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MICROSTRUCTURE AND GRAIN REFINING PERFORMANCE OF Ce ON A380 ALLOY

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Abstract

In the present work, the microstructure and grain refining performance of Ce on A380 alloy have been investigated, using thermal analysis, light microscopy with polarized light and scanning electron microscopy (SEM).

The purpose was to study the influence of Ce addition on the formation of the microstructure. Ce changed the morphology of eutectic Al_2Cu phase and caused small formation of primary crystals of α_{Al}. Furthermore Ce phase was detected indicating quaternary phase AlCeCuSi ($Al_9Ce_2Cu_5Si_3$).

Keywords: A380 alloy; Ce addition; Microstructure; Grain refining.

1. Introduction

Aluminium–silicon (Al–Si) alloys are the most important of the aluminium casting alloys mainly because of high fluidity, low shrinkage in casting, high corrosion resistance, good weldability, easy brazing and low coefficient of thermal expansion. These alloys are extensively used in the automotive industry in areas such as vehicle weight reduction and fuel economy improvement. [1] Al−Si alloys with copper are used for thin-wall castings [2] in automobile, aircraft and chemical industry. The addition of copper (beside silicon) as main alloying element (mostly in range 3–6 wt. %, but it can be much higher), with or without magnesium as alloying constituent (in range 0–2 wt. %), allows material strengthening by precipitation

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hardening, resulting in very good mechanical properties. Also the fatigue properties are very good for this series. The presence of copper is however very bad for the corrosion resistance. Copper tends to precipitate at grain boundaries, making the metal very susceptible to pitting, intergranular corrosion and stress corrosion, but it is increasing of the mechanical properties of these alloys [3-5].

Cooling rate influences on the shape and size or primary α_{Al} and on the shape, size and distribution of eutectic phases (Fig. 1). With fast cooling rate and/or grain refining small grain size is established and the rough formation of eutectic phase β_{Si} is avoided. Because the crack usually advances through the fragile eutectic β_{Si} phase, smaller and rounded particles of β_{Si} are desired, which enhance the mechanical properties [3, 5, 6]. To establish small grain size, A380 alloy is usually grain refined with master alloy AlB3 and AlTi5B1. The grain refining influence of Ce on A380 alloy is not known yet.

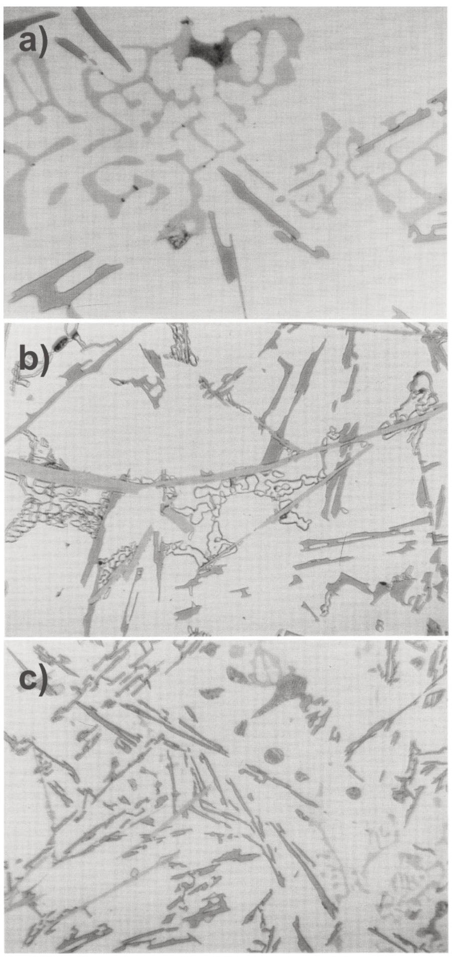

Figure 1. Microstructure of A380 alloy at various cooling rates: 0.3 °C/s (a), 0.6 °C/s (b) and 4.5 °C/s (c) at magnification 200x [3]

