Effects of melt temperature on mechanical properties and fracture structure of commercial purity aluminum purified with salt-based flux

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Melt temperature is one of the key processing parameters that affects the property and structure of aluminum and aluminum alloy castings. To obtain favorable melt fluidity, high melt temperature is often demanded. However, higher melt temperature is more unfavorable to the purification of aluminum melt [1–5]. Salt-based flux is often used to protect molten aluminum from oxidation and gas adsorption. In order to gain a good purifying effect, proper melt temperature range should be held when different flux is used to purify aluminum melt.

In this paper, a newly developed salt-based flux was used to purify commercial purity aluminum melt at different temperatures. The variation of as-cast mechanical properties and fracture microstructure at different melt temperatures was studied in order to determine the suitable melt temperature range for the salt-based flux.

The material used in the experiment was commercial purity aluminum. The main impurity elements of the material are given in Table I. The melting unit was a crucible resistance furnace (12 kw) with a removable clay-graphite crucible. The initial weight of the material was 2 kg in each case. The flux used to purify aluminum melt was NaCl and KCl based flux with rare earth elements. The main compositions of the flux can be seen in Table II.

The total consumption of flux was 1% of the initial weight of aluminum. To exploit both the purifying function and covering function of the flux, the flux was added in twice. Of the total flux 30% was spread at the bottom of the clay-graphite crucible before the crucible was loaded with commercial purity aluminum ingots and heated in the furnace. The remaining 70% of total flux was spread on the surface of aluminum when the aluminum ingots began to melt. Then the melt was heated to a prearranged temperature point ranging between 690 and 810 °C and the temperature was held at this point for 30 min. During the process, the melt was not stirred. After the slag was skimmed away, the melt was poured into a permanent die to form specimens for tensile test and metallographic analysis.

The ultimate tensile strength and elongation of the as-cast specimens (three test specimens at each temperature) were measured on a WE-60 tensile-strength tester. The size of as-cast specimens is $\Phi 12 \times 60$ mm. The fracture generated from tensile-strength test was observed using EDAX-S-520 scanning electron microscope. Metallographic structure of the as-cast specimens was observed by OLYMPUS optical microscope and was analyzed with LECO image analysis software. The metallographic specimens were prepared by electrolytic polishing. The composition of the electrolyte was: 200 ml 30% $HClO_4$ + 100 ml glycerinum + 700 ml 95% Cl_2H_5OH.

The mechanical properties of commercial purity aluminum refined at different melt temperatures are given in Fig. 1. It is found that the ultimate tensile strength and elongation percentage of the specimens fluctuate widely at different melt temperatures, 50–70 MPa and 15–40%, respectively. The tensile strength and elongation percentage of the specimens are both relatively high when the temperature is within the range of 690–750 °C. However, they drop down dramatically when the temperature is above 750 °C, especially for the elongation percentage. Accordingly, the suitable temperature range should be 690–750 °C when the NaCl and KCl based flux is used to purify the commercial purity aluminum melt.

The variation of mechanical properties of the specimens at different temperatures can also be reflected by the scanning electron microscope observation of the fracture (as shown in Fig. 2). It is found that there

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TABLE I Impurity element analysis of commercial purity aluminum with Inductively Coupled Plasma-Atomic Emission Spectrometry

Impurity elements	Pb	B	Ca	Cr	Fe	Mg	Na	Si
Content (wt%)	0.0417	0.044	0.015	0.0779	0.0779	0.0047	0.0056	0.0516

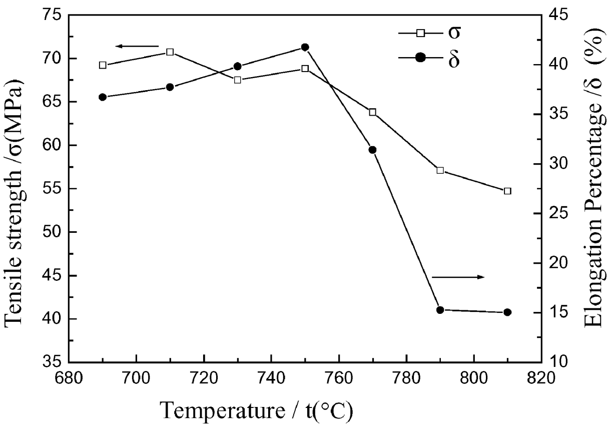

Figure 1 Mechanical properties of commercial purity aluminum at different melt temperatures.

