High temperature behaviour of 46000, 46100, 47100 Al die cast parts

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Hypo- or nearly eutectic Al-Si-Cu alloys are widely used as high pressure die casting alloys in foundry. Due to high strength-to-weight ratio, they offer a wide range of applications. Some of the most commonly used Al-Si alloys are EN AC-46000, EN AC-46100 and EN AC-47100 alloys. Their beneficial properties have been characterized in plenty previous works. Less attention got their tensile behaviour at relatively high temperature, which is becoming of interest due to the possibility that the cast parts are applied at moderate temperatures and in the presence of external applied forces. On the other hand, the mechanical behaviour of these alloys at temperatures as high as those reached during possible homogenization or solution treatment processes could help modelling the thermomechanical behaviour of castings during heat treatments. The research work focuses on the evolution of the tensile properties of diecast EN AC 46000-AlSi9Cu3(Fe), EN AC 46100 – AlSi11Cu2(Fe) and EN AC 47100-AlSi12Cu1(Fe)alloys. Hot tensile testing with increasing temperature from room temperature up to 450°C were carried out on 3 mm thick specimen in view of proposing a temperature-dependent description of the main material properties.

KEYWORDS: HIGH TEMPERATURE - TENSILE PROPERTIES - EN AC 46000-AlSi9Cu3(Fe), EN AC 46100 - AlSi11Cu2(Fe), EN AC 47100-AlSi12Cu1(Fe)

INTRODUCTION

Hypo- or nearly eutectic Al-Si-Cu alloys are widely used as high pressure die casting alloys in foundry. Due to high strength-to-weight ratio, they offer a wide range of applications. In particular, they are employed in the automotive industry for components like engine blocks, rocker covers, inlet manifolds, brackets, steering boxes, etc. During the lifecycle of the diecast parts, these materials can be hold for short or long times at moderate or high temperature, and their mechanical response is heavily affected by holding temperature. In the case of potentially age-hardenable alloys, the time spent at high temperature also affect mechanical behavior, even if to a minor extent unless cases of long service at high temperature. A description of the tensile behavior of these alloys in a wide temperature range is of interest for predicting the short-term behavior of structural parts hold for relatively short time at high temperature, such as during processing transients in service life. Currently the evaluation of high temperature mechanical behavior of casting alloys based on the Al-Si system has mainly be done for piston alloys [1, 2], of nearly eutectic or hypereuectic composition, while only very recently the attention as been focused on hypoeutectic alloys [3]. The alloy creep properties should then be added to tensile behavior (or, alternatively, low strain rate effects) to take into account in the description of mechanical behavior to design components serviced for long times at high temperature.

The present contribution was focused on experimental identification of high-temperature tensile behavior of casting alloy widely used for high pressure die casting mainly characterized by different Si and Cu contents.

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MATERIALS AND EXPERIMENTALS

Experimental tests for the description of the high temperature of Al-Si alloys selected within those proposed by EN 1706 standard in order to have at the same time a set of widely diffused alloys with different amounts of Si and Cu as elements correlated to the amount of eutectic structure and of the possibility to give rise to precipitates. The selected alloys were EN AC

46000- AlSi9Cu3(Fe), EN AC 46100 - AlSi11Cu2(Fe) and EN AC 47100-AlSi12Cu1(Fe), which actual content of alloying elements as well as compositional limits are given in Table 1. The amount of Si increases moving from the first to the latter alloy, while that of Cu decreases. The last one is further characterized by a lower amount of Zn.

