Hot-Work Steels for Additive Manufacture and Additive Manufacture of High Pressure Die Casting Die Inserts Containing Conformal Cooling Channels

Yuzeng Chen[1], Jie Wan[1], Fang Lin[1], Jinyue Wang[2], Zhiqiang Liu[2], Yuanyuan Wang[2]
1. State Key Lab. of Solidification Processing, Northwestern Polytechnical University, Xi'an 710072, P.R. China
2. Suzhou Yunjing Metal Technologies Co., Ltd., Suzhou 215024, P.R. China
*Corresponding address: e-mail: yzchen@nwpu.edu.cn

Abstract: High pressure die casting (HPDC) is an important approach to fabricate Al-based structural components. The structures of HPDC Al-based castings are usually complex. Therefore, to ensure the precision forming of the HPDC castings, it's important to realize an accurate and efficient temperature control of the casting process. As a carrier of the high pressure die casting process, the temperature field of the HPDC die is mainly controlled via cooling channels. To achieve an efficient temperature control, conformal cooling channels embedded in mold core inserts are fabricated, which is complicated in geometry and can be only produced via additive manufacture. However, the additive manufacture processibility of traditional hot-work tool steels are poor and can't meet the requirement for producing the mold inserts containing conformal cooling channels via additive manufacture. In this presentation, the latest research progress of our team on additive manufacturing hot-work tool steels will be shared. Meanwhile, relevant examples on additive manufacture of the mold core inserts containing conformal cooling channels and its advantages in reducing the casting defects of Al die castings and improving the producibility will be shared.

Keywords: Hot-work steels, Additive manufacture, High pressure die casting, Mold inserts

1 Introduction

High pressure die casting (HPDC) is one of the most efficient ways in producing Al, Mg, Zn, and Cu alloys castings. The geometries of the HPDC castings are usually complex. Temperature control via the HPDC die is essentially important for controlling casting defects and production rate of these castings. The reasons are as follows. It is known that solidification of metals is a volume shrinkage process. The finally solidified parts of a casting inevitably subject to significant volume shrinkage which leads to the formation of shrinkage induced defects, such as pores and hot cracks. If the solidification sequence of the castings is manipulated by temperature control via the HPDC die, it will be possible to keep the shrinkage induced defects in the regions that will be removed from the castings. On the other hand, the solidification of the castings releases latent head of the metals which leads to increase of the die temperature. For a scale production, if the latent heat of the die can be conducted out, the production rate of the castings will be inevitably decreased, leading to an increased cycle time of the castings. Further, the over-heat of the die may cause pre-failure of the die. The traditional way in temperature control of the HPDC die is to machine channels in backside of the die where the liquid cooling medium, e.g. water and oil, can be filled in and used to control the temperature of the die. However, due to the restriction of the machining techniques, only straight channels can be usually machined. This will reduce the efficiency and precision of the temperature control.

The concept of conformal channels was proposed to enable a more efficient and precise control of die temperature [1]. Apparently, due the complexity of the conformal channels, these channels are not able to be prepared by traditional machining method.

An additive manufacture technique i.e., selective laser melting (SLM) is a most widely used method to produce the HPDC die inserts. The mostly investigated SLM hot-work steels include medium carbon hot-work steels (e.g., H13, Dievar, a trademark of Assab, and W360, a trademark of Böhler) and maraging steels (e.g., 18Ni300 and 18Ni350). The investigations focus on development of the SLM parameters, failure analyses of the as-produced inserts, and effects of the SLMed inserts containing conformal channels on the casting effects. A comprehensive investigation on evaluation of the properties of the hot-work steels for SLM, and applications of the SLMed inserts in solving casting defects and production rates is still limited. In this work, a systematic study on these issues will be reported.

2 Experimental procedure

A hot-work steel with a trademark of YJ01 which was developed by Suzhou Yunjing Metal Technologies Co., Ltd was used to prepare the specimens for mechanical property tests and produce the HPDC inserts. The hardness and Charpy V notched impact energy of the as-prepared specimens were performed. The as-produced inserts was installed in a HPDC die for tests.

3 Result and discussion

Figure 1 shows an SEM image of the YJ01 steel manufactured by SLM method and subjected to heat treatment. It is seen that the microstructure shows a typical cellular morphology of the alloys manufactured by SLM method. Formation of the cellular structure of the SLMed alloy can be ascribed to high positive temperature gradient up to 10^7-10^8 K/m, extremely high cooling rate upon solidification (10^6-10^7K/s), and ultrahigh solidification rate (around 1m/s) which suppress the development of secondary dendrite arms.

