An investigation on mechanical properties of ($Al_{63}Cu_{25}Fe_{12}$)p/ZL101 composites by squeeze casting

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Abstract: Influence of different extrusion pressures and pouring temperatures on comprehensive performance of ($Al_{63}Cu_{25}Fe_{12}$)p/ZL101 composites is studied in this paper. The results show that the tensile strength, elongation and hardness of ($Al_{63}Cu_{25}Fe_{12}$)p/ZL101 composite increase with the squeezing pressure increasing from 50 MPa to 100 MPa, and gradually reduce from 100 MPa to 150 MPa. In addition, the mechanical properties of the composite can be improved with pouring temperature growing, while the temperature should not exceed 760 ℃. When squeezing pressure is 100 MPa and pouring temperature is 720 ℃, mechanical properties of composites are the best. Finally, the mechanical properties of ($Al_{63}Cu_{25}Fe_{12}$)p/ZL101 composite will be improved by suitable heat treatment technology.

Key words: ($Al_{63}Cu_{25}Fe_{12}$)p/ZL101 composites; quasicrystalline; heat treatment; squeeze casting

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0 Introduction

In order to get higher properties of metal or alloys, one of the best methods is adding a kind of hard second phase[1-2]. About 20 years ago, SiC as a second phase was widely used for improving material properties. But the interfacial reaction between SiC and alloys (such as Al alloys) could be induced during casting with high temperature, which results in lower ductility and tensile strength[3]. Furthermore, the particles of SiC tend to agglomerate to form clusters because of the poor wettability between SiC and alloys[4].

The quasicrystalline (QC) phases have been used to reinforce metal or alloys lately, due to its high hardness and strength, low coefficient of friction and good wear resistance[5-8]. And the wettability between QC and matrix is better compared with SiC[9]. Recently, there has been a great of interest in the new field that metal or alloys matrix composites reinforced with QC particles. Ali F et al.[9] studied the interfacial reaction between Al-based metal matrix composites and Al-Cu-Fe QC particles. It is found that the yield strength has been remarkably enhanced by the reaction of QC-to-ω phase (ω: $Al_7Cu_2Fe_1$) transformation. In addition, Kaloshkin et al.[10] prepared Al/Al-Cu-Fe composites by mechanically alloyed. No pore can be seen in the composite alloy formed by this method. Other researchers have studied the similar methods that improve mechanical properties of matrix with QC. For example, Litynska-Dobrzynska et al.[11] reported that Al matrix composites reinforced by different contents of $Al_{65}Cu_{20}Fe_{12}$ QC particles (20, 40 and 60 wt.%) with vacuum hot pressing technique. The QC phase with the content of 20 wt.% and 40 wt.% does not change after consolidation, but when the content of QC phase is 60 wt.%, its approximant (Al_2Cu) is formed at the $Al/Al_{65}Cu_{20}Fe_{12}$ interfaces and inside, and compressive strength is up to 370 MPa.

In this paper, the $Al_{63}Cu_{25}Fe_{12}$ QC powder reinforcing ZL101 is produced by squeeze casting. The effects of squeeze pressure and heat treatment on

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mechanical properties of composite materials are analyzed.

