

# Research of quasi-solid fracture behavior of casting Al-4.5Cu alloys

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**Abstract:** The influencing mechanisms of elements Ti and Ce and their interactions on fracture behaviors of casting alloys Al-4.5Cu-0.6Mn were studied by observing tensile fracture behavior in quasi-solid zone under SEM and EDX instruments. The results indicate that the resistance stress against hot cracking can be improved obviously by addition of Ti, because of its grain refining function. It is also found that, when Ce is added into the alloys, besides its effect in refining crystalline, the mechanical behavior of lower melting point eutectic phase in quasi-solid zone can be improved efficiently by some compounds with Ce formed and deposited between dendrites. Therefore, a colligating effect of Ti and Ce on improving resistance stress against hot cracking is more efficient than that only single alloy element is applied. When hot cracking occurs, grains yield at first, and then crack spreads. Both inter-grain and trans-grain fractures are observed, but the major fracture manner is brittleness.

**Keywords:** casting Al-4.5Cu alloys; quasi-solid; fracture behavior; hot cracking

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## 1. Introduction

Casting Al-Cu alloy with high strength is widely used for its excellent properties in common temperature and high temperature applications. However, this family of alloys has a very special solidification behavior, i.e. wider solidification range, which will result in an inferior casting performance and severe tendency to hot cracking. Hot crack<sup>[1]</sup> is a very dangerous solidification defect in casting and welding processes. But, up to day, the research on hot cracking is still less than perfect and needs to progress further. Many of research results achieved in the last century<sup>[2-5]</sup> conclude that there is a close relationship between the quasisolid properties and hot cracking behaviors.

In order to find the mechanism of hot cracking<sup>[6-8]</sup>, the effect of alloying elements on the formation of hot cracking and the mechanical properties of Al-4.5Cu in quasi-solid zone during the solidification has been investigated in the present work.

The alloys at different temperature during the solidification have different ability to resist the fracture strain and stress because of the discrepancy between their variable solid fractions and their corresponding dendrite morphological shapes. The study of tensile test in quasi-solid zone at variable temperature during solidification is

of great significance. Based on the research method of Qingchun LI and applying SEM and EDX technologies, both fracture morphology and hot cracking behaviors for a set of alloy samples in quasi-solid zone under a tensile-loading strain test were investigated. In the study, effects of Ti, Ce, as well as their colligating effect, on the fracture behavior in quasi-solid region of Al-4.5Cu-0.6Mn were also included.

## 2. Experiment procedure

The influences of the alloy elements on the quasi-solid behavior and the formation of hot cracking are investigated through the fracture strain tests in quasi-solid region of Al-4.5Cu and the SEM observation on the tensile and rupture fractures of the alloy samples.

The device and the principle of applying tensile load into the quasi-solid zone can be referred to reference<sup>[6]</sup>. Melt alloy was poured at 720 °C then cooled in furnace and shrank freely till the temperature preset previously. And the tensile loading speed was 0.025 mm/s. The influence of 0.2% Ce and 0.3% Ti as well as their colligation on properties of quasi-solid fracture of Al-4.5Cu-0.6Mn was performed. The tensile fractures were observed under AMARY-1000 B.

## 3. Results and analysis

### 3.1 The results and the analysis of linear shrinkage rate test

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The experimental results of the quasi-solid tensile fracture stress against variable temperature for a set of alloy samples are summarized and illustrated in Fig. 1.

From the Fig. 1, we can see that the quasi-solid tensile stress values go up with temperature decreasing in the solidification process. When temperature continuously decreases, proliferous inflexions of tensile strength occurs. The increasing rate of tensile stress and the temperature of proliferous inflexions in the prophase were altered because of additive alloy elements.

