Effect on Solidification Structure of Hypoeutectic Grey Cast Iron by Vacuum Condition in Lost Foam Casting

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Abstract. In this paper, the solidification structure of hypoeutectic grey iron under different vacuum conditions in lost foam casting (LFC) were discussed. In order to better research solidification structure under different cooling conditions, we designed different thickness step test casting and took actual casting experiment in two vacuum degree environments (0.02MP and 0.055MP). By setting the thermocouple to the cooling curves during the mold filling and solidification process is recorded at the center of different thickness step. Finally, through the use of thermal analysis and metallurgical comparative analysis, the solidification structure feature of hypoeutectic gray cast iron in lost foam casting process by vacuum degree environments is demonstrated to guide designer to advance the casting processes design.

Introduction

LFC is a technology near and precise shaped casting process which known as highly promising [1]. Different from the general cavity of sand casting, LFC is characterized in the role of negative pressure, foam models form in sealed tight sandbox dry sand. During liquid metal filling, the foam gradually form pyrolysis, gasification and liquefaction or discharged under the action of heat liquid metal and through the vacuum system. After the liquid metal replace original foam mold, the cavity is formed to be the casting. Classic lost foam casting process is shown in Fig. 1.

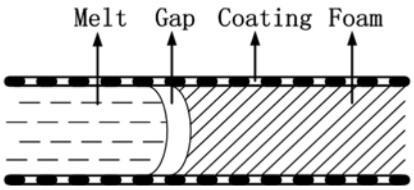


Figure 1 Classic lost foam casting processes

Because of above specific phenomenon in lost foam casting, the initial temperature field is greatly affected by the mold filling process in vacuum degree environments to effect on the solidification process and further change feature of final solidification structure of casting.

In recent years, considering characteristics of the lost foam casting, lots of researchers [2-7] pay more attention to understand characteristics of mold-filling and pyrolysis of cast iron. Through experiments and mathematical methods, they built the fluid melt and temperature distribution models of interface moving of metal and foam. Meanwhile, researchers[8-11] have also focused on the possible casting defects in LFC, such as gas cavity, carbon black, wrinkled skin, shrinkage and etc. In the studies of the microstructure and properties, the researchers [12-13] established the relationship of foam material, production process and preparation of the alloy with graphite morphology. However, few reports are emerged to study the unique structural features of hypoeutectic grey iron by measuring the cooling curves of casting and its detailed analysis.

However, in the vacuum environment, the influence of different vacuum degree on hypoeutectic gray cast iron studies rarely reported. In this paper, characteristics of solidification conditions and corresponding structure are revealed by thermal analysis from the mold-filling stage and the solidification stage of melt.

Experimental

In this paper, stepped test bar and thermocouple arrangement is shown in Fig. 2. The K-type thermocouple is used with 1mm diameter. Thermocouple is installed into corresponding measured position of casting model embed under dry sandbox. 6 temperature measurement points is set in this experiment: the wall thickness for 6 measuring points is 5, 10, 15, 20, 30 and 45 respectively.

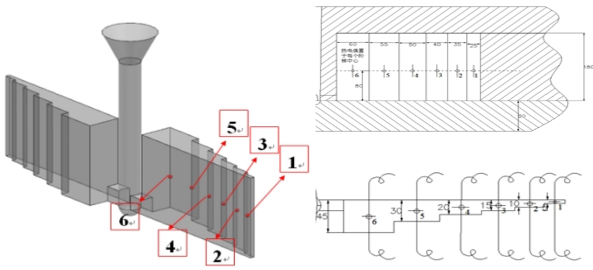


Figure 2 Step test casting and thermal-couple installation

Figure 3 Practical pouring experiments

Figure 4 Vacuum condition setting in pouring (Left: Higher degree; Right: Lower Degree)

Each group of thermocouples is connected to measurement device and PC (Agilent 34972A). The PC is starting to record the cooling data when the melt is pouring in actual implementation of the foundry , as shown in Fig. 3 and Fig. 4. The pouring condition and parameter is shown in the Table 1.

Table 1 Pouring parameter and composition of hypoeutectic grey cast iron

Pouring	Vacuum	Chemical composition（%）					
Temperature(time)	0.02 Mp	C	Si	Mn	P	S	CE%
1400(10s)	0.055Mp	3.12	1.73	0.83	0.023	0.045	3.64

Carbon equivalent: CE= C+ 0.3(Si+P) – 0.03Mn + 0.4S;

Temperature cooling data (as shown in Fig. 5) at measuring points is integrity and could describe characteristic of temperature change for the hypoeutectic grey cast iron, and also showed features of a cooling rate variation with the thickness of the position change.

