Study on the Microstructure and Mechanical Properties of High Strength and Toughness Al-9Si-Mn-Mg-xCu Casting Alloy

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Abstract: With the development of automobile lightweight, lightweight structures and lightweight materials are increasingly used in the automobile manufacturing industry. Aluminum alloy has become the first choice for lightweight materials in automobiles due to its many advantages such as low density, high specific strength, good corrosion resistance, and easy forming. At present, cast aluminum alloy accounts for the highest proportion of automotive aluminum, among which, the largest amount is Al-Si cast alloy. Ordinary Al-Si cast aluminum alloy has good casting performance, but its strength is low and toughness is poor, which is not suitable for the manufacture of load-bearing structural parts such as automobile shock absorbing towers, suspension arms, engine mounts, subframes (it requires the tensile strength of cast aluminum alloy parts≥300 MPa, the yield strength≥200 MPa, and the elongation≥12%).

In order to obtain high-strength and high-toughness cast aluminum alloy materials, methods and means such as solution strengthening (adding Cu, Mg, Mn, Ti and other elements), fine-grain strengthening and heat treatment strengthening are usually used. Among them, heat treatment strengthening requires aluminum alloy castings to have a very low porosity. Obviously, the ordinary die casting process cannot meet the requirements. Squeeze casting and high vacuum die-casting technology are very suitable for the forming and processing of high-strength and tough, heat-treatable strengthened cast aluminum alloys. Therefore, three alloys of Al-9Si-0.4Mn-0.25Mg-xCu (x=1.0 wt.%, 2.0 wt.%, 3.0 wt.%) with different Cu contents were designed. The microstructure and mechanical properties of Al-9Si-0.4Mn-0.25Mg-xCu alloy prepared by squeeze casting and high vacuum die-casting were studied, and the effects of copper content and T6 treatment (solution treatment and peak aging) on the microstructure, precipitated phase and mechanical properties of Al-9Si-0.4Mn-0.25Mg-xCu alloy were analyzed, and the similarities and differences between the two processes were compared and analyzed.

Keywords: Squeeze casting, High vacuum die casting, High strength and toughness AlSiMgMnCu alloy, Heat treatment, Microstructure, Mechanical property

1 Introduction

At present, the development and exploration of lightweight materials is an important development direction to realize the lightweight of automobiles. The density of aluminum alloy is 1/3 that of steel, the specific strength is high, the electrical and thermal conductivity is good, the corrosion resistance is good, the impact toughness is better, about twice that of steel, and it has excellent performance in the fuel consumption, acceleration, braking, and handling of automobiles[1]. Therefore, aluminum alloy is the material of choice for lightweight automobiles. At present, cast aluminum alloy accounts for the highest proportion of aluminum used in automobiles. Cast aluminum alloys are mainly divided into Al-Si series, Al-Cu series, Al-Mg series and Al-Zn series alloys. Among them, Al-Si alloys have been studied as structural materials in the automotive and aerospace industries due to their excellent castability, low coefficient of thermal expansion, and good wear resistance and corrosion resistance[2-5]. However, Al-Si alloys generally have low strength and toughness, which is difficult to meet the requirements of the automotive industry for high-strength and high-toughness structural parts, so some strengthening elements such as Cu are usually added to further improve the mechanical properties of the alloys by heat treatment[6, 7].

Casting forming technology is the main technology for aluminum alloy forming for automobiles, and the most widely used technology is die-casting forming technology. However, ordinary die castings are prone to entrapment during the forming process and reduce elongation. On the contrary, high vacuum die casting technology and squeeze casting technology can effectively reduce porosity and inclusions, and the formed castings not only have high density, but can also be heat treated to improve their mechanical properties. Therefore, it is of great significance to explore the effects of squeeze casting and high vacuum die-casting on the microstructure and mechanical properties of high-strength and toughness Al-Si casting alloys.

缺少 Experimental procedure， Result and discussion 等文章主体内容

3 Conclusion

(1) Squeeze casting Al-9Si-0.4Mn-0.25Mg-xCu alloys mainly include α-Al, Al-Si eutectic, α-Fe, θ phase (Al_2Cu) and Q phase ($Al_5Cu_2Mg_8Si_6$). With the increase of Cu content, the contents of θ phase and Q phase in Al-9Si-0.4Mn-0.25Mg-xCu alloy increased, and the change of θ phase was the most obvious. The tensile strength and yield strength of Al-9Si-0.4Mn-0.25Mg-xCu alloy increased with the increase of Cu content, and the elongation decreased gradually. Among the three alloys, Al-9Si-0.4Mn-0.25Mg-1.0Cu alloy has the best comprehensive mechanical properties, with tensile strength, yield strength and elongation of 252 MPa, 137 MPa and 8.5%, respectively. With the increase of Cu content, the number of dimples and

tear ridges on the fracture surface decreased, the number of microcracks increased, and the porosity increased.

