Research on Cost-effective New Alloy Cast Iron

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Abstract. Cast iron is the basic material of the manufacturing industry. It has excellent casting processability and good shock absorption and wear resistance, so it is widely used. With the awareness of energy conservation and environmental protection, the defects of low energy and high consumption of traditional materials are gradually revealed. They are gradually being replaced by new alloy cast iron. This paper introduces the latest developments in new alloy cast iron production technology in recent years in detail, involving iron purification, furnace selection, melt ratio, chemical composition control, inoculant type and application, and stress relief annealing. And this paper analyzes the strengthening mechanism of cast iron, puts forward the problems and solutions in the production process, and expounds the development trend of cast iron production technology and the prospect of China's cast iron industry.

1. Development Background of High Performance Cast Iron Parts
Among the cast materials, cast iron has excellent cutting performance, shock absorption and wear resistance, it is widely used in pillar industries such as automobile, steel, petrochemical and electric power. As of 2017, the total output of various types of castings in China was 49.4 million tons, an increase of 4.7% over 2016. It is estimated that by 2020, China's cast iron parts will reach 49.52 million tons [1]. From the perspective of production, it is clear that China has become a major casting country, but there is still a gap between the comprehensive performance, material structure, production technology, energy conservation and emission reduction of castings compared with foreign advanced industrial countries. Therefore, how to develop cost-effective new alloy cast iron has become a hot topic in domestic enterprises [2] [3].

For example, with the continuous improvement of fuel utilization rate and international exhaust emission standards, the lightweight and high power of automotive castings has become the focus of current research and development. According to a study by the European Aluminium Association, carbon dioxide emissions can be reduced by 1 kg for every 100 kg of weight lost. Therefore, the development of thin-walled high-performance alloy cast iron will become the primary goal of people [4]–[6].

2. Casting Process

2.1. Quality of Molten Iron
The quality of the molten iron determines the performance of the casting. Compared with foreign models of the same type, the castings in China have different performances, which is partly due to the low purity of the molten iron. The quality of molten iron is affected by many factors. First, the temperature of the molten iron is the basis for obtaining pure molten iron. Increasing the temperature
of the molten iron promotes the precipitation and refinement of the graphite, improves the fluidity of the molten iron, and eliminates the heritability of the casting. If the tapping temperature is too low or the standing time is too short, the casting is genetically affected and coarse graphite is formed. However, if the temperature is too high or the standing time is too long, it will cause severe oxidation of the molten iron and reduce the graphite nucleation. China's tapping temperature is generally around 1480 °C, while abroad is above 1550 °C, the holding time is controlled at 5 to 10 minutes [7] [8] [9].

Secondly, selecting the appropriate ratio of charge can stabilize the chemical composition of the molten iron and control the content of trace impurity elements. The molten iron compound usually consists of pig iron, scrap steel, recycled material and recarburizer. Carbon is mainly obtained by means of pig iron and the addition of a recarburizer to the molten iron. The structure and defects of pig iron are hereditary. We try to use high-quality pig iron with less harmful elements as a melting material to avoid rust formation on the surface of pig iron and want to ensure that the trace impurity content is less than 0.01%. Adding high-quality nitrogen-containing recarburizer can form heterogeneous points such as BN, which can provide a base for graphite crystal nucleation, promote graphitization, make the matrix structure uniform, improve the strength and processing performance of the casting [10].

2.2. Smelting Process
At present, the furnace for melting molten iron has two kinds of cupolas and induction furnaces. The cupola has a fast melting speed, easy slag discharge and low consumption, but it has large environmental pollution, high energy consumption and slow regulation temperature [11]. Compared with the cupola, the induction furnace has the advantages of low pollution, flexible temperature control, rapid temperature rise, precise heat preservation and easy control of molten iron chemical composition. Therefore, the application of medium frequency induction furnace is the future development trend [12].

Secondly, it is necessary to reduce impurities such as gas and slag in the molten iron. In order to avoid the production of air holes in the casting, it is possible to add a venting needle near the core and sand to discharge the gas generated during the casting process. The slag inclusion system should be equipped with a slag casting system. It selects a suitable slag agent to collect the residue and exclude them [13]. We choose ceramic filter instead of fiber filter to filter iron liquid, which can effectively reduce the scrap rate of castings [14].

2.3. Birth Treatment
Iron liquid is inoculated to improve cast iron performance [15]. Common inoculants are the following: (1) ferrosilicon inoculant: its incubation time is short, and the pregnancy is fast. Such as 75SiFe inoculant, it's low cost and wide application. (2) Silicon germanium inoculant: it can refine the eutectic group, promote graphitization, eliminate the white mouth phenomenon, and have strong anti-pregnancy decline ability. (3) Silicon germanium inoculant: It can eliminate white mouth phenomenon, reduce shrinkage and shrinkage, improve cross-sectional uniformity, reduce scum and prevent seepage. (4) Silicon zirconium inoculant: It has strong anti-pregnancy decline ability, reduces white mouth tendency, improves graphite structure and promotes the formation of fine uniform A-type graphite. And zirconium has a strong ability to deoxidize and desulfurize nitrogen, which can eliminate defects such as nitrogen pores in castings. (5) Silicon calcium inoculant: its initial inoculation effect is good; it can promote the formation of original eutectic group and improve the strength of casting. However, the solubility of calcium is poor and the rate of decay is fast. It is easy to form slag, which causes a large number of defects in the casting. Therefore, the inoculant is often used in combination with other inoculants. (6) Rare earth inoculant: it has deoxidation and desulfurization properties. It is prone to sulfides, increases graphite nucleation base, and promotes graphitization. However, when the rare earth is used in excess, it will increase the degree of subcooling and increase the tendency of white mouth.