Tab. 1 - Actual chemical composition of the investigated materials compared to the compositional limits for the investigated alloys according to EN 1706 (in mass %)

		CHEMICAL COMPOSITION											
Alloy		Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Pb	Sn	Ti	Al
EN AC 46000 AlSi9Cu3Fe	actual	8.227	0.799	2.825	0.261	0.252	0.083	0.081	0.895	0.083	0.026	0.041	bal.
	limits	8.0-11.0	<1.3	2.0-4.0	<0.55	0.05-0.55	<0.15	<0.55	<1.20	0.35	0.15	<0.25	bal.
EN AC 46100 AlSi11Cu2(Fe)	actual	10.895	0.889	1.746	0.219	0.224	0.082	0.084	1.274	0.089	0.029	0.047	bal.
	limits	10.0-12.0	<1.1	1.5-2.5	<0.55	<0.30	<0.15	<0.45	<1.70	0.25	0.15	<0.25	bal.
EN AC 47100 Al Si12Cu1(Fe)	actual	10.510	0.721	0.941	0.232	0.242	0.045	0.080	0.354	0.055	0.025	0.038	bal.
	limits	10.5-13.5	<1.3	0.7-1.2	<0.55	<0.35	<0.10	<0.30	<0.55	0'.20	0.10	<0.20	bal.

The specimens for tension tests were high pressure die cast using specifically designed die and optimized process parameters aimed at minimizing the porosity level and at obtaining a controlled microstructure. Details of the casting procedure, of the die and of the microstructural features and defect content are described in previous works by some of the authors of the present contribution [4, 5] and in CEN T/R 16748 [6]. The specimen geometry was flat, with nominal thickness of 3 mm. The length and width of the gauge length were 35 and 10 mm, respectively. Outside gauge length, in a distance of 12,5 mm, the width of the specimen gradually increased to the 20 mm of the gripping ends. These were drilled to produce holes for insertion of pins (6 mm diameter, 70 mm spaced) to connect the specimen in the loading train.

Tension tests were carried out at temperatures in the range 24 - 450°C (up to 350°C for 46100 alloy) at 50°C temperature step. Attention was paid that the specimen did not remain for long time in the furnace before testing. The heating up process lasted for approximately 30-40 min for each sample, and was typically shortened for tests carried out at the highest temperatures. The limited specimen availability prevented repetition of tests and data scatter cannot be derived.

Tests were carried out in displacement control. Displacement rate was fixed to 0.76 mm/min for all testing temperature, with the target to meet for them a strain rate in the plastic range of $2.5*10^{-5}$ 1/s, corresponding to rage 2 in CEN ISO 6892-2 standard for high temperature tensile tests.

Due to the special geometry of the specimens, to the need to avoid brittle fractures at relatively low temperatures and to the available geometry of high temperature extensometers, the specimen elongation was measured between pins, considering a fixed reference length close to 60 mm in order to estimate strain values. Elongation (A%) and reduction of area (RA%) at rupture were estimated on the basis of changes in the specimen gauge length and on the changes in cross-section, this latter considered to keep its rectangular shape during the test. At high temperature the material ductility was very high and tests were interrupted when extensometric system limits were reached, corresponding to gauge length elongation of about 35%.

RESULTS AND DISCUSSION

An overview of the stress- strain curves is given in Fig.1 for EN-AC 4600 alloy. The effect of temperature on the mechanical response of the alloy is clear. By increasing the temperature, the deformation mode progressively changes from brittle to ductile and the strain hardening behavior is reduced with every temperature step till it almost completely vanished at 400°C. The maximum of the stress-strain curves is typically reached only at or above 300°C.

