Heat treatments effect on the EN AC-46500 alloy produced by SSR

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ABSTRACT: This work demonstrates the possibility to apply T5 and T6 heat treatments to EN AC-46500 aluminium components conformed by Semi-Solid Rheocasting (SSR). The study of temperature and time effect in annealing, tempering and artificial aging conditions has permitted to optimize the component mechanical properties. The experimentation has been accomplished by means of hardness Brinell tests, tensile tests, optic and electronic microscopy. The mechanical properties obtained in SSR components, reach analogous values to the ones obtained by die cast components and submitted to the same heat treatments.

Key words: Heat treatment, SSR, EN AC 46500, Hardness

1 INTRODUCTION

Semi-solid metalworking (SSM) is a hybrid of forging and moulding processes. The challenge in developing SSM technologies is to produce components with fewer faults and at a similar cost to conventional processes. One of the advantages offered by SSM is the decrease in trapped gas and porosity due to the reduction in turbulence during the injection process, which produces components that can be treated thermally. The solid fraction content ranges between 20% and 50%, which ensures high viscosity reduces contraction during the solidification phase [1,2].

SSM technology is based on the high-pressure injection of semi-solid slurry previously obtained from an SSR agitator (Figure 1a). The agitator cools the metal, which produces a small solid fraction (Figure 1b) [3].

The SSM process consists of the following steps: [1]:

- Step 1: The molten aluminium remains above the melting point (Figure 1b).
- Step 2: A graphite cooling rod is lowered into the metal and cools it to a temperature below the liquidus point by agitating at high speed. The rod is kept in the broth for very short periods of time and the agitation speed does not exceed 60 rpm. The most critical part of the process is to obtain the first 1% by volume of the non-dendritic solid fraction. The cooling rate must also be carefully controlled during the agitation phase (0.3-3 ºC · s^{-1}) (Figure 1b).
- Step 3: After a short agitation period, the graphite tube is extracted, leaving a slurry with a low solid fraction content (<20 %) that is transferred into the HPDC machine (Figure 1b).

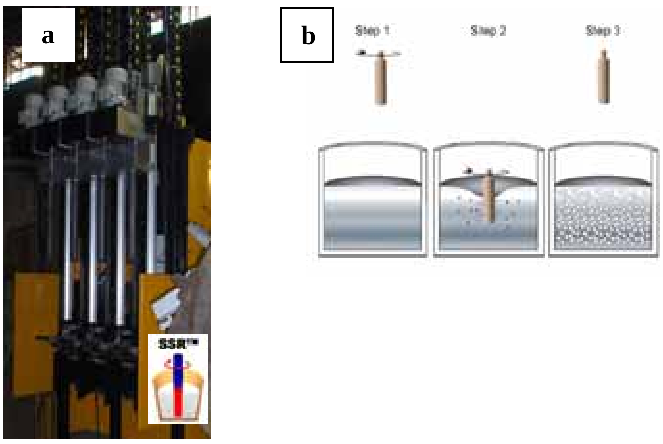

Fig. 1. a) Photograph of the SSR Station, b) Schematic representation of the SSR process

The aim of this study was to optimize the T5 and T6 heat treatments for the secondary alloy EN AC-46500 obtained by semi-solid rheocasting (SSR). The composition of the alloy is shown in Table 1.

Table1. Composition in % weight of the EN AC-46500 alloy.

Al	Si	Cu	Fe	Mg	Mn
Base	8.7	2.5	0.7	0.15	0.25
Zn	**Ti**	**Ni**	**Cr**	**Pb**	
0.5	0.05	0.06	0.03	0.08	

2 BOUNDARY CONDITIONS

The optimization of the T5 and T6 treatments was assessed using the Brinell hardness test to determine the maximum final hardness.

The T5 and T6 heat treatments were carried out using a Hobersal HCV-125 forced air circulation oven with controlled cooling and a precision of ±1 ºC.

The components used in the study were made of the aluminium alloy EN AC-46500 obtained by SSR (Figure 2). Rectangular cross-section samples (30x20x4 mm) were taken from the components.

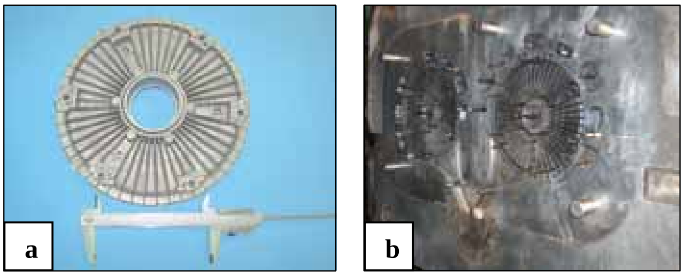

Fig. 2. a) SSR component, b) SSR mould

The Brinell hardness test was performed for each treatment in accordance with international standard EN ISO 6506-1, using a load of 62.5 kg and a ball diameter of 2.5 mm in each case.

