Advances in Machinery, Materials Science and Engineering Application X
M. Giorgetti et al. (Eds.)

doi:10.3233/ATDE240728

Research on Steel Leakage Control Technology of Argon Atomization Pulverizing Furnace Based on Six Sigma Method

Yang HU [a,b,1], Zhiwei YU [b], Xiandong ZHANG [b] and Shuangxi WANG [a]
[a] *AECC Beijing Institute of Aeronautical Materials, Beijing 100095 China*
[b] *HFYC (Zhenjiang) Superalloy Co., Ltd, Zhengjiang Jiangsu 212132 China*

Abstract. The steel leakage rate of tundish crucible during the preparation of superalloy powder by argon atomization pulverizing furnace in a factory was high, based on the systematical analysis of tundish crucible rupture engineering batch data, the key reasons of causing defects were found by six sigma method: the kind and the thickness of tundish crucible. The improvements were established after mechanism analysis and binary logistic regression calculation and so on. It was found that the Al_2O_3 sintered tundish crucible performed better than the MgO isostatic pressure forming crucible according to its better internal quality and compressive strength during producing superalloy powder in argon gas atomization furnace, in addition, the wall thickness of Al_2O_3 sintered tundish crucible was controlled between 8.0mm and 9.1mm, which was more beneficial to reduce the steel leakage probability. Hence, these measures made the steel leakage rate of tundish crucible reduce from 5.7% to 0.4% and the six sigma level of the preparation of superalloy powder by this argon atomization pulverizing furnace increase from 1.6 to 2.7. The production cost was greatly saved and the mass production of key parts for the advanced aero engines was stably ensured.

Keywords. Superalloy, steel leakage, tundish crucible, six sigma

1. Introduction

Superalloy powder is the key raw materials of advanced aircraft engine superalloy parts, Europe and the American countries have widely used vacuum induction melting argon atomization powder furnace to produce it, the basic preparation principle is to pour the superalloy melt in the vacuum melting crucible into the tundish crucible in stages, and then the melt falling from the tundish crucible is quickly broken into very fine droplets by high-pressure argon gas, and then quickly solidified to form powder particles, and the prepared powder particle size distribution is uniform, and the size of the inclusions is fine [1-2]. But in the actual preparation process of superalloy powder, the tundish crucible is often ruptured, which leads to the steel leakage, resulting in the powder scrap, and also brings safety hazards to the production process. There are many studies on the argon atomization to prepare superalloy powder forming technology and powder

[1] Yang HU, Corresponding author, AECC Beijing Institute of Aeronautical Materials, Beijing 100095 China; E-mail: 13401162963@163.com.

quality control at home and abroad [3-5]. However, there are few reports on the actual production process of the powder furnace and the prevention methods.

Therefore, in the context of engineering application and mass production process, based on the systematical analysis of tundish crucible rupture engineering batch data, this study aimed to select the reasonable quality tool of six sigma to find the key factors, so as to reduce the leakage rate of tundish cruncible in argon atomization pulverization furnace, and ensure the stable mass production of key parts for our advanced aero engines in China.

2. The Methods of the Study

As shown in figure 1, one certain brand of superalloy powder was produced by vacuum induction melting argon atomization pulverizing furnace, and the rupture of the tundish crucible was visually inspected during the pouring process of 348 rounds (the leakage of molten steel >0kg, the insulation power and temperature decreased, and the cracks of the tundish crucible were visible)). According to the rupture of tundish crucible, the process capacity, management control, process control and other conditions were calculated, the causes of the tundish crucible rupture were found, and statistical analysis, mechanism research and improvements were carried out. Then, the ruptures of tundish crucible in the production process of the improved 251 heats of vacuum induction melting argon atomization pulverizing furnace were visually inspected again, and the process capacity, management control, process control and other conditions were re-analyzed to verify whether the steel leakage rate of the tundish crucible was stably reduced.

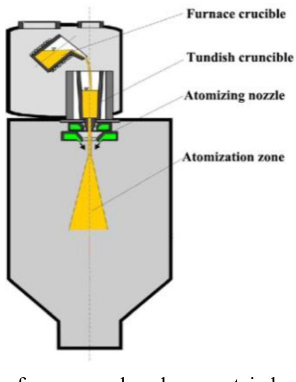

Figure 1. Powder making furnace produced one certain brand of superalloy powder.

3. The Results of the Study

As shown in figure 2, in the production process of 348 rounds of argon atomization pulverizing furnace visually inspected before the implementation of improvements, the number of molten steel leakage was 20 times, and the steel leakage rate was as high as 5.7%. By checking the table [6], the six sigma level was 1.6, which could be seen that the control ability of the tundish crucible rupture in pulverizing process before the improvements was generally low.