Rare earth metals, such as cerium (Ce), have been found to improve the mechanical properties of Al-Si castings through modifying their microstructure and enhancing the tensile strength [8] and ductility [9], heat resistance and extrusion behaviour [10]. Ce has been found very helpful and favourable for many other alloys and applications like hypereutectic aluminium alloys and lead-free solders [11]. The solidification of hypoeutectic Al-Si alloys with Ce addition can be described by Al-corner of ternary system Al-Si-Ce (Fig. 2) [12], which unfortunately does not include

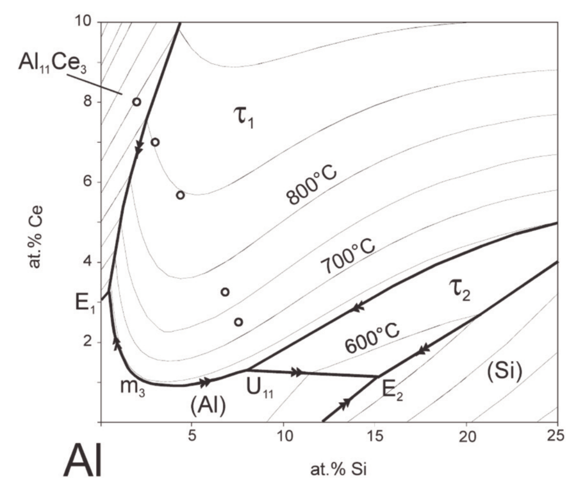

Figure 2. Al-corner of ternary system Al-Si-Ce [11,12]

other alloying elements and other multicomponent phases with Ce. It was reported that these Ce-phases may act as nucleation sites for (Al) or (Si) crystals in both hypo- and hypereutectic Al-Si alloys [12, 14]. Because of a high cost of Ce its modification did not find wider applications.

2. Experimental

A commercial A380 alloy was melted in an electric induction furnace, and various concentrations (0, 0.01, 0.02 and 0.05 wt. %) of pure (99.9 %) Ce were added. After the basic alloy was melted, the Ce was added into the melt. After 10 minutes the melt was poured into a measuring cell with a controlled cooling system (simple thermal analysis-STA) with the purpose to record cooling curves at different cooling rates. Various thermal analyses could be used to determine the influence of heating and cooling rates, atmosphere, on the characteristic temperature (like in our case), oxidation resistance, melting and solidification heat, mass change in the controlled temperature program [15]. Chemical composition of the investigated samples is presented in Table 1.

The characteristic solidification temperatures were determined from the cooling curves, and the influence of Ce was defined.

The samples were prepared by the standard metallographic procedure for optical microscopy and by the anodic oxidation for observation in polarized light. Anodized samples were used for determining the grain size according the standard ASTM E112. The grain size number *G* was calculated after intercept method by following equation: $G = (6.643856 \cdot \log \overline{N}_L) - 3.288$ where is $\overline{N}_L$ number of grains per mm [16]. In addition the specimens were examined using a scanning electron microscope (SEM) SIRION 400nc, FEI Company equipped with an EDS analyzer INCA 350 and JEOL JSM-5610 with EDS analyzer and electron microanalyzer JEOL SUPERPROBE 733 with two WDS-spectrometers. Cerium phase was identified.

3. Results and discussion

The solidification sequence, according the cooling curve in Fig. 3, of such investigated alloy is following: primary crystals of α_{Al} at 566.8 °C with recalescence 4.6 °C, eutectic (α_{Al} + β_{Si}) solidification at 564.7 °C with eutectic recalescence 0.8 °C, eutectic (α_{Al} + Mg_2Si) and eutectic (α_{Al} + Al_2Cu) solidification at 520.1 °C and 501.8 °C and at the and also eutectic (α_{Al} + $Al_5Mg_8Si_6Cu_2$) [3] solidification at 483.2 °C. From the cooling curves (Fig. 3) of STA with various Ce-additions was established that the

Table 1. Chemical composition of A380 alloy /mass %

Specimen	Mg	Mn	Cu	Ti	Fe	Si	Ce (nominal)	Ce (actual)	Al
A380	0.35	0.24	2.61	0.04	0.69	10.72	0		Rest
A380 + 0.01 mass % Ce	0.34	0.27	2.55	0.04	0.75	10.6	0.01		Rest
A380 + 0.02 mass % Ce	0.35	0.29	2.69	0.04	0.8	10.66	0.02	0.015	Rest
A380 + 0.05 mass % Ce	0.32	0.29	2.57	0.04	0.81	10.59	0.05	0.043	Rest

temperature of eutectic solidification (α_{Al} + Al_2Cu) and solidus temperature shifts to higher temperature when Ce is added to the alloy (Fig. 4, Table 2). The solidification interval also decreases which indicates smaller formation of primary crystals of α_{Al}. At higher cooling rates the influence of Ce was neglected.