exist fracture dimples in the fracture surface (as seen in Fig. 2a and b) when the temperature varies within the range of 690–750 °C. It is apparent that the fracture mechanism is a typical microvoid coalescence fracture mode. However, when the temperature is above 750 °C, there appear some quasi-cleavage planes or/and cleavage planes which are caused by porosities, inclusions and shrinkage cavities (as seen in Fig. 2c and d). In this case, the fracture mechanism is altered to a quasi-cleavage crack or cleavage fracture mode [6, 7].

TABLE II The compositions of flux

Compositions	NaCl	KCl	(La,Ce)F_3	Rest
Content (wt%)	40	40	10	10

Metallographic observations show that there do not exist inclusions larger than 10 μm in the microstructure of the specimens refined by the flux at 710 and 730 °C, as shown in Fig. 3a and b, respectively. However, at 770 °C, some inclusions larger than 30 μm are found (as seen in Fig. 3c). When the temperature reached 810 °C, many large inclusions and gas porosities appeared in the microstructure (as seen in Fig. 3d). As a result, when the NaCl and KCl based flux is used to purify commercial purity aluminum, the melt temperature should not be higher than 770 °C, and in no case higher than 800 °C.

It is known that NaCl and KCl based flux with rare elements has the effect of covering protection when it is spread on the surface of melt. The flux film becomes more compact and hinders the melt from adsorbing hydrogen from atmosphere during the process of smelting [8–10]. Moreover, it can also adsorb the inclusions in molten aluminum and produce the purification effect.

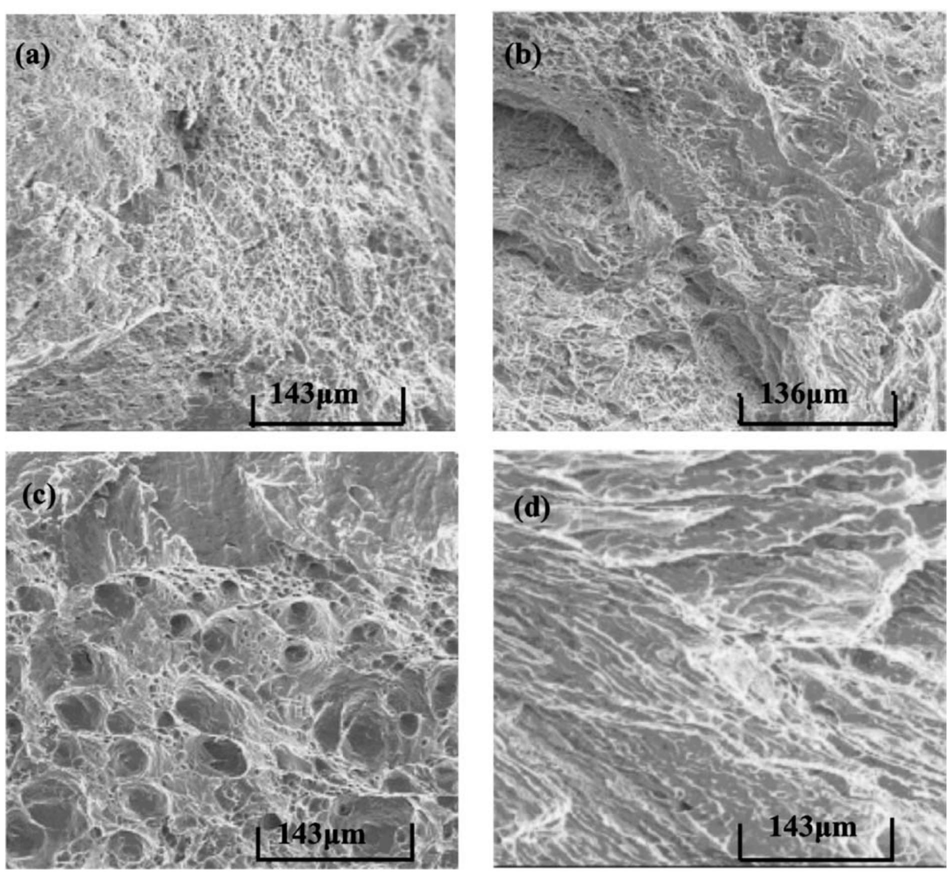

Figure 2 The scanning electron microscope photograph of specimen fracture at different temperatures: (a) 710 °C, (b) 750 °C, (c) 770 °C, and (d) 810 °C.