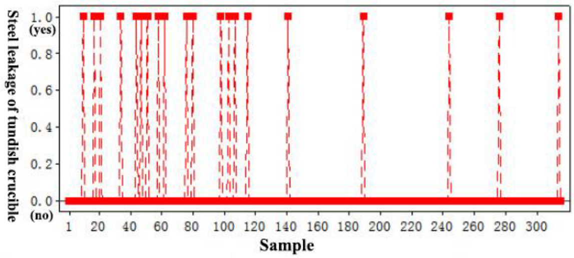

Figure 2. Operation diagram of the steel leakage of tundish crucible.

Table 1. Results of binary logic regression analysis of steel leakage and assemblers of tundish crucible.

Influencing factors	Hypothesis tests P-values	Dominance ratio	Remarks
Tundish crucible holding temperature	1.000	/	
Tundish crucible heating-up time	0.202	/	
Tundish crucible thickness	0.016	/	
Tundish crucible material	0.000	0.09	MgO isostatic pressure forming crucible , Al_2O_3 sintered crucible
Tundish crucible assembler	0.371,0.535	0.61,0.72	assembler A / B, assembler A / C

As seen in table 1, the binary logic regression analysis of the possible reasons of leakage: the tundish crucible holding temperature, tundish crucible heating-up time, tundish crucible thickness, tundish crucible material, tundish crucible assembler was calculated, which found that only the P-values of tundish crucible thickness and tundish crucible material were less than 0.05. It was an obvious correlation among the tundish crucible thickness, tundish crucible material and the steel leakage [6]. Moreover, the leakage rate of tundish crucible of MgO isostatic pressure forming crucible was 11.11 times higher than Al_2O_3 sintered forming crucible. The correlation between the crucible thickness and the leakage rate of tundish crucible was shown in figure 3, when the thickness of tundish crucible was controlled at 8.0mm to 9.1mm. The probability of steel leakage was 0, the goodness of fit established in figure 3 was tested by Hosmer-Lemeshow method [6], the P-value was 0.429, higher than 0.05, indicating that the fitting relationship established in figure 3 was reliable.

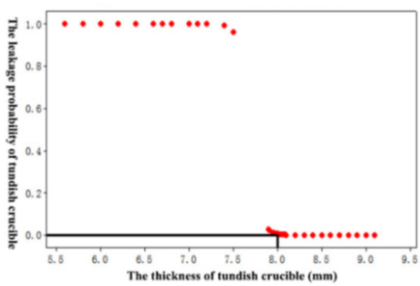

Figure 3. The relationship between the thickness of tundish crucible and the leakage probability of tundish crucible.

4. Analysis and Discussion

At present, the refractory crucibles commonly used in the production of superalloy powder are mainly MgO isostatic pressure forming crucible and Al_2O_3 sintered crucible [7]. In this study, by the results of scanning electron microscopy in figure 4, for the MgO isostatic pressure forming crucible, the internal MgO raw material particles were uneven, whose thermal expansion coefficient were different, the isostatic pressure pressing molding temperature was low (about 150℃), the bonding between particles was not good, so there were many cavities inside and outside, many small original cracks were observed, which resulted in poor thermal shock resistance of crucible. Refer to table 2, the compressive pressure strength of the crucible with the wall thickness of 8mm at 800℃ was low, only 9.8MPa, after heating, the original crack was easy to expand and lead to steel leakage. For the Al_2O_3 sintered crucible: its internal Al_2O_3 raw material particles were uniform, the sintering forming temperature was high (about 650℃), the bonding between particles was very good, so no cavities and cracks inside were observed, the surface roughness was small, the strength and thermal shock resistance of crucible was better, the compressive pressure strength of the crucible with the wall thickness of 8mm at 800℃ was 12.2MPa, which was not easy to produce crack after heating, so steel leakage probability was low.

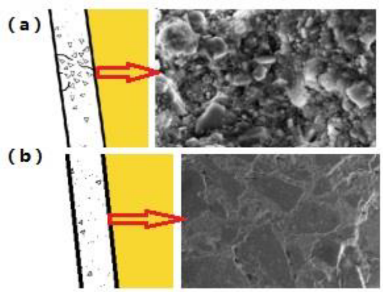

Figure 4. The morphology of tundish crucible wall: (a) MgO isostatic pressure forming crucible, (b) Al_2O_3 sintered crucible.

Table 2. Comparison of two kinds of tundish crucible with the wall thickness of 8mm.

Crucible type	Apparent porosity	Compression strength (800℃)	Thermal shock resistance
MgO isostatic pressure forming crucible	13.2%	9.8MPa	24 Times
Al_2O_3 sintered crucible	16.5%	12.2MPa	42 Times

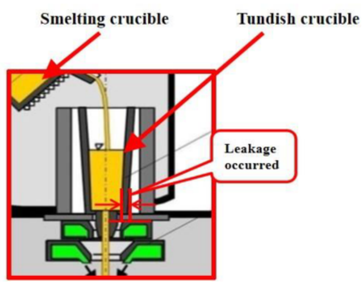

Figure 5. Location of steel leakage.