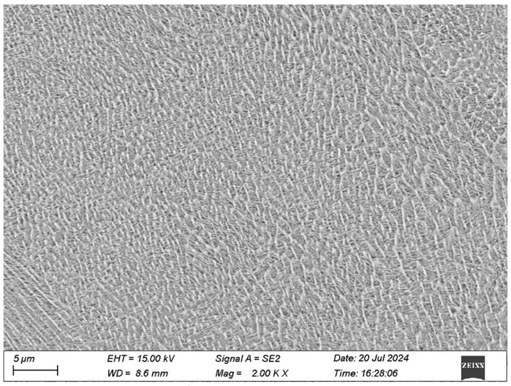

Figure 1. Microstructure of the YJ01 specimen which was prepared by SLM method and subjected to heat treatment.

Table 1 shows the mechanical properties of the SLMed and heat treated YJ01 steel where it can be seen that the YJ01 exhibits excellent mechanical performance as a hot work steel. Especially, the Charpy V notched impact energy is as high as 39 J which is higher than commonly used hot work steels, e.g., H11, H13, and Dievar, with a value usually less than 30 J at a similar hardness. Also, the yield strength and elongation to failure are also comparable to the normal commercial hot work steels.

Table 1. Mechanical properties of the SLMed and heat treated YJ01 steel.

Properties	Hardness, HRC	Charpy V notched impact energy, J	Yield strength, MPa	Elongation to failure, %
Values	45	39	1433	11

Figure 2 shows the fading of the hardness against heating at 550 ℃ and 600 ℃, which are two typical surface temperatures of HPDC dies. The data for a well-known commercial hot work steel, Dievar, were also added in the plot for comparison. It is seen that after 100 h heating at 550 ℃ and 600 ℃, the hardness of YJ01 faded by 2 HRC and 6 HRC, respectively, which are much lower than those of Dievar. This indicate that the SLMed YJ01 exhibits an excellent thermal resistance during service.

Figure 3 shows the results of a comparison test for HPDC castings, which is highly susceptible to solidification cracks in deep cavity of the castings (see Figure 3a). It is shown in Figure 3b, by replacing the machined insert with a straight cooling channel by the SLMed one, the casting defects are eliminated, showing the enhanced efficiency of temperature control of the inserts with conformal cooling channels.

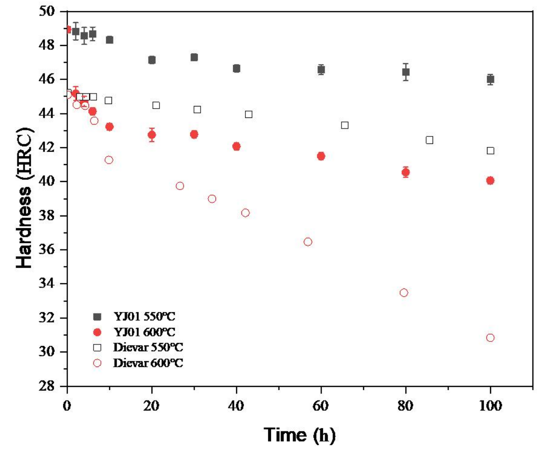

Figure 2. Evolution of hardness of the YJ01 specimen at 550 ℃ and 600 ℃ for a period up to 100 h. Data of Dievar were cited from Ref. [2]

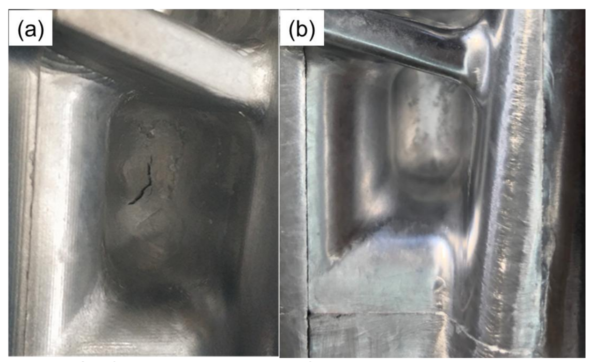

Figure 3. Surface morphologies of the test castings produced by using (a) machined insert with straight cooling channel, and (2) SLMed insert with conformal cooling channel.

4 Conclusion

The YJ01 hot work steel for SLM method exhibits excellent performance when used as a material to fabricate HPDC die inserts with conformal cooling channels. The application of the SLMed insert is highly helpful in controlling the casting defects.

Acknowledgments

This work was supported by the National Key R&D Program of China (No. 2022YFB3404203).

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