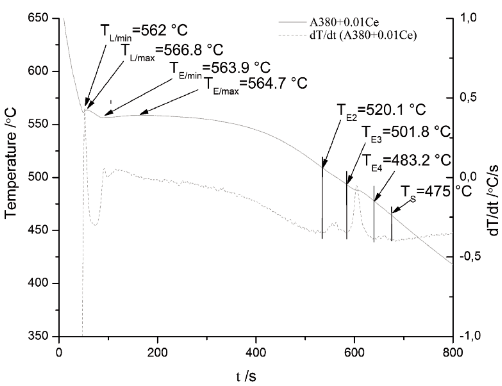

Figure 3. Cooling curve and differential cooling curve of A380 alloy with 0.01 mass % Ce and marked characteristic temperatures.

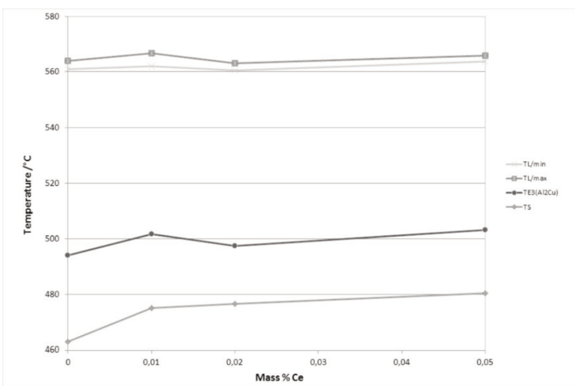

Figure 4. Some characteristic temperatures of solidification of A380 alloy regarding various Ce-additions

Wen the microstructure was observed in the polarized light it was determined that the size of primary grains of α_{Al} decreases when Ce is added to the alloy (Fig. 5) and when the cooling rates are higher (Fig. 6). Grain sizes and the grain size numbers (*G*) were determined by intercept counting method from ASTM standard with analySIS 5.0 computer program. It was established that the largest primary crystals formed in the alloy without Ce. When 0.01 mass % Ce was added the size dropped from 601 µm to 356 µm. At specimens with 0.02 and 0.05 mass % Ce the analyzed grain size was 362 and 375 µm (Table 3). It was also confirmed that higher cooling rate decreases the size of primary crystals from 1514.28 µm at cooling rate 10 K/min to 231.95 µm at cooling rate 350 K/min (Table 4).

The influence of Ce on the microstructure constituents was investigated also using SEM. It was established that Ce in A380 alloy changes the morphology of Al_2Cu eutectic constituent. Figure 7.a shows that without Ce the normal eutectic morphology is obtained, while Figure 7.b shows that with Ce s divorced eutectic is obtained.

Phase based on Ce was also analysed using EDS analyzer. Ce-phase was found to be composed of Al, Ce, Cu and Si, indicating AlCeCuSi (calculated stoichiometry was $Al_9Ce_2Cu_5Si_3$) phase. This phase was found to form in a needle shape (Fig. 8).

Table 2. Some characteristic temperatures of solidification from STA

Specimen	$T_{L/min}$ /°C	$T_{L/max}$ /°C	$T_{E3(Al2Cu)}$ /°C	T_S /°C	$\Delta T_{Solidification}$/°C	$t_{Solidification}$/s
A380	561	564	494	463	98	629
A380 + 0.01 mass % Ce	562	566.8	501.8	475	87	582
A380 + 0.02 mass % Ce	560.5	563	497.5	476.5	84	539
A380 + 0.05 mass % Ce	563.7	565.9	503.3	480.5	83.2	574

