Crack Initiation Mechanism in Casting AC4B Aluminum Alloy Parts with Complex Structure

Daliang Yu[1], Wen Yang[2], Wanqing Deng[2], Songzhu Zhu[2], Qingwei Dai[1, 3*], Dingfei Zhang[3]
1 School of Metallurgy and Materials Engineering, Chongqing University of Science and Technology, Chongqing, 401331, China.
2 Chongqing Zhicheng Machinery Co., LTD, Chongqing, 400039, China.
3 College of Materials Science and Engineering, Chongqing University, Chongqing, 400045, China
*Corresponding address: e-mail: daiqingwei@cqust.edu.cn (Q. Dai)

Abstract: Hot tearing is a common defect observed in aluminum (Al) components with intricate geometries. In this study, optical microscopy (OM), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and the finite difference method (FDM) were employed to investigate the mechanisms underlying hot tearing in cast AC4B aluminum alloy engines. Shrinkage porosities, ranging from 300 to 500 μm in size, were identified near the surface of the cast specimens. Additionally, numerous fractured brittle Fe-bearing phases were detected on the crack surfaces of the castings. Analysis of the secondary dendrite arm spacing (SDAS) across five typical locations revealed that the cooling rate at position 5 was significantly higher than at position 1. The improper solidification sequence between these positions disrupted the feeding of liquid metal to position 1 during solidification, potentially resulting in casting defects or crack formation. Numerical simulations further corroborated these findings, demonstrating that the solidification sequence influenced defect formation, consistent with the microstructural observations. Moreover, impurity accumulation was observed at position 5 during the filling process. The study concludes that the presence of large β-Fe intermetallics, coupled with an improper solidification sequence, jointly contributed to crack initiation in the aluminum engine components.

Keywords: Aluminum alloy, casting defects, casting sequence, microstructure

1 Introduction

To enhance vehicle fuel efficiency, aluminum (Al) alloys have been increasingly employed as engineering materials in the automotive industry. Among them, Al-Si-Cu series cast alloys are widely utilized for engine components and engine blocks due to their superior castability and excellent mechanical properties at both ambient and elevated temperatures. However, the performance of cast Al alloy components is influenced by various factors, including alloy composition, casting techniques, and processing parameters. Common casting defects such as hot tearing, brittle secondary phases, porosity, and solidification shrinkage can significantly degrade the mechanical performance of these components in service.

The newly developed cast AC4B Al alloy engine, characterized by its complex structural design, has frequently exhibited hot cracking at specific locations. Understanding the mechanisms of hot crack initiation in these engines is crucial for enhancing product quality and provides valuable insights into the interplay between component geometry and casting defects.

In this study, the microstructural evolution in five representative regions of the engine components was examined to elucidate the changes occurring during the casting process. Detailed observations of crack surfaces were performed to investigate the mechanisms of crack initiation during manufacturing. Numerical modeling techniques were also applied to analyze the temperature distribution and solidification sequence during casting. The relationship between microstructure, solidification behavior, and crack initiation mechanisms in the cast alloys was systematically evaluated.

2 Experimental procedure

The materials used in this study were AC4B Al alloys. The chemical compositions of the alloys were measured by the optical emission spectrometer, the results were 9.26 wt.% Si, 2.89 wt.% Cu, 0.65 wt.% Mg, 0.78 wt.% Zn, 0.86 wt.% Fe, 0.12 wt.% Mn and the balance Al. The melt was refined at 700 ^{o}C then casted by low pressure die casting. After casted, the engines were successively processed by decore, solution treatment, quenching and aging treatment. The casted, quenched and aging treated specimens were chosen for microstructure observation. These specimens were cut into two parts, microstructure observation was carried out on the cross section in different positions. SEM and optical microscope were used for microstructure observation. The specimens and positions that selected for microstructure were illustrated in Fig.1. Five typical positions were chose. The position 3 is in the button of engine and position 4 is in the top of engine. The casted, quenched and aged engine were tested by eddy current inspection. If macro cracks were detected, then the crack area were cut off and specimens were break into two parts along cracks for crack surface observation.