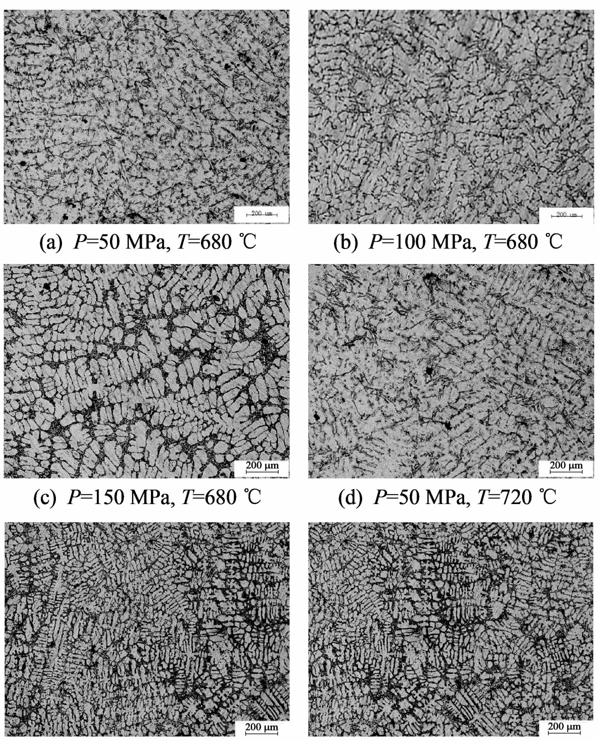
1 Experiment

This paper has selected the $Al_{63}Cu_{25}Fe_{12}$ quasicrystal particles as reinforced particles and the ZL101 as matrix material. The ingot of $Al_{63}Cu_{25}Fe_{12}$ alloy is obtained by casting method[12-13]. After heat treatment, the ingot is crushed by simple physical crushing, then the $Al_{63}Cu_{25}Fe_{12}$ alloy is ball milled in the planetary ball mill at 140 rpm. Powders with 100—200 mesh have been selected. Then the QC powders are added to ZL101 alloy under 600 ℃ when the alloy is in a semi-solid state. After fully mixing, the alloy liquid is poured on extrusion machine. The pouring temperature is 680, 720 and 760 ℃, and the extrusion pressure is 50, 100 and 150 MPa, respectively. Time holding is 20 s. In order to reduce the oxide inclusion during the casting, a purified argon atmosphere is carried out.

2 Results and discussion

2.1 Effects of extrusion pressure on microstructure of ($Al_{63}Cu_{25}Fe_{12}$) p/ZL101 composite

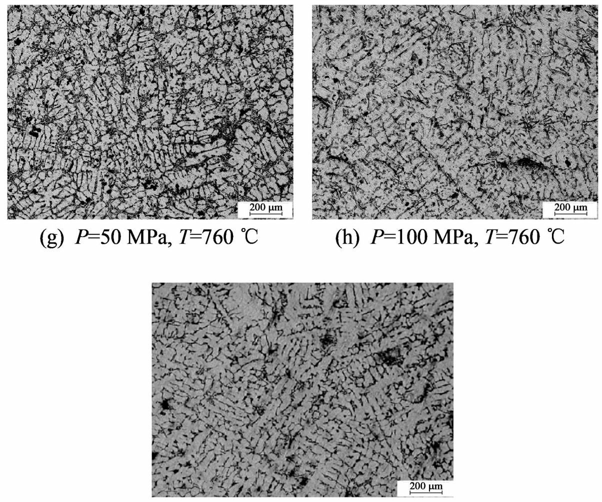
The microstructure of ($Al_{63}Cu_{25}Fe_{12}$) p/ZL101 composite under different pouring temperatures and extrusion pressures are shown in Fig. 1.



(a) P=50 MPa, T=680 ℃ (b) P=100 MPa, T=680 ℃

(c) P=150 MPa, T=680 ℃ (d) P=50 MPa, T=720 ℃

(e) P=100 MPa, T=720 ℃ (f) P=150 MPa, T=720 ℃



(g) P=50 MPa, T=760 ℃ (h) P=100 MPa, T=760 ℃

(i) P=150 MPa, T=760 ℃

Fig. 1 Metallographic structure of ($Al_{63}Cu_{25}Fe_{12}$) p/ZL101 composite

It can be found that primary α-Al phase becomes finer and its shape changes from developed dendrite to rose-shape with the increase of extrusion pressure. In order to further understand the change of grain size, the average diameters of primary α-Al have been measured by straight-line method. The results are shown in Fig. 2.

