Enhanced Melt Quality Rapid Analysis of Aluminum Alloy Assisted by Machine Learning

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Abstract: The quality of aluminum alloy melts decisively influences the molding process and mechanical properties of castings. Rapid and accurate pre-pour inspection of melt quality has significant engineering value and scientific significance. This research conducts temperature measurement experiments on aluminum alloy melts to obtain cooling curves. Algorithms to identify characteristic values during the solidification process of aluminum alloy melts are proposed and developed. A database on the quality of aluminum alloy melts is established. Data including cooling curves and characteristic values obtained during the solidification process of the aluminum alloy melts utilizing algorithms such as random forests, support vector machines, and deep neural networks, combined with results from thermodynamic calculations and numerical simulations of the solidification process of aluminum alloy melts with inclusions. This research identifies factors affecting melt quality and proposes a new criterion for melt quality assessment. Results demonstrate that the melt quality analysis method developed in this study is significantly faster than traditional methods. The proposed melt quality criterion accurately and stably reflects the quality of the melt, facilitating the optimization of production processes and enhancing the quality of castings.

Keywords: aluminum alloy; melt quality;melt quality criterion; machine learning

1 Introduction

Aluminum alloys play a pivotal role in the lightweighting of automobiles. Optimizing the performance of aluminum alloy castings has received widespread attention. The liquid quality of aluminum alloys before casting is a critical factor that directly influences the microstructure and mechanical characteristics of the castings[1]. To enhance the overall performance of aluminum alloy castings, it is essential to first improve the quality of the liquid melt[2]. There are numerous factors affecting the liquid quality of aluminum alloys. Among these, increasing the cooling rate prior to casting can effectively improve shrinkage porosity, dendritic spacing, grain size, and microstructure in aluminum-silicon alloys[3]. However, due to limitations in production conditions and casting processes, the cooling rate cannot be infinitely increased, machine learning should be introduced into melt quality analysis [4]. Typically, refining and degassing of the liquid alloy, grain refinement, and modification treatments are necessary to improve the quality and performance of the aluminum alloy.

2 Experimental procedure

The thermal analysis experiment of aluminum alloy melts conducted at CITIC Dicastal Co., Ltd. primarily takes place in a low pressure die casting melting furnace(Figure 1). Initially, it is imperative to ensure that all equipment, including the melting furnace and the test cup, are in optimal working condition, followed by preheating the furnace to an appropriate temperature for melting the aluminum alloy. Subsequently, the aluminum alloy raw material is placed in the furnace for melting. During this phase, the temperature is regularly monitored to ensure uniform heating, and slag removal agents are employed to purify the melt from impurities. Prior to sampling, an appropriate test cup is selected and preheated to the correct temperature. During the sampling process, the aluminum alloy melt, at an ideal pouring temperature, is carefully extracted from the furnace and slowly and steadily poured into the test cup, taking caution to avoid splashing and oxidation. Following this, temperature data are immediately recorded using an IMC temperature acquisition device and thermocouples to monitor the cooling process of the melt. A cooling curve is then plotted, which illustrates the cooling trajectory of the aluminum alloy from the pouring temperature to room temperature. Analyzing this curve is crucial for understanding the thermal characteristics of the aluminum alloy and is essential for optimizing casting processes and enhancing product quality.

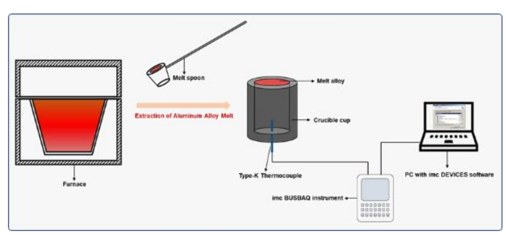

Figure 1 Experimental schematic diagram of aluminum alloy melt quality analysis

3 Result and discussion

Melt quality criteria have been defined by considering the area under the cooling curve within the primary and eutectic phase transformation temperature ranges. The cooling curve and its higher-order derivatives is shown in Figure 2.

Cooling curve slope criteria, such as the slopes of the pure liquid phase and pure solid phase, have been considered. The slope of the cooling curve before and after the phase transformation temperature points can reflect changes in cooling rate during solidification. A larger slope (first derivative) indicates rapid cooling. Therefore, a standard can be established where the cooling curve slope near the primary and eutectic phase transformation temperature points should be within a specific range to ensure ideal solidification characteristics and material quality.

Melt quality analysis programis shown in Figure 3. The criteria for the ductility at the phase transformation temperature points involve observing the behavior of the phase transformation temperature points on the cooling curve, such as the length of time the temperature remains stable. This reflects the stability of the phase transformation process. A longer stable phase may indicate a more uniform phase transformation process, resulting in a more uniform microstructure. A standard can be set where the cooling curve should maintain a stable state for a certain period at the phase transformation temperature point to ensure good solidification characteristics.

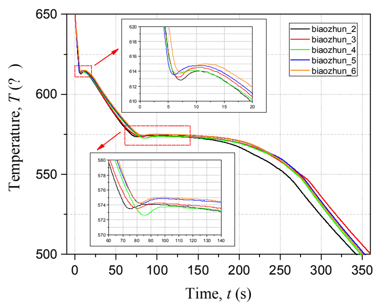

Figure 2 Cooling curve and its higher-order derivatives

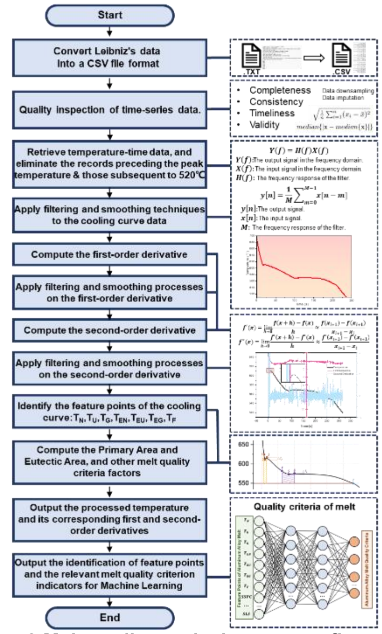

Figure 3 Melt quality analysis program flow chart

4 Conclusion

An experiment on the measurement of aluminum alloy melt temperature was conducted.The raw cooling curve data is processed using methods such as smoothing and filtering. An algorithm for feature point identification is established, which identifies the characteristic values during the primary solidification stage and the eutectic solidification stage, respectively. Based on the extracted characteristic values, criteria for melt quality assessment are developed using approaches like machine learning and linear regression, enabling the scoring of melt quality.

5 Acknowledgments

This work was supported by a grant from the Beijing Natural Science Foundation (No. L223001) and Tsinghua-CITIC Dicastal Cooperation Project.

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