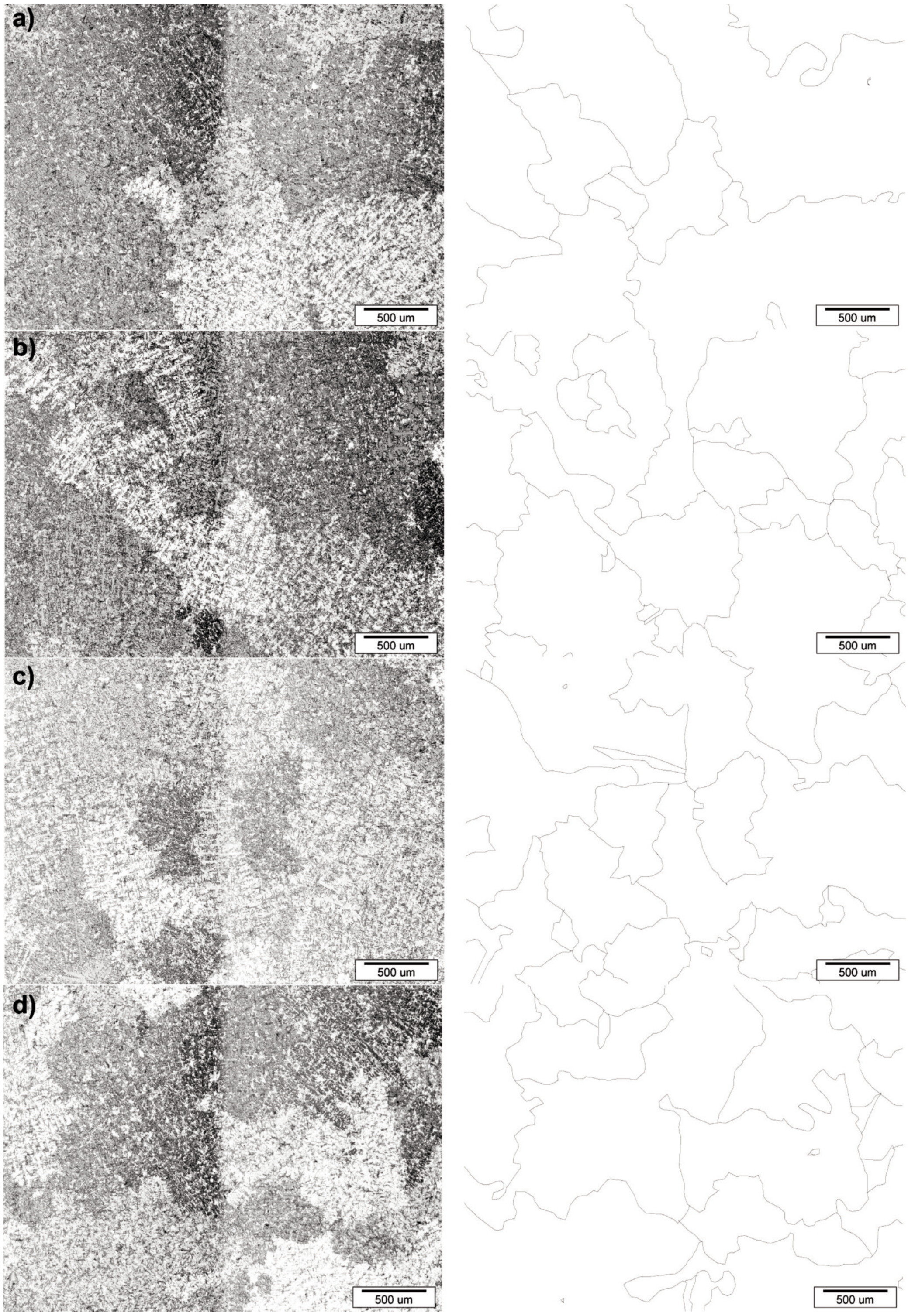

Figure 5. Primary crystals of αAl in polarized light regarding Ce-addition: A380 at 300 K/min (a), A380 + 0.01 mass % Ce at 300 K/min (b), A380 + 0.02 mass % Ce at 300 K/min (c) and A380 + 0.05 mass % Ce at 300 K/min (d)