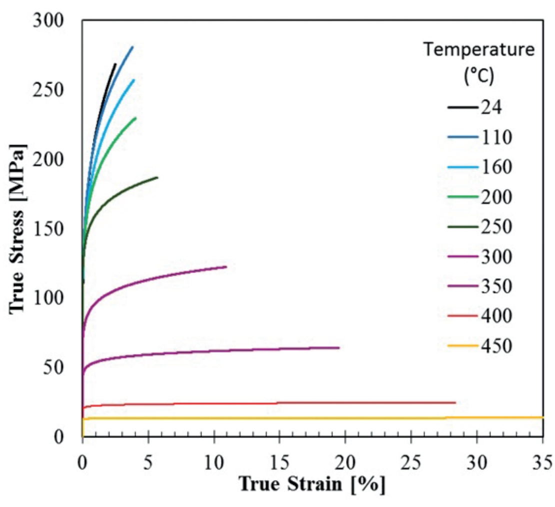
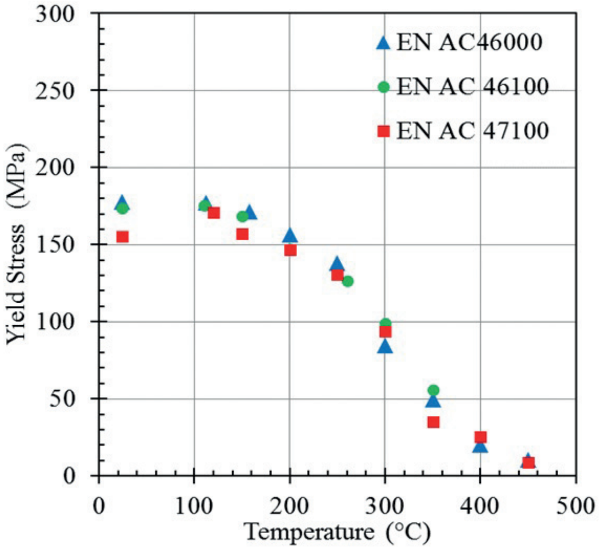


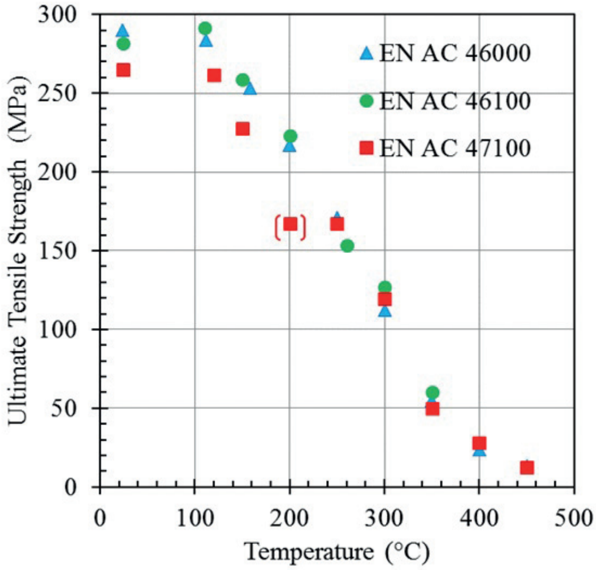
Fig. 1 - Overview of the true stress-strain curves in tension tests at different temperatures in the range 24-450°C for EN-AC 46100 alloy.

The temperature dependences of the main tensile properties for the three alloys are summarized in Fig. 2 and Fig. 3. At room temperature the Ultimate Tensile Strength of the alloys are in the range 270-290 MPa, the lowest values being that of EN AC 47100-AlSi12Cu1(Fe) alloy, reasonably due to its minor amount of Cu and Zn. As test temperature increases to 110°C, a plateau or a slight increase in UTS can be noticed. The plot of yield stress confirms the slightly reduced resistance to plastic deformation of the above alloy and at the same time its more stable tensile behaviour value in the intermediate temperature range (110-250°C). In the temperature range 250 and 350°C the three alloys have very close strength parameters. Above 350°C UTS and YS of all alloys decreases to 50-60 MPa.

This above strength changes with test temperature are compatible with the possibility or age-hardenable Cu- containing Al-alloys to form fine precipitates and redissolve them at increasing temperatures, thus leading to an increase of strength at relatively low temperatures followed by its steep reduction at higher temperatures. The initial microstructural condition of the alloys as well as the combination of heating/holding time and temperature can affect the peak stress reached by each alloy. In the present case the initial alloy microstructure and precautions in experimental testing reasonably did not induce significant hardening effects also for the alloy with nominal Cu content of 3%.