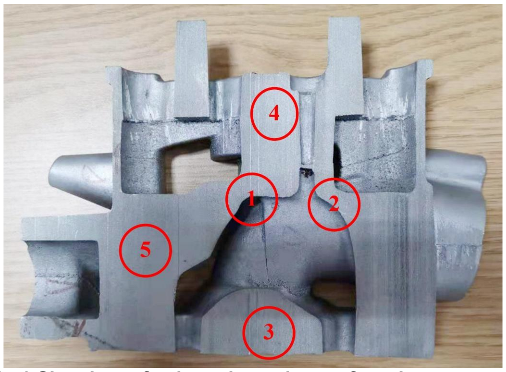

Fig.1 Sketches of selected specimens for microstructure observation

3 Result and discussion

Solidification sequence

The secondary arm spacing and solidification sequence of eligible specimens were shown in Table 1. In order to obtain precise secondary arm spacing, hundreds of secondary dendrite were measured for each position. It can be seen that the specimens in different positions had different secondary arm spacing.

Table 1 Secondary arm spacing and solidification sequence of rejected specimens

Position	Statistical magnitude	Secondary Arm Spacing	Solidification sequence
1	795	48.8	
2	504	39.8	
3	413	52.2	4 2 5 1 3
4	308	22.2	
5	830	42.2	

The cooling rate and solidification sequence has a great influence on casting quality. Since the engine had a complex structure, the cooling rate was various in different positions that result in the unpredictable solidification sequence, impertinent solidification sequence could lead to casting defects.

Crack initiation mechanisms

During casting process in AC4B alloy, casting defects were closely related with casting techniques especially cooling rate. As discussed above, since the engine had complex structure, the unexpected solidification sequence resulted in casting defects. What was worse, these casting defects might promote crack initiation. In casting Al alloys, the plate-shaped β-Fe (β-AlxFeySiz) was always considered to be the most detrimental intermetallic in crack initiation. The crack initiation mechanisms in the engine could be summarized in Fig.2.

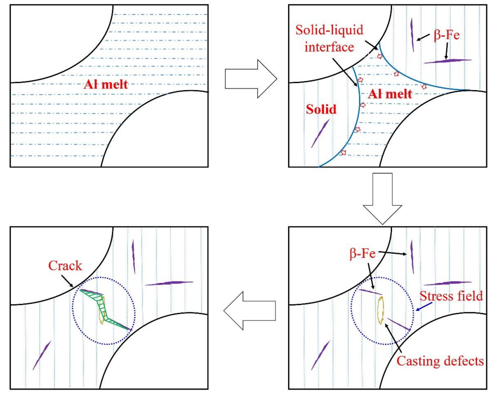

Fig.2 Sketches of crack initiation during casting in position 1

Fig.2 showed the sketches of crack initiation in position 1. During casting process, the solid-liquid interface converged at position 1. The improper solidification sequence impeded solidification feeding in position 1, and two interfaces' interaction could cause air entrainment. As the result, casting defects emerged in position 1. Since the solidification feeding was hindered, the solidification contraction induced stress field in this region. Plate-shaped β-Fe precipitated in Al alloy. In stress field, the elasticity and plasticity incompatibility between β-Fe and Al matrix lead to crack initiation in these region. The presence of casting defects facilitated crack coalescence with each other in the stress field. Therefore, cracks were frequently found in position 1.

4 Conclusion

- Fe-bearing bulk was found in crack surface, the cracked big compound with many cleavage-liked features. There brittle Fe-bearing phase would promote crack initiation in service, and lead to deteriorative mechanical properties.
- The secondary dendrite arm spacing in five typical positions were significantly different. The secondary dendrite arm spacing in position 5 is smaller than that in position 1. The variation of secondary dendrite arm spacing is related to cooling rate during casting.

5 Acknowledgments

This work was sponsored by Zhicheng Company, Chongqing Science and Technology Commission (cstc2018jcyjAX0607, cstc2019jcyj-msxmX0284), Scientific and Technological Research Program of Chongqing Municipal Education Commission (KJQN201801523), Project funded by China Postdoctoral Science Foundation (2019M653317, 2016T90831, 2015M572447), Chongqing Talent Project (CQYC201905100).