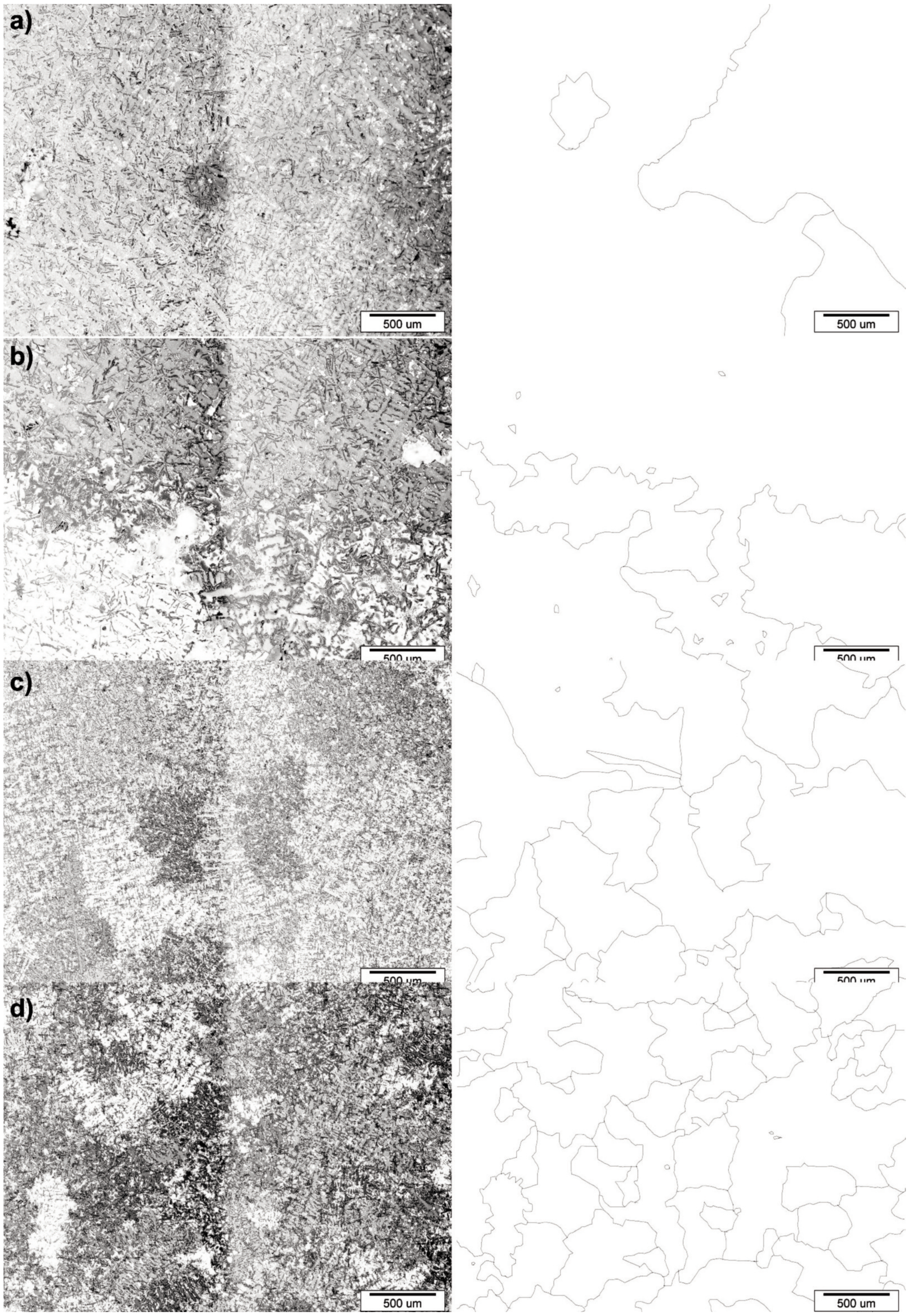

Figure 6. Primary crystals of αAl in polarized light regarding cooling rate: A380+ 0.02 mass % Ce at 10 K/min (a), A380+ 0.02 mass % Ce at 100 K/min (b), A380+ 0.02 mass % Ce at 300 K/min (c) and A380+ 0.02 mass % Ce at 350 K/min (d)

Table 3. ASTM size number G, No. of grains/mm and mean intercept distance/μm of A380 alloy cooled with 300 K/min with various Ce-additions.