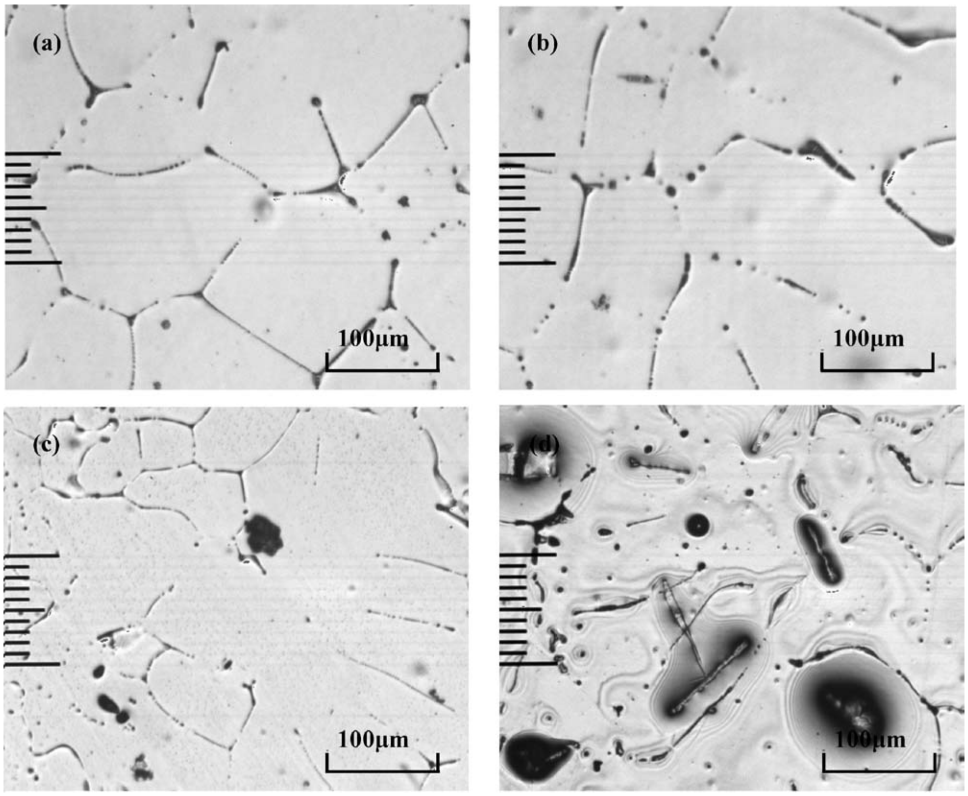

Figure 3 Microstructures of specimens at different temperatures (electrolytic etching): (a) 710 °C, (b) 730 °C, (c) 770 °C, and (d) 810 °C.

However, with the increase of melt temperature, the melt is stirred more violently. The flux film on the surface of melt will be easily corrupted. Accordingly, the effect of covering protection fails and the effect of purification becomes worse [11–14]. The content of gas and inclusions in the melt increases with the fading of purification effect. Gas porosity not only reduces the effective cross-sectional area of the cast, but also causes local stress concentration and forms crack source. Large inclusions also impair mechanical properties of castings significantly, especially the elongation percentage. As a result, both the strength and ductility of castings will decrease [15–17].

In conclusion, the suitable temperature range should be 690–750 °C when the NaCl and KCl based flux is used to purify the commercial purity aluminum melt. When the flux is properly used, the fracture mechanism is a microvoid coalescence mode. Otherwise, it will be a quasi-cleavage fracture or cleavage fracture, resulting in dramatic decrease in mechanical properties.

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