The solution step of in the T6 treatment has several important functions: the intermetallic precipitates Mg_2Si and $CuAl_2$ are dissolved; the solid solution is homogenized; and the eutectic silicon is fragmented and becomes spheroid and enlarged [2].

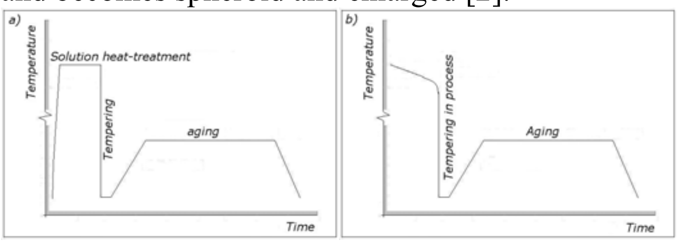

Fig. 3. a) Schematic representation of the T6 heat treatment, b) Schematic representation of the T5 heat treatment

Figure 3 contains schematic representations showing the different steps in the T6 and T5 heat treatments.

Table 2 shows the different combinations of temperatures, the solution times and the aging times used in the study.

Table2. Heat treatment conditions

Heat treatment	**T6**	**T5**
T solution / ºC	500, 505, 510, 515	-
t solution / h	5, 6, 7, 8	-
Tempering	Water at 25 ºC	Water at 25 ºC
T of aging / ºC	155, 160, 165, 170	180, 190, 200, 205
t of aging / h	1, 3, 6, 12	1, 4, 5, 6, 7

The heat treatment was optimized using the T5 and T6 processes for the alloy A333 as a guide, since this alloy only differs from EN AC-46500 in the percentage of copper (Table 3). The optimization was assessed on the basis of hardness measures under the different aging conditions given in Table 2.

Table3. Compositions of the alloys EN AC-46500 and A333.

	Si	**Cu**	**Fe**	**Mg**	**Mn**	**Zn**	**Ni**	**Ti**
EN AC-46500	8.7	2.5	0.7	0.15	0.25	0.5	0.06	0.05
A333	8-10	3-4	<1	0.05-0.5	<0.5	<1	<0.5	<0.25

According to ASM guidelines, aging of the A333-T5 alloy should be carried out at 205 ºC for 7-9 hours; for A333-T6, the solution phase should take place at 505 ºC for 5-12 hours and aging should be carried out at 155 ºC for 2-5 hours [4].

3 RESULTS AND DISCUSSION

The microstructure of as-cast EN AC-46500 (Figure 4) consists of primary grains of the α-solid solution.

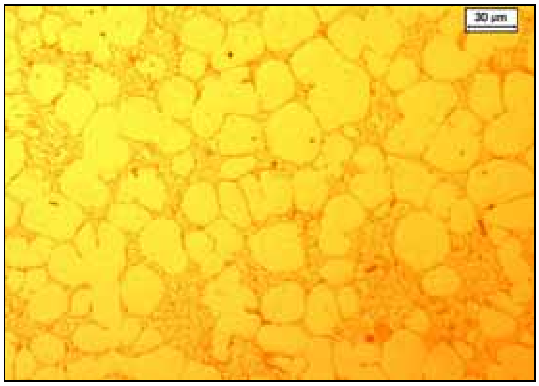

Fig. 4. Micrograph of as cast EN AC-46500 SSR

The micrographs in Figure 5 show the evolution of the microstructure under the T5 and T6 treatments. It can be seen that the eutectic silicon grows considerably with respect to the structure of the as-cast material (Figure 4) due to a combination of fragmentation and enlargement [5].

The α-phase is surrounded by a very thin eutectic layer in which intermetallic compounds can be detected. EDS analysis revealed Al(Si,Fe,Mn,Cu), Al(Si,Fe,Mn,Cu,Cr), α-AlFeSi, Mg_2Si and $CuAl_2$. In contrast to the thixocasting process, eutectic microconstituent occluded in the α-grains was not observed.

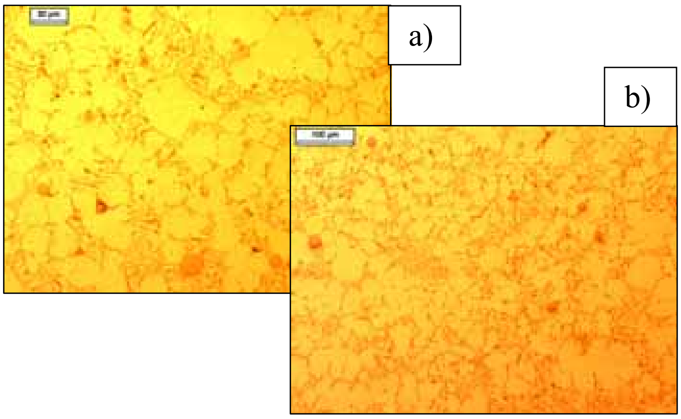

Fig. 5. Micrographs of the EN AC-46500 SSR microstructure under the (a) T5 heat treatment and (b) T6 heat treatment

The highest values of hardness during heat treatment were obtained after 8 hours for all dissolution temperatures, except for the value 505 ºC, which was obtained after 7 hours.

