

Analysis of Common Casting Defects and Process Countermeasures

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Abstract: In the casting production process, casting quality is of critical importance. This paper investigates common casting defects, including porosity-related defects, surface and internal inclusions, crack-related defects, and shape and dimensional defects. The causes of these defects are analyzed from multiple perspectives, such as materials, process design, operating equipment, and environmental and storage conditions. Corresponding process countermeasures are proposed for different types of defects, including optimization of the gating system, improvement of sand mold and sand core quality, structural optimization, and control of cooling rates. This study provides effective guidance for improving casting quality, reducing defect occurrence, lowering production costs, and enhancing production efficiency.

Keywords: Casting defects; process countermeasures; porosity defects; inclusion defects; crack defects

Introduction

Castings are widely used in the field of mechanical manufacturing, and their quality directly affects product performance and reliability. However, influenced by various factors, castings often exhibit different types of defects, such as porosity, inclusions, and cracks. These defects not only reduce the mechanical properties of castings but also adversely affect assembly accuracy and service life. A systematic analysis of the classification, characteristics, and causes of common casting defects, together with the proposal of