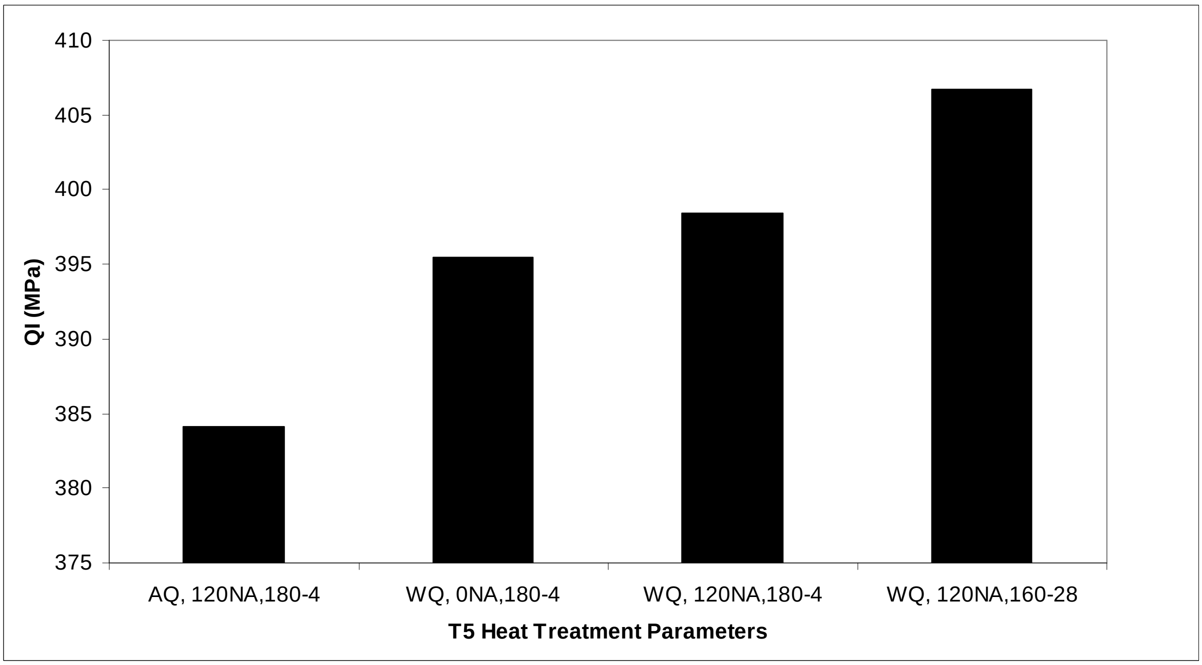

Figure 1. Quality Index (QI) of SSM-HPDC F357–T5.

Figure 1 shows the Quality Index values for the various T5 treated samples. The advantages of using a water quench, as well as a lower artificial aging temperature (unfortunately coupled with a much longer artificial aging time) can be seen.

Table 2 also compares the tensile properties of SSM-HPDC F357 in different temper conditions. Alloy F357-T4 has a lower YS, but a higher UTS and %A than F357-T5. The excellent ductility of F357-T4 is due to spheroidisation of Si during the solution treatment [2,4,5]. F357-T6 has a much higher YS and UTS than both F357-T4 and T5. The advantage of Si-spheroidisation is highlighted even more by considering the Quality Index in Figure 2 (for T5, only WQ,120NA,180-4 is shown). The lack of Si-spheroidisation in F357-T5 results in a relatively poor QI when compared to the T4 and T6 temper conditions.

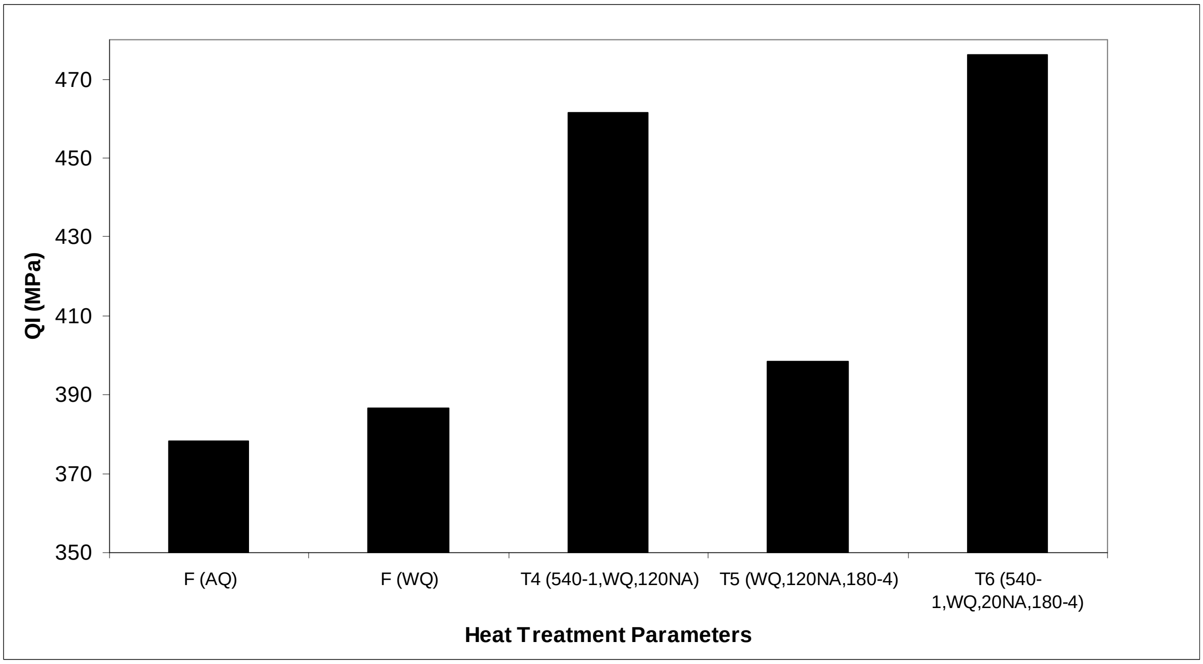

Figure 2. Quality Index of SSM-HPDC F357 in different temper conditions.

Conclusions

The Quality Index of SSM-HPDC alloy F357-T5 can be improved by using a water quench after casting, as well as using lower artificial aging temperatures for longer times. The YS and UTS for F357-T5 are fairly similar to that of F357-T4. However, the ductility is much lower due to the lack of any Si-spheroidisation. This concurrently leads to a relatively low Quality Index for the T5 temper condition. The YS and UTS of F357-T6 are much higher than for F357-T4 and T5.

References

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Acknowledgements

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