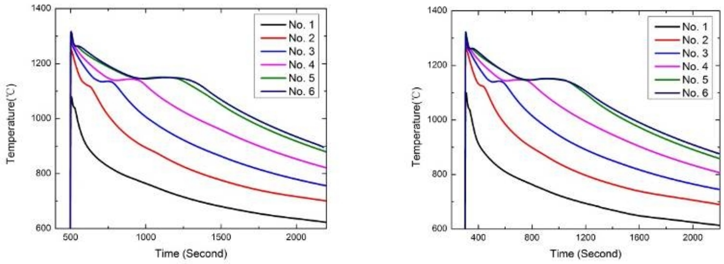


Figure 5 cooling curve recording of measurement points in vacuum condition (Left: higher degree; Right: lower degree)

Result and Discussion

Thermal analysis is useful tools to analyze the key temperature point on the cooling curve. Typical relationship between cooling curve and first derivative curve is presented in Fig. 6.

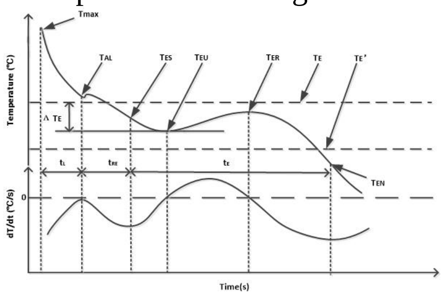


Figure 6 Typical cooling curve and first derivative curve

TE’	Stable (graphite) eutectic equilibrium temperature
TE	Metastable (carbide) eutectic equilibrium temperature
Tmax	Maximum Temperature of cooling curve
TAL	Liquid temperature of austenitic precipitation
TES	Temperature of start of eutectic freezing
TEU	Lowest eutectic temperature
TER	Highest eutectic temperature
TEN	Temperature of the end of solidification
△TE	Eutectic undercooling of grey cast iron,(TE- TEU)

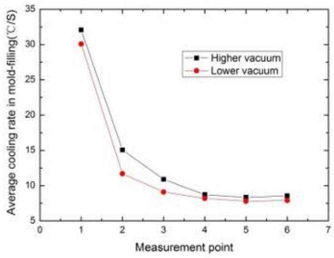


Figure 7 Average cooling rates during mold-filling

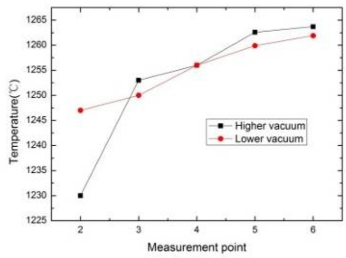


Figure 8 Temperature of primary austenite formation

Average cooling rate during mold-filling: As shown in Fig. 7, cooling rate is the highest at the thinnest point and deceases with the increasing wall thickness. In higher vacuum condition the cooling rate is overall slightly higher than in lower vacuum conditions.

Primary austenite formation: As shown in Fig. 8, in thinner part, the difference of temperature of primary austenite formation is obvious large, however, the difference is small in thickness part.

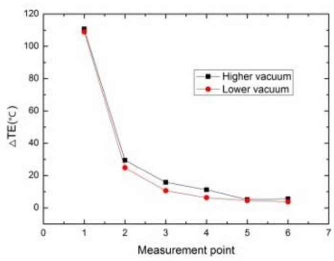


Figure 9 the compassion of the undercooling degree

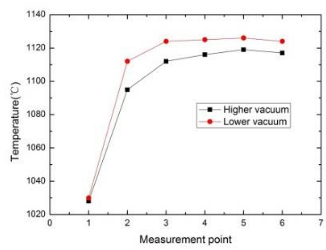
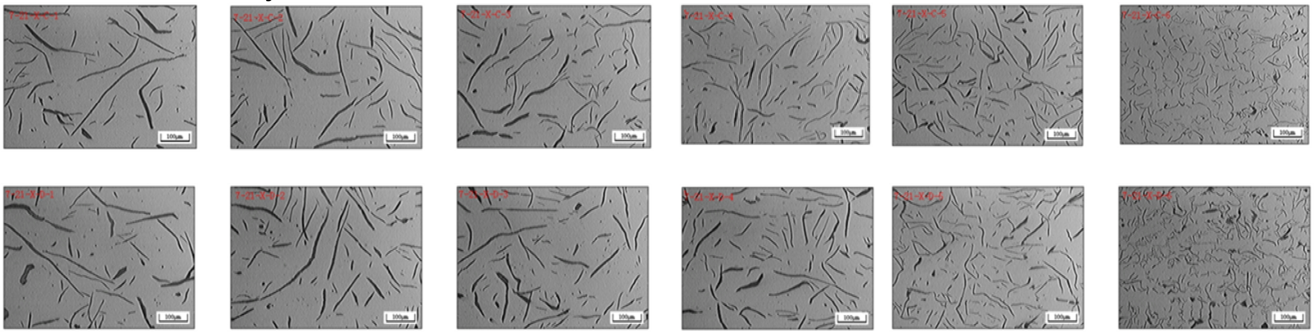