(2) When the solution temperature is constant, with the extension of the solution time, the Si phase in the squeeze casting Al-9Si-0.4Mn-0.25Mg-xCu alloy will coarse and grow, the content of θ phase and Q phase will decrease rapidly, the tensile strength and yield strength of the alloy will gradually increase, and the elongation will decrease. When the solution time is constant, with the increase of solution temperature, the contents of θ phase and Q phase in the alloy decrease, and the tensile strength and yield strength of the alloy increase, and the elongation does not change significantly. The tensile strength, yield strength and elongation of squeeze-cast Al-9Si-0.4Mn-0.25Mg-1.0Cu alloy at 530°C for 4h were 292 MPa, 156 MPa and 13.2%, respectively.

(3) With the increase of Cu content, the average length and size of Q' and θ' precipitated phases in the squeeze-cast Al-9Si-0.4Mn-0.25Mg-xCu alloy decreased, and the area fraction and number density of Q' and θ' phases increased. When the Cu content is 1.0 wt.%, the precipitate phase is dominated by the Q' phase, and when the Cu content increases to 3.0 wt.%, the precipitate phase is dominated by the θ' phase. Among the three alloys, Al-9Si-0.4Mn-0.25Mg-1.0Cu alloy T6 (530°C×3 h+180°C×4 h) has the highest elongation, and its tensile strength, yield strength and elongation are 340 MPa, 255 MPa and 9.8%, respectively. The strength of Al-9Si-0.4Mn-0.25Mg-3.0Cu alloy T6 (530°C×3 h+180°C×5 h) is the highest, and its tensile strength, yield strength and elongation are 404 MPa, 317 MPa and 7.7%, respectively. The tensile fractures of Al-9Si-0.4Mn-0.25Mg-xCu alloy in the peak aging state after different solution temperatures are basically mixed fracture forms, and the brittle fracture characteristics of Al-9Si-0.4Mn-0.25Mg-xCu alloy become more obvious with the increase of Cu content under the same solution treatment process, and the ductile fracture characteristics of Al-9Si-0.4Mn-0.25Mg-xCu alloy become more obvious with the increase of solution treatment temperature under the same alloy treatment process.

(4) The microstructure of Al-9Si-0.4Mn-0.25Mg-1.0Cu alloy is plum-shaped, mainly composed of α-Al, Al-Si eutectic, α-Fe, θ phase and Q phase, and its tensile strength, yield strength and elongation are 296 MPa, 130 MPa and [8] .

11.4%, respectively. In the T6 state (530°C×3 h+180°C×4 h), the precipitated phases in the alloy are mainly Q' phase and θ' phase, and the alloy has the best comprehensive mechanical properties, with tensile strength, yield strength and elongation of 346 MPa, 245 MPa and 14.2%, respectively. The high-vacuum die-cast Al-9Si-0.4Mn-0.25Mg-1.0Cu alloy exhibited ductile fracture.

(5) Compared with the squeeze-cast Al-9Si-0.4Mn-0.25Mg-1.0Cu alloy, the microstructure of the high-vacuum die-cast Al-9Si-0.4Mn-0.25Mg-1.0Cu alloy is similar, but the grain size of α-Al is smaller and the porosity is lower. Under the same heat treatment state (T6: 530°C×3 h+180°C×4 h), compared with the squeeze casting state, the Q' phase size in the high-vacuum die-casting Al-9Si-0.4Mn-0.25Mg-1.0Cu alloy was larger, while the θ' phase was smaller, and the content of the two precipitated phases increased significantly. There is little difference in the strength of the alloys formed by the two processes, but the elongation of the high-vacuum die-cast Al-9Si-0.4Mn-0.25Mg-1.0Cu alloy specimens before and after heat treatment is higher, and the as-cast and heat-treated specimens show ductile fracture.

References

[1] Armao F G. Design & fabrication of aluminum automobiles[J]. Welding Innovation, 2002, 19(2): 2-6.
[2] Wu W, Gong M, Wei B, et al. Atomistic modeling of interface strengthening in Al-Si eutectic alloys[J]. Acta Materialia, 2022, 225: 117586.
[3] Cho Y H, Kim H W, Lee J M, et al. A new approach to the design of a low Si-added Al-Si casting alloy for optimising thermal conductivity and fluidity[J]. Journal of Materials Science, 2015, 50: 7271-7281.
[4] Liu Y Q, Wei S H, Fan J Z, et al. Mechanical properties of a low-thermal-expansion aluminum/silicon composite produced by powder metallurgy[J]. Journal of Materials Science & Technology, 2014, 30(4): 417-422.
[5] Liang Z X, Ye B, Zhang L, et al. A new high-strength and corrosion-resistant Al-Si based casting alloy[J]. Materials Letters, 2013, 97: 104-107.
[6] Niu G, Wang Y, Zhu L, et al. Fluidity of casting Al-Si series alloys for automotive light-weighting: a systematic review[J]. Materials Science and Technology, 2022, 38(13): 902-911.
[7] Ravi K R, Pillai R M, Amaranathan K R, et al. Fluidity of aluminum alloys and composites: A review[J]. Journal of Alloys and Compounds, 2008, 456(1-2): 201-210