In the process of gestation, we should pay attention to controlling the size of the inoculant. Small particle size inoculant particles are easily mixed into the slag, which is removed along with the slag and wastes inoculant. The inoculant is too coarse to be completely dissolved in the molten iron, which
causes hard spots on the surface of the casting and deteriorates the mechanical properties of the casting. Inoculants generally have the best effect in 1-2 minutes, and then slowly decline. Multiple births can delay the decline of pregnancy and give full play to the function of inoculant [16]–[18].

3. Chemical Composition Control

3.1. Carbon Equivalent and the Proportion of Silicon Carbon Content
Carbon equivalent is an important parameter that determines the performance of a casting. Increasing the carbon equivalent can promote the graphitization of the casting and enhance the fluidity of the molten iron, thereby eliminating defects such as shrinkage cavities and shrinkage. However, if the carbon equivalent is too high, the graphite of the casting is coarsened, and the tensile strength and hardness of the casting are lowered. For this reason, the carbon equivalent should be controlled between 3.9% and 4.2% [20].

3.2. Manganese, Sulfur and Content Ratio
Appropriate addition of manganese can increase the strength of cast iron. Generally, the Mn content is controlled at 0.3% to 0.8%. Appropriate addition of sulfur can improve the morphology of graphite, stabilize cementite, and prevent excessive graphitization. However, excessive sulfur causes the formation of low melting point FeS and MnS at the grain boundary of the cast iron. They are still in a liquid state when the molten iron is solidified, and are prone to cracks. Therefore, a suitable manganese to sulfur ratio is an important factor in improving the performance of castings. The data shows $w(\text{Mn})=1.71w(\text{s})+(0.01-0.03)$ [17] [21].

3.3. Phosphorus
Phosphorus is present in the form of phosphorus eutectic in cast iron, and its character is related to the distribution of graphite. It has hard and brittle properties. When the graphite is uniformly distributed in the phosphorus eutectic region, a good wear-resistant skeleton is formed in the matrix to improve the wear resistance of the casting. However, if there is less graphite in the phosphorus eutectic aggregation region, the hard and brittle phosphorus eutectic will separate the continuity between the grains, reduce the strength and plasticity of the casting, increase its hardness, and deteriorate the cutting performance of the casting. Usually the mass fraction of phosphorus is controlled below 0.07% [22].

3.4. Alloying Elements: Copper, Molybdenum, Chromium, Tin, Antimony
We can add appropriate amounts of alloying elements such as copper, molybdenum, chromium, tin and antimony to the molten iron to improve the mechanical properties of the cast iron. However, if we add too much, the performance will decrease. For example, excessive amounts of copper and chromium will increase the strength and hardness of castings and reduce the machinability of castings. Therefore, the mass fraction of copper is generally controlled at 0.6% to 1.0%, and the mass fraction of chromium is controlled at 0.2% to 0.35% [22]. When the molybdenum element is excessive, it is easy to form P-Mo quaternary eutectic with phosphorus, which seriously increases the brittleness of the casting and deteriorates the processing performance. Usually the molybdenum content is controlled between 0.2% and 0.6% [24]. Tin and antimony elements have similar properties, and tin and antimony are added to enhance the effect. However, excessive tin will form brittle compounds at the eutectic grain boundaries, which will affect the mechanical properties of the casting. Therefore, the tin element in the molten iron is generally controlled at 0.04% to 0.10% [24].

4. Heat Treatment Process
Heat treatment of cast iron can change its matrix structure, eliminate internal stress and improve mechanical properties. Because the ferrite and austenite content in cast iron are different under different temperature conditions. After different heat treatment processes, the castings can obtain different proportions of ferrite and pearlite, which changes the mechanical properties of the casting. There are many types of common heat treatment processes, such as stress relief annealing and graphitization annealing.
Stress relief annealing: It can eliminate the internal stress generated by the cast iron during solidification and cooling, and prevent the casting from cracking or deforming. Usually, the casting is installed at room temperature, then the furnace temperature is slowly heated to 500-550°C, and the temperature is kept for 3 to 5 hours. Finally, the casting is furnace-cooled or air-cooled.

Graphitization annealing: low temperature graphitization annealing and high temperature graphitization annealing. Low-temperature graphitization annealing promotes the decomposition of cementite. It transforms the original pearlite and graphite into pearlite, ferrite and graphite, which reduces the hardness of cast iron and improves its ductility and toughness. Generally, the cast iron is slowly heated to 720-750°C and kept for 2-6 hours. High-temperature graphitization annealing eliminates cementite and decomposes cementite into austenite and graphite, which reduces the hardness and brittleness of cast iron surface and improves processing performance. Generally, the heating temperature is about 900°C, and the temperature is kept for 4 hours. Then the casting is cooled to 500°C with the furnace temperature, and finally the casting is cooled in air [25].

5. Conclusion
With the increasing environmental and energy problems, traditional materials will face improvement and elimination. The new alloy cast iron with high efficiency and low consumption will become the focus of research and development in the future. In the context of increasingly fierce market competition, China must increase its efforts to carry out technological transformation of the foundry industry, strive to improve the quality of castings, and make full use of alloying technology to improve the performance of castings. At the same time, we must reduce energy consumption and reduce the degree of environmental pollution, and strive to develop efficient alloy cast iron materials as soon as possible.

6. References
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