As shown in figure 5, after inspection, it was found that the ruptures of the two kinds of tundish crucible concentrated on the lower side wall. The main reasons were as follows: in the process of steel pouring, the pressure and the concentrated stress on the lower side wall of tundish crucible were the biggest. The wall of crucible was thinner, the compressive strength of crucible was smaller, when the wall thickness of tundish crucible was lower than 8mm, and the concentrated stresses such as static pressure or thermal stress of steel liquid were greater than 12.2MPa, cracks in the crucible would occurred, which could lead to steel leakage. But, the wall thickness of tundish crucible was not the greater the better, in the process of pouring steel, the temperature difference between the tundish crucible (about 800°C) and the liquid steel (about 1500°C) from smelting crucible was about 700°C, if the tundish crucible was too thick ,the heat conduction speed was faster and the heat would lose more, the temperature of liquid steel into the tundish crucible decreased severely, the poor liquid liquidity would be unable to complete the subsequent pouring atomization, instead, lead to the occurrence of steel blocking problem.

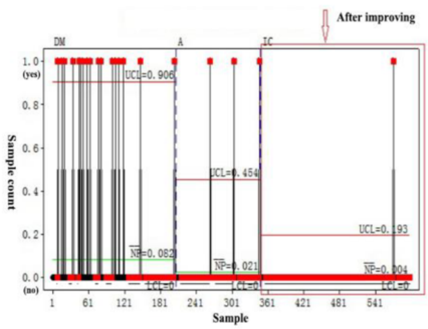

Figure 6. NP control chart of the steel leakage of tundish crucible.

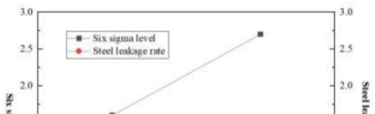

Figure 7. Chart of Comparison between steel leakage rate and six Sigma level before and after improvement.

As shown in figure 6 and 7, the 251 argon atomization powder furnace production processes were visually inspected after the improvements: totally selecting Al_2O_3 sintered tundish crucible, and controlling its wall thickness from 8.0mm to 9.1mm, the total number of tundish crucible rupture leading to steel leakage was only one time, the steel leakage rate was 0.4%. The main reason was that in the process of argon atomization preparation, the cryogenic pump of argon gas's air source could not be started, which lead to the too long waiting time of tundish crucible insulation, the internal cracks of Al_2O_3 sintered tundish crucible occurred because of long-term heating, then the rupture of crucible in the pouring process lead to steel leakage. The steel leakage was not contradictory to the improvements. By checking the table [6], the six sigma level after improving was 2.7, which could be seen that the control ability of the rupture of tundish crucible in argon atomization furnace was significantly improved, and the leakage rate of steel liquid was significantly reduced.

5. Conclusion

(1) By using the six sigma method, the reasons which affected the rupture of tundish crucible and the steel leakage were found, through mechanism analysis and implementing control measures, the control ability of the rupture of tundish crucible was significantly improved, the six sigma level raised from 1.6 to 2.7 and the steel leakage rate decreased from 5.7% to 0.4%.

(2) The Al_2O_3 sintered tundish crucible performed better than the MgO isostatic pressure forming crucible according to its better internal quality and compressive strength during producing superalloy powder in argon gas atomization furnace, in addition, the wall thickness of Al_2O_3 sintered tundish crucible was controlled between 8.0mm and 9.1mm, which was more beneficial to reduce the steel leakage probability.

References

[1] Li JR, Xiong JC, Tang DZ. Advanced High-temperature Structural Materials and Technology. Beijing: National Defense Industry Press, 2012.
[2] Zhang GQ, Zhang YW, Zheng L, et al. Research progress and preparation technology of powder superalloy for aero-engine. Journal of Metals. 2019; 55(9): 1133-1144.
[3] Zhang YW, Liu JT. Progress in powder superalloy research. Material Progress in China. 2013; (1): 1-11.
[4] Hu LX, Feng XY. Research and development status of powder metallurgy superalloy. Powder Metallurgy Industry. 2018; 28(4): 1-7.
[5] Han ZY, Zeng G, Liang SJ, et al. Development status of nickel-based superalloy powder preparation technology. Materials China. 2014; 33(12): 748-755.
[6] He Z. Six Sigma Management (Third Edition). Beijing: China Renmin University Press, 2023.
[7] Zhang YB, Xu WY, Li Z. Study on interface between FGH96 superalloy and refractory slurry with different soaking time. Materials Science Forum. 2021; 1035: 318-327.