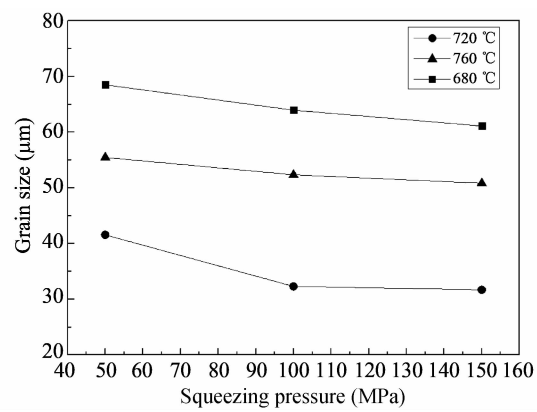


Fig. 2 Average diameters of primary α-Al phase

When pouring temperature is 680 ℃ and extrusion pressure is 50 MPa, the primary α-Al alloy phase exhibits well-developed dendritic morphology, and the average grains size of primary dendrite is 68.52 μm. When extrusion pressure is 100 MPa, the coarse primary α-Al phase has changed into rose-shape and average particles diameter is 63.96 μm. When extrusion pressure is 150 MPa, the strips of eutectic Si are interrupted into punctation or fine acicula.

When pouring temperature is 720 ℃ and the extrusion pressure is 50 MPa, primary α-Al phase shows a well-developed dendritic morphology. But average diameter of α-Al phase has decreased 39.8% comparing with the primary Al phase (Fig. 1(a)). When the pressing pressure is 100 MPa, grain size of primary α-Al phase becomes smaller significantly, and some spherical α-Al grains appear. When the extrusion pressure is 150 MPa, grain size of primary-Al phase has no obvious change, while the eutectic Si phase becomes finer. At the same time, we find that this experimental organization is compact and does not exist hole comparing with other groups.

When pouring temperature is 760 ℃ and the extrusion pressure is 50 MPa, primary α-Al developes dendritic morphology too. But there are some defects, such as the shrinkage cavity is still there with the increase of pressure.

The SEM microstructures of ($Al_{63}Cu_{25}Fe_{12}$) p/ZL101 composite with extrusion pressure of 100 MPa and pouring temperature of 720 ℃, are shown in Fig. 3. The black gray is the primary α-Al and precipitated phase is eutectic Si phase. The eutectic Si is distributed in composite. The results agree with metallographic structure.

Fig. 3 SEM structures of ($Al_{63}Cu_{25}Fe_{12}$)p/ZL101 composite

2.2 Effects of extrusion pressure on properties of ($Al_{63}Cu_{25}Fe_{12}$)p/ZL101 composite

The mechanical properties of ($Al_{63}Cu_{25}Fe_{12}$) p/ZL101 composite under different extrusion pressure are shown in Fig. 4.

When the extrusion pressure is between 50 MPa and 100 MPa, the tensile strength, elongation and hardness increase with the increase of pressure. When the extrusion pressure is between 100 MPa and 150 MPa, the tensile strength, elongation and hardness of the compound gradually reduce as the increase of pressure. Therefore, when pouring temperature is appropriate and the extrusion pressure is 100 MPa, composites with better mechanical properties can be obtained.