Figure 6 shows the effect of dissolution time on the final hardness of the samples. The lower the hardness value after tempering, the greater the maximum hardness after 12 hours of aging.

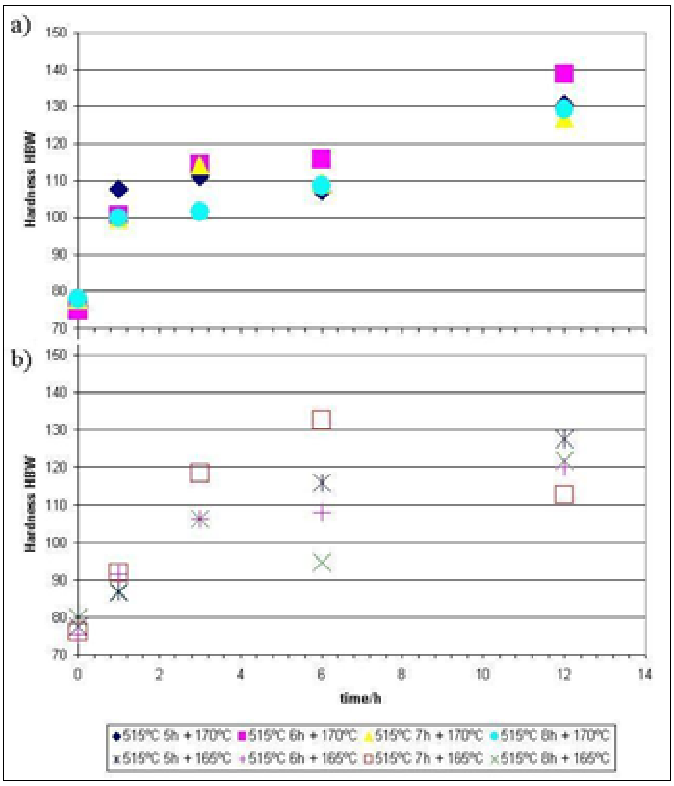

Fig. 6. T6. Evolution hardness against aging time at aging temperatures of (a) 170 ºC and (b) 165 ºC

Figure 7 shows the influence of the dissolution temperature on the hardness of the aged material at 170 and 160 ºC. The hardness values do not vary noticeably with the dissolution temperature except with aging times of 6 hours.

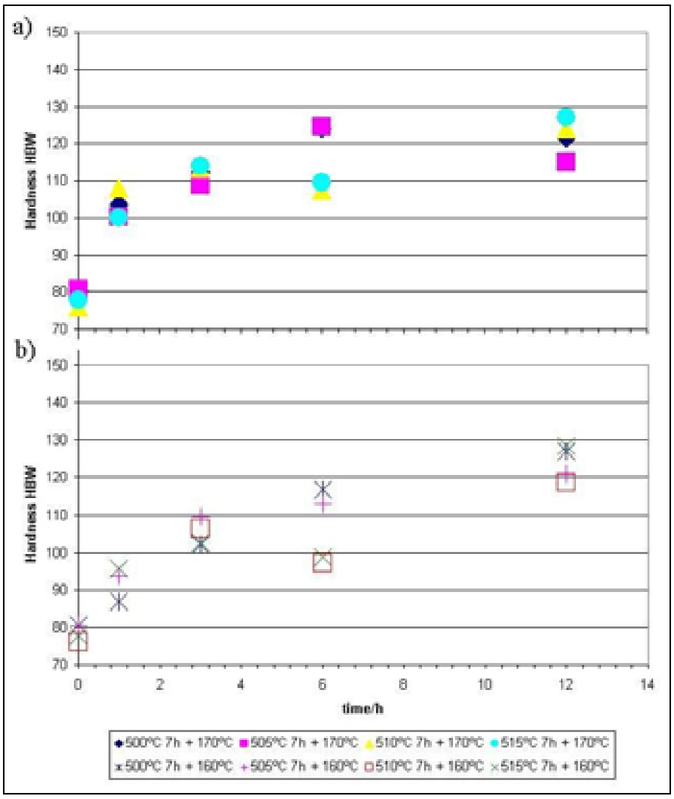

Fig. 7. T6. Evolution of hardness against aging time at aging temperatures of (a) 170 ºC and (b) 160 ºC

Figure 8 shows the effect of the aging temperature. It can be seen that the hardness increases with the aging temperature.