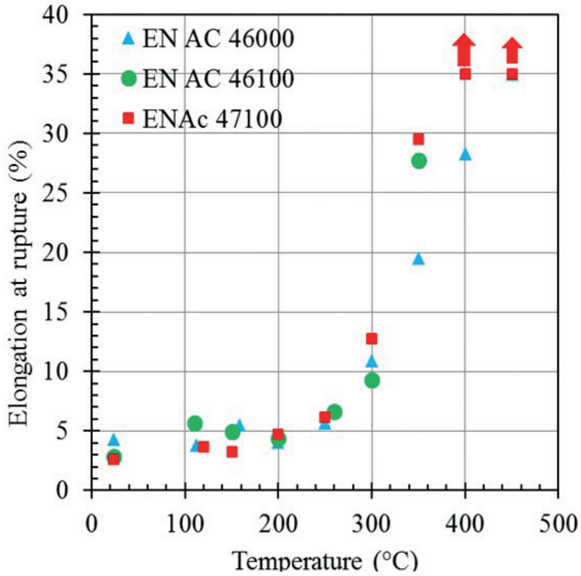
a)



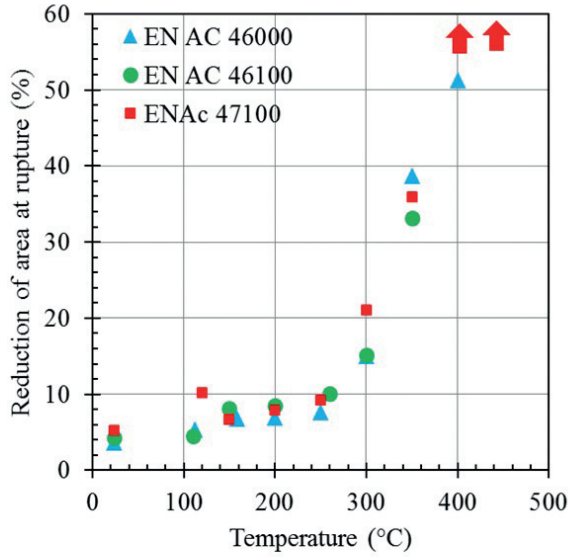
b)

Fig. 2 - 0.2% offset Yield Stress (a) and Ultimate Tensile stress (UTS) (b) plotted as functions of test temperatures for the three investigated alloys. The point in square brackets corresponded to an anomalous rupture.

While at temperatures below 200°C the elongation at rupture remains of about 5% with some scatter, above 250°C it rapidly increases and 400 and 450°C 35% is exceeded for EN AC 47100 alloy. A similar behavior is observed for reduction of area at rupture. Both ductility indexes do not show significant differences between the investigated alloys in the low and intermediate temperature range. Differences could be partly hindered by experimental scatter involved in measurements of small elongation of the broken gauge length. At the highest investigated temperature, the comparison between EN-AC 47100 and EN AC 46000 shows the lower ductility of this latter. This could be partly related to alloying elements Cu and Zn, reasonably in solid solution in alpha grains at these temperature, but the role played by microstructure and microstructural changes at these temperatures has also to be deeply investigated.



a)



b)

Fig. 3 - Elongation at rupture (a) and reduction of area at rupture (b) plotted as functions of test temperatures for the three investigated alloys.

CONCLUSIONS

The tensile tests carried out on alloys EN AC 46000-AlSi9Cu3(Fe), EN AC 46100 - AlSi11Cu2(Fe) and EN AC 47100-AlSi12Cu1(Fe) in the range 24-450°C revealed only slight differences in their high-temperature short-term mechanical behaviour. The three materials showed a clear decrease of tensile properties above temperature reaches of exceeds 200°C, with a steep decrease of them occurred at testing temperatures between 250 and 350°C, corresponding to a significant increase in ductility. Among the three alloys, EN AC 47100 showed the lowest but more stable tensile strength up to about 250°C, consistently with its minor amount of elements that can potentially cause age-hardening effects during high temperature exposure.

ACKNOWLEDGMENTS

The process development to produce the investigated material was developed inside **NADIA** Project, supported by European Union (FP7-2012-NMP-ICT-FoF, grant agreement n° 314145). The authors would like to thank Raffineria Metalli Capra for the supplying of alloys and SAEN for the high pressure diecasting of specimens.

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