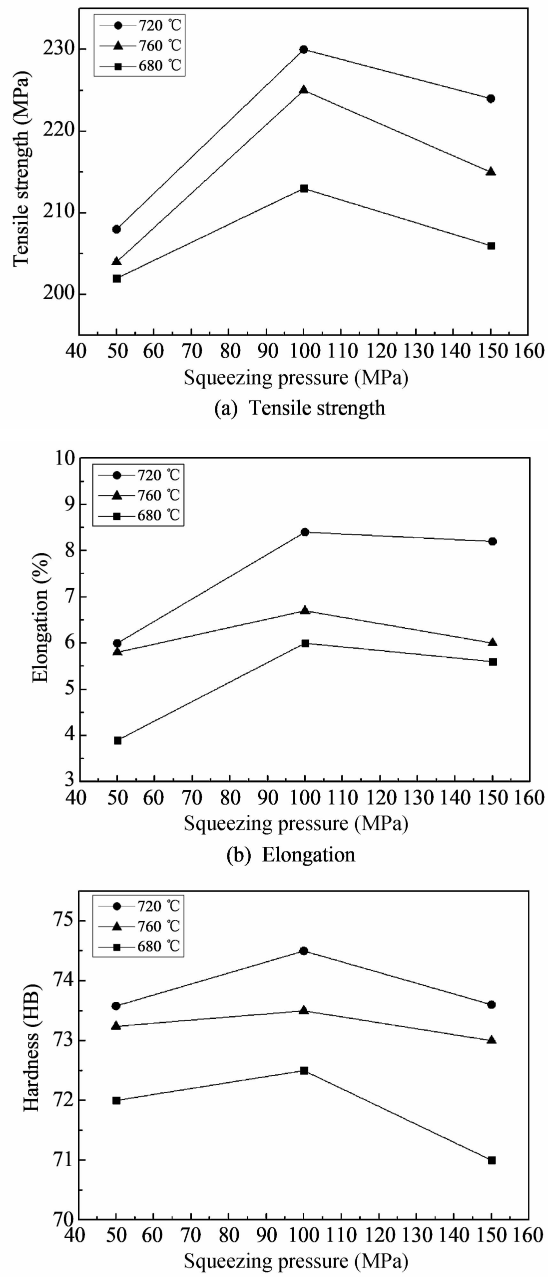


Fig. 4 Mechanical properties of ($Al_{63}Cu_{25}Fe_{12}$) p/ZL101 composite

2.3 Effects of pouring temperature on ($Al_{63}Cu_{25}Fe_{12}$) p/ZL101 composite

When the extrusion pressure is 100 MPa, the composites exhibit excellent mechanical properties. So the microstructure and performance of $Al_{63}Cu_{25}Fe_{12}$/ZL101 composite are analyzed, the extrusion pressure is 100 MPa and pouring temperatures are 680, 720 and 760 ℃, respectively.

When pouring temperature is relative lower (680 ℃), it is not good for filling, and it is easy to produce cold shuts and misrun defects. Therefore its mechanical properties are relatively low. The tensile strength, elongation and hardness of composites are 213 MPa, 6.0% and 72.50 HB, respectively.

When the pouring temperature is 760 ℃, the melt splash easily and would produce "burr", and then serious shrinkage cavity and porosity defects can be formed in the process of extrusion casting. These defects will reduce the mechanical properties of the composite, and its tensile strength, elongation and hardness are 225 MPa, 6.7% and 73.50 HB, respectively. In addition, if the pouring temperature is too high, it will reduce the lifetime of the die. At the same time, it will make the liquid metal get a lot of oxidation, and directly affect the quality of composite materials.

Suitable pouring temperature is particularly critical for extrusion casting of aluminum based composite materials, which can improve the filling ability and prevent the defects. A large number of experiments show that properties of $Al_{63}Cu_{25}Fe_{12}$/ZL101 composite material are the best when the pouring temperature is 720 ℃.

2.4 Influence of heat treatment on microstructure and properties of ($Al_{63}Cu_{25}Fe_{12}$)p/ZL101 composite

In general, the mechanical properties of casting aluminum alloy can't meet the using requirements. The mechanical properties of the alloy, such as tensile strength and hardness, can be improved significantly by heat treatment. And the heat treatment can also eliminate internal stress and improve the internal segregation and microstructure of alloy internal.

The optimum process parameters (the extrusion pressure is 100 MPa and pouring temperature is 720 ℃) have been selected in as-cast specimen for heat treatment. And the heat treatment process is as follows: solid solution process is 535 + 5 ℃/8h followed by water quenching, and aging process is 180+5 ℃/6h.

The microstructures of ($Al_{63}Cu_{25}Fe_{12}$) p/ZL101 composite material under as-cast condition and after heat treatment state are shown in Fig. 5.

The organization of eutectic Si alloy have changed a lot after heat treatment. In the as-cast condition, eutectic Si have exhibited acicular or strip shape and dispersed in the primary α-Al grain boundary. But the morphologies of the eutectic Si are not uniform and have different lengths, which is easy to split the matrix and reduce the mechanical properties of the alloy. As shown in Fig. 5(b), the chunk or long eutectic Si have melted, and finally changed into spherical or ellipsoidal shape after heat treatment. They are evenly distributed in the base of α-Al, which is beneficial for the mechanical properties of composite materials.