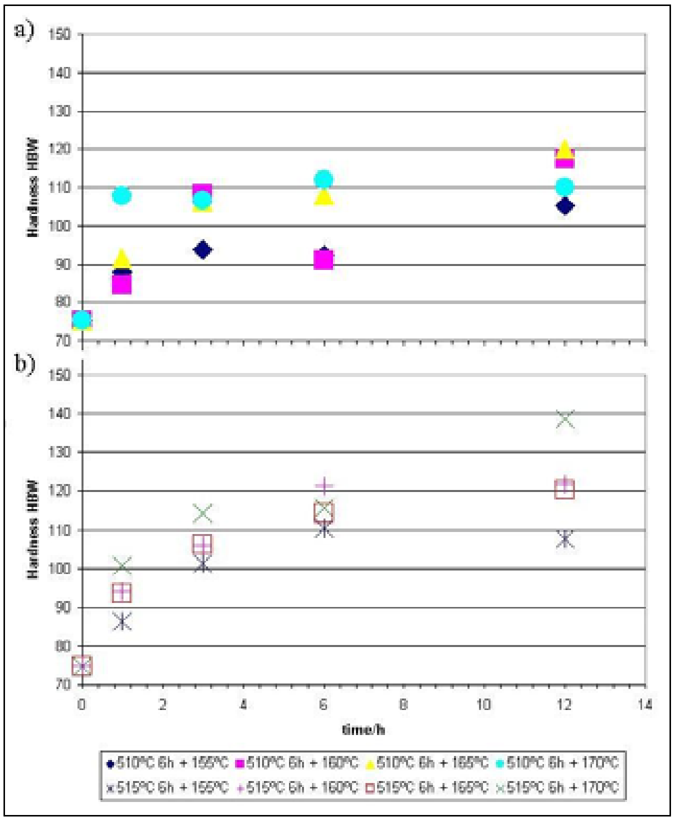

Fig. 8. T6. Evolution hardness against aging time at dissolution temperatures of (a) 510 ºC and (b) 515 ºC (b)

Figures 6, 7 and 8 reveal two peak hardness points. The first can be seen in the aging time interval of 1-4 hours and is due to the precipitates β' and β''. After this point the hardness falls due to over-aging caused by the precipitation of Mg_2Si. The second peak can be seen after an aging time of 6 hours and is due to the formation of the coherent precipitates θ' and θ ''.
The highest Brinell hardness values are obtained in the heat treatment at 515 ºC for 6 hours, followed by aging at 170 ºC for 12 hours. The values reach a maximum of 139 HBW (the hardness of the as-cast material is 90 HBW).
Heat treatment of less than four hours produced low hardness values.
In most of the experiments the maximum hardness was obtained after an aging time of 12 hours. These hardness values could be increased by optimizing the aging times. However, at 6 hours a remarkable degree of hardening can already be appreciated. The presence of an intermetallic precipitate of the type Al(Si,Fe,Mn,Cr,Cu), which dissolves with difficulty, could reduce the hardening capacity. The hardness values of EN AC-46500 SSR-T6 (maximum 139 HBW) are higher than those of the A333-T6 alloy (115 HBW).
The highest Brinell hardness values were obtained by aging at 190 ºC for 4 hours (105 HBW). If we consider that the as-cast material has a hardness of 90 HBW, the increase in hardness produced by the T5 heat treatment can be considered limited. Better results might be obtained by increasing the temperature of the component on exiting the mould and optimizing the tempering step. The values given above are similar to those obtained for the A333-T5 alloy under the same heat treatment [4].

4 CONCLUSIONS

The T6 heat treatment can be applied to secondary alloy EN AC-46500 components obtained by SSR and produces increases in hardness of up to 100%.

The good results of the T6 heat treatment suggest that the T5 treatment could be improved by increasing the ejection temperature.

When we increased the heat treatment solution time, the hardness increased after the tempering step in all the studied cases and reached values of up to 82 HBW. However, when long heat treatment solution times were used the hardness values after the aging step were comparatively low due to the growth of the eutectic silicon.

The presence of intermetallics of the type Al(Si,Fe,Mn,Cr,Cu) in the EN AC-46500 alloy can hinder the aging process.

In the T6 heat treatment, the maximum hardening of the EN AC-46500 alloy (139 HBW) was obtained following treatment at 515 ºC for 6 hours and aging at 170 ºC for 12 hours. This hardness value is greater than the maximum hardness of the A333-T6 alloy (115 HBW).

In the T5 heat treatment, the maximum hardening of the EN AC-46500 alloy (105 HBW) was obtained following aging at 190 ºC for 4 hours. This hardness value is similar to the maximum hardness of the A333-T5 alloy. Better results could be achieved by increasing the ejection temperature.

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