Figure 10 Interval period of eutectic solidification

Eutectic formation: In this paper, Eutectic solidification undercooling degree: △TE=1150˚C-TE. As shown in Fig. 9, because of higher cooling rate in thinner part, the undercooling at No. 1 measurement point is large and decrease with the increasing wall thickness in higher and lower vacuum condition

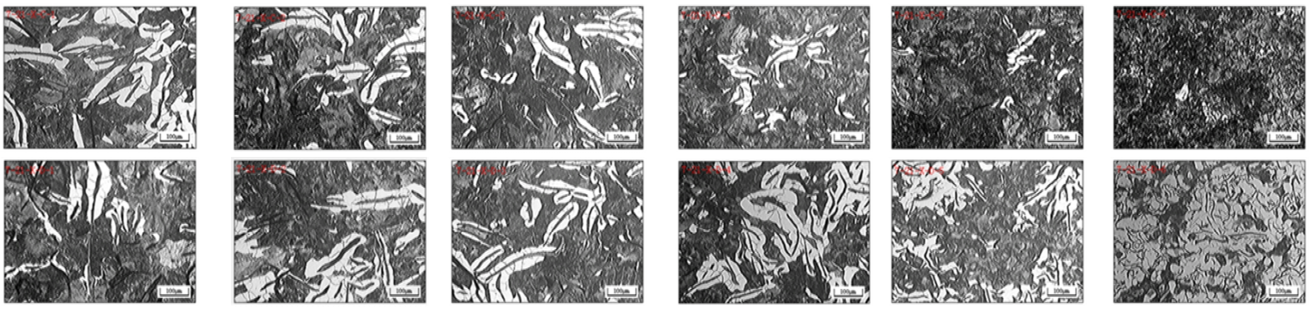
End of Solidification: It is generally believed that the lower TES and the easier to form carbide and shrinkage defects. The analysis of TES value shows that different vacuum condition observe a similar rule which with the increase of wall thickness, and TES value has a trend of increase, as shown in Fig. 10.

Using wire cutting approach to cut the step test cast in each thermocouple position, the 20X20mm sample is obtained to observe microstructure differences of sample section face with cooling curve information and analysis.



No. 6 No. 5 No. 4 No. 3 No. 2 No. 1

Figure 11 graphite types of samples (Up: lower degree; Down: higher degree)



No. 6 No. 5 No. 4 No. 3 No. 2 No. 1

Figure 12 matrix structures of samples (Up: lower degree; Down: higher degree)

Fig. 11 and Fig. 12 show metallograph including graphite types and matrix structure at temperature measurement points. During mold filling process of grey iron melt in vacuum environment, the temperature drops quickly, he graphite type is mainly formed D-type at the No. 1 sample (The thinnest position). The shape of graphite is similar between in higher and lower vacuum condition. On the other hand, the matrix structures consist of pearlite and ferrite. However, the ratio of pearlite is larger in higher vacuum condition than lower one. In 2 to 6 measurement point, with the increasing of the thickness, graphite morphology is transformed to A-type graphite and matrix structures is mainly pearlite. By analyzing TAL, TE and TEN, difference of key parameters is small between higher vacuum conditions than lower one. Therefore, the vacuum environment is limited to impact on further solidification process after finishing filling processes. So, graphite morphology in both vacuum environments is close and no significant difference of matrix structures.

Summary

In this paper, we focuses on understand solidification characteristics hypoeutectic gray cast iron under different vacuum environment in lost foam casting. By obtaining the cooling curves and using thermal analysis to analyze microstructure of final solidification structure, the conclusions are deduced as follow:

(1) Temperature cooling curve: Heat loss of melt is significantly influenced by the filling process under vacuum environment, and ultimately effects on the cooling conditions of the solidification process. Particular in the thinner part, the cooling rate is the most obvious impacted, however, at thicker wall no significant difference is found.

(2) Solidification microstructure: With the increasing thickness of the casting, graphite structure is transformed from D-type graphite to be the A-type graphite and matrix structure of pearlite also is increased. Like the phenomenon found in cooling curve, the impact degree is more critical by higher vacuum condition in thinner part.

From above analysis, the vacuum condition significantly affects the filling process and lightly impact on the solidification processes. This effect is more sensitive in the thin wall area.

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