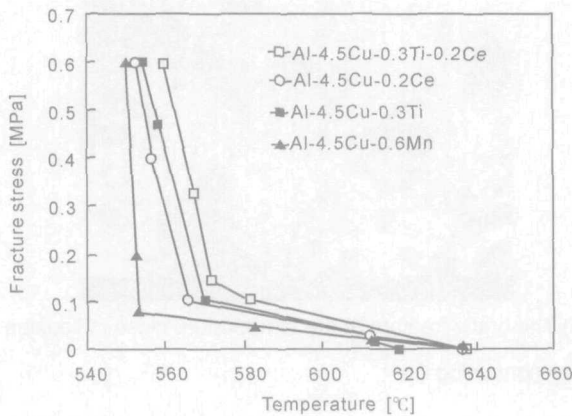


Fig.1 The fracture stress of experimental alloys in different temperature

The effect of single Ti or Ce and their colligation improves the increasing rate of tensile stress, moreover, the proliferous inflexions move to higher temperature. The result on the colligating effects of Ti and Ce indicates that the experimental alloys give a relatively rapid increasing rate of stress in a shorter temperature range during cooling. This means that the Ti and Ce additions into the experimental alloy play a role in reducing the tendency to hot cracking effectively.

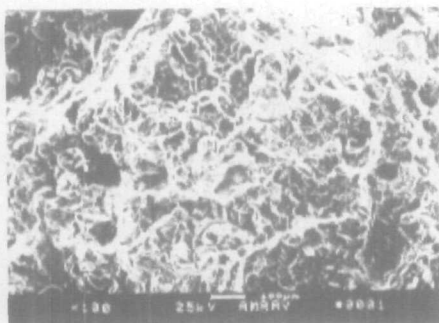
### 3.2 The observation on the fracture of quasi-solid tensile

Fig.2 is the microscopic images of quasi-solid tensile fractures of Al-4.5Cu alloy under the experiment. In Fig.2(a), there is much liquid remained and only fewer dendrites formed because of relatively higher temperature. While in Fig.2(b), the grains are arranged orderly; almost no "liquid silk" can be found between dendrites at the temperature; all of which cause to promote spreading of hot crack.

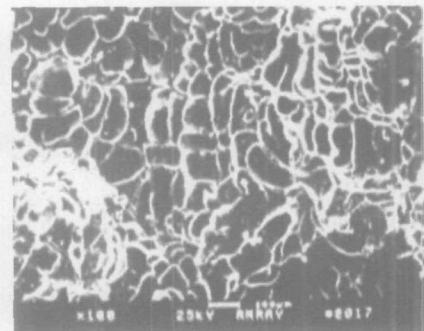
Fig.3 is the microscopic fracture of quasi-solid tensile of Al-4.5Cu-0.6Mn-0.3Ti. From Fig.3, we can see that the grains apart from each other severely in the case of higher temperature. The shape of grains is highly slipped because the grains are surrounded by the remaining liquid. The separation severity level of grains reduces slightly with temperature decreasing. However, the grain distortion on the fracture surfaces becomes more and more densely. At 550°C, only a small number of grains in tearing are found from the images, and most of fractures happen on breaking dendrites.

Fig.4 is the tensile fracture of alloy containing Ce (fracture temperature is about 610 °C). There are lots of tensile "silks" of liquid film that are arranged closely on the fracture at high temperature. Since Ce is always apt to segregate in grain boundaries, so it can be concluded that additive Ce improves the surface stiffness of liquid. At low temperature, since little liquid is existing, the bonding of grains is relatively firm, so the dendrite fracture shows a brittle manner.

Hence, Ti or Ce can reduce the temperature, at which the dendrite skeleton forms during the solidification, and the increasing of strength in the prophase of the solidification. Adding trace element of Mn to Al-4.5Cu has no influence on the function of Ti or Ce. This result is consistently with Qingchun LI's<sup>[6]</sup>.



(a) 620 °C



(b) 600 °C

Fig.2 The tensile fracture of Al-4.5Cu-0.6Mn at high temperature

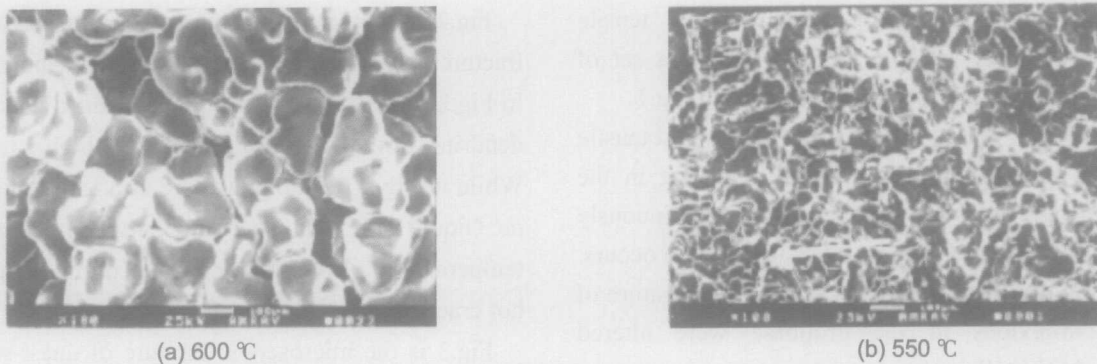


Fig.3 The tensile fracture of Al-4.5Cu-0.6Mn-0.3Ti at high and low temperature

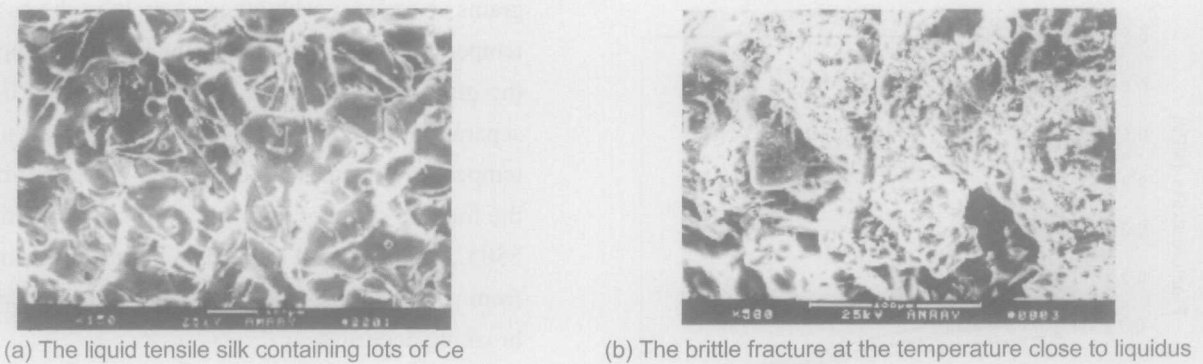


Fig.4 The tensile fracture of alloy containing Ce

Fig.4 and Fig. 1 reveal that Ti can put off the time when the stress begins to increase (the temperature goes down at which the stress begins to increase). And then, the bonding connections between dendrites are strengthened, as a result of finer grains, which detracts the stress concentration, so the tensile stress rises rapidly. The main fracture manner is brittle with little trace of plastic distortion existence.

Although the effectiveness of Ce in grain refining is less than that of Ti, for the latter, besides its refining function, it can also reduce the secondary dendrite arm spacing. Therefore, mechanical behaviors of eutectic with low melting point in quasi-solid zone can be improved significantly by Ti-compounds deposited between dendrites.

Compared Fig.5(b) or Fig.5(c) with Fig.5(a), the liquid existed in the former is less than that in the latter. For Al-4.5Cu-0.3Ti or Al-4.5Cu-0.2Ce, while hot cracking occurs, cracks intergranularly expand and compounds between dendrites break, too. So it can be concluded that the fracture temperature of Fig.5(b) or Fig.5(c) is lower than that of Fig.5(a), while the fracture stress of Fig.5(b) or Fig.5(c) is higher than that of Fig.5(a). This conclusion is accorded with the experimental data. There are lots of compounds containing Ce (something like muscle in bright) found from the experiment. These compounds can resist the stress under the shrinkage. So it weakens the negative effect of intergranular precipitates on the behavior in the solid and liquid region.

### 3.3 Fractography of hot cracking

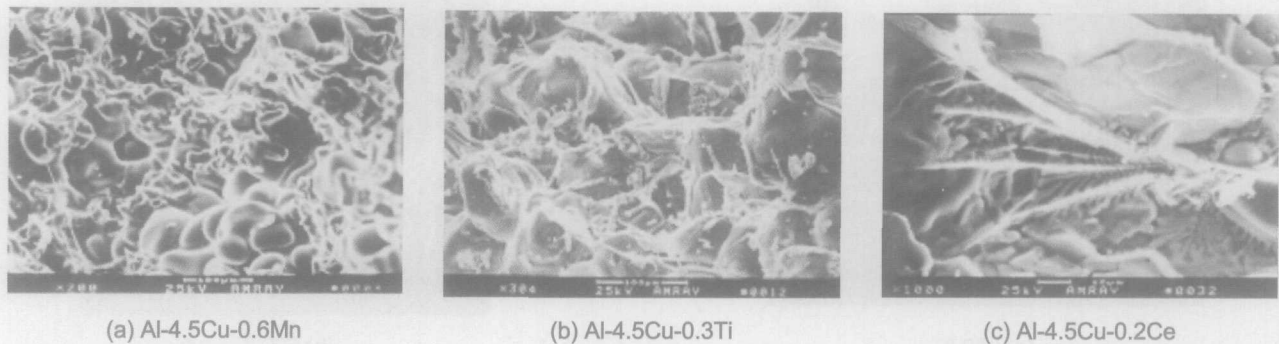


Fig.5 The typical fractography of the samples with the different components

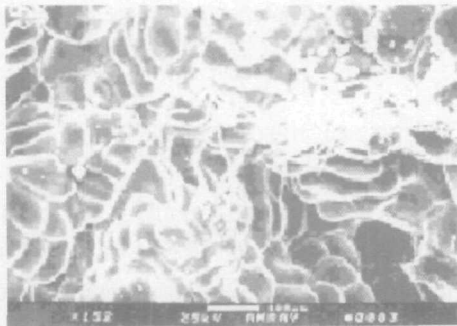
### 3.4 The feature of hot cracking fracture

For a long time, the behavior of hot cracking when the alloy's shrinkage is prevented in the solid and liquid region is a focus in research. Various opinions are put forward about what provide stress before hot cracking, what causes the hot cracking and how the hot cracking develops. Further evidences will be offered through the feature of hot cracking fracture fractography.

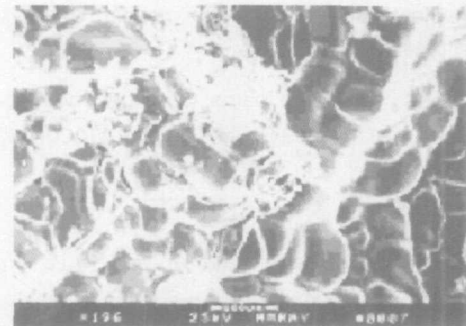
From the Fig.6 (a) and (b), we can see that two kinds of special morphology features on the fracture surface. The cracking trace proves that it is not very accurate to use the

explanation of brittle cracking or the strain exceeding the limit of plastic strain. It has been proved that the liquid film<sup>[7]</sup> cannot illuminate what affords the quasi-solid strength, while the theory of intergranular bridge<sup>[8]</sup> does not point out what is bridge definitely.

Therefore, it can be deduced that under the effect of shrinkage stress, the dendrite arms in the heat nodes bear stress intensity mostly, so at the beginning it yields, causes the grains separated, and then cracks expand quickly. The manner of the development is a mix of intergranular and transgranular fractures.



(a) The plastic fiber on the fracture layer



(b) The mix layer of intergranular and transgranular fracture

Fig.6 The typical hot cracking fracture of Al-4.5Cu

## 4. Conclusions

(1) Resistance stress against hot cracking can be improved significantly by applying additive Ti because of its refining crystalline function;

(2) When Ce is added into the alloys, besides its refining function, mechanical behavior of eutectic with low melting point in quasi-solid region can be improved efficiently by the compounds with Ce deposited between dendrites;

(3) Colligating effects of Ti and Ce on increasing resistance stress against hot cracking is more efficient than that only single alloy element is applied;

(4) When hot cracking occurs, grains firstly yield, then spread. Intergranular fracture and transgranular fracture are both represented, but the main fracture way is

brittleness.

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