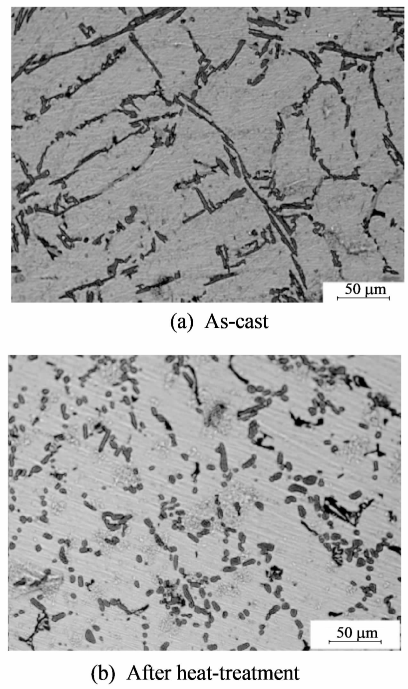


Fig. 5 Microstructures of $Al_{63}Cu_{25}Fe_{12}$/ZL101 composite

The mechanical properties of $Al_{63}Cu_{25}Fe_{12}$/ZL101 composite in as-cast and heat-treatment conditions are listed in Table 1. After heat treatment, the mechanical properties of composite materials are increased. Its tensile strength has increased from 230 MPa to 308 MPa, rising by 34.6% and the hardness of as-cast condition has increased from 74.5 HB to 110.4 HB, rising by 48.2%.

Table 1 Mechanical properties of $Al_{63}Cu_{25}Fe_{12}$/ZL101 composite in as-cast and heat-treatment conditions

State	Tensile strength σ_b(MPa)	Hardness (HB)	Elongation δ (%)
($Al_{63}Cu_{25}Fe_{12}$)p/ZL101	230	74.5	8.4
($Al_{63}Cu_{25}Fe_{12}$)p/ZL101-T6 308	308	110.4	10.5

The strengthening mechanisms of composite are also discussed. The main strengthening mechanisms are as follows:

1) The number of grains in a unit volume increases with the addition of quasicrystal particles, and the grains will be refined. Fine grains in material can significantly improve the mechanical properties.

2) The $Al_{63}Cu_{25}Fe_{12}$ quasicrystal is an important

strengthening phase for aluminium alloy due to high hardness and good wettability. In addition, some Cu atoms diffuse into the aluminum matrix, which are mainly acted as solution strengthening elements in heat-treatment course.

3 Conclusion

($Al_{63}Cu_{25}Fe_{12}$)p/ZL101 composite is prepared by squeeze casting method in this paper. The influences of the extrusion pressure, pouring temperature and heat treatment on the mechanical performance of ($Al_{63}Cu_{25}Fe_{12}$)p/ZL101 composite are also studied. The main conclusions are summarized as follows:

1) When pouring temperature is certain, the defects decrease and mechanical properties of composites are improved with the increase of squeezing pressure during 50 MPa to 100 MPa. These properties gradually reduce from 100 MPa to 150 MPa. In short, the alloy has best mechanical properties while the extrusion pressure is 100 MPa.

2) When the extrusion pressure is certain, the mechanical properties of the composite have increased with the rising of pouring temperature. But when pouring temperature continues increasing, its mechanical performance is significantly reduced. So the optimal casting temperature is 720 ℃.

3) The mechanical properties of the composite are improved greatly after heat treatment. Its tensile strength has increased from 230 MPa to 308 MPa, rising by 34.6% and the hardness of as-cast condition has increased from 74.5 HB to 110.4 HB, rising by 48.2%.

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挤压铸造法对($Al_{63}Cu_{25}Fe_{12}$)p/ZL101复合材料性能的影响

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摘　要： 研究了挤压压力和浇注温度对($Al_{63}Cu_{25}Fe_{12}$)p/ZL101复合材料性能的影响。结果表明：当挤压压力为50－100 MPa时，复合材料的抗拉强度、伸长率和硬度会随着压力的增加而增大，然而当挤压压力为100－150 MPa时，随着压力的升高，其综合力学性能会随之下降。此外，复合材料的力学性能会随着浇注温度的升高而提高，但温度不能超过760 ℃。当挤压压力为100 MPa，浇注温度为720 ℃时，复合材料的综合力学性能最优。最后，选择合适的热处理工艺来进一步提高复合材料的力学性能。

关键词： ($Al_{63}Cu_{25}Fe_{12}$)p/ZL101复合材料；准晶；热处理；挤压铸造

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