Specimen	ASTM size number *G*	No. of grains/mm	Mean intercept distance /μm
A380	-1.82	1.665085	600.57
A380 + 0.01 mass % Ce	-0.31	2.80749	356.19
A380 + 0.02 mass % Ce	-0.36	2.762633	361.97
A380 + 0.05 mass % Ce	-0.46	2.663414	375.46

Table 4. ASTM size number G, No. of grains/mm and mean intercept distance/μm of A380 alloy with 0.02 mass % Ce after various cooling rates.

Specimen	ASTM size number *G*	No. of grains/mm	Mean intercept distance /μm
A380 cooled with 10 K/min	-4.48	0.66038	1514.28
A380 cooled with 100 K/min	-1.78	1.688707	592.17
A380 cooled with 300 K/min	-0.36	2.762633	361.97
A380 cooled with 350 K/min	0.93	4.311182	231.95

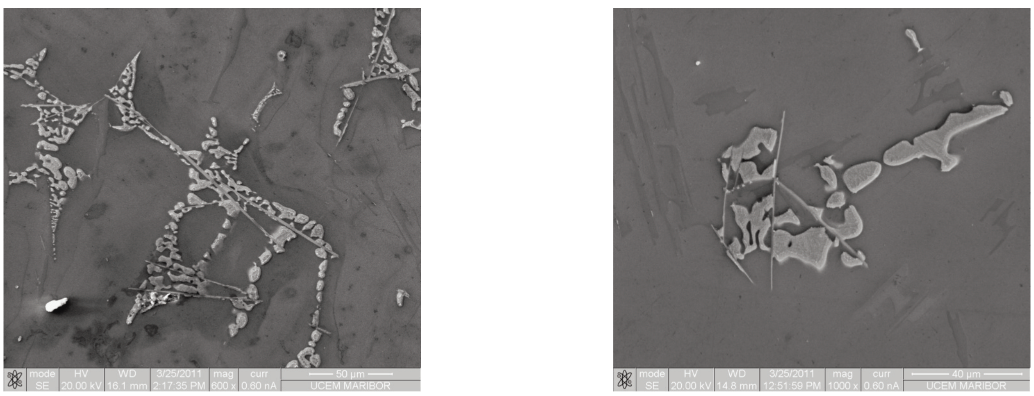

Figure 7. SEM micrographs of specimen without Ce (a) and with 0.02 mass % Ce (b)

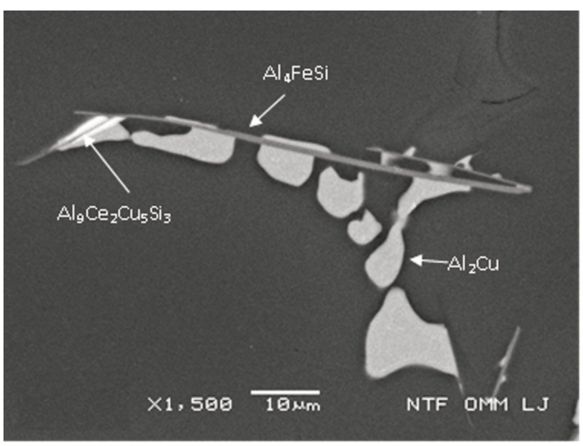

Figure 8. SEM micrograph of Ce-phase.

4. Conclusions

The effect of Ce content on the microstructure in A380 alloy has been analyzed. Moreover, the grain refining influence of Ce in A380 alloy has been also studied. The results are as follows:

Primary crystals of α_{Al} appeared smaller when Ce was added to the A380 alloy which corresponds to higher solidus temperature and smaller solidification interval and shorter solidification time. Temperature of eutectic solidification (α_{Al} + Al_2Cu) also shifts to higher values in alloy with Ce. Higher cooling rate also caused small formation of primary aluminium.

The morphology of Al_2Cu eutectic phase changes from ″crumbled″ to fully formed.

Ce−phase was detected indicating AlCeCuSi (presumably $Al_9Ce_2Cu_5Si_3$) phase. This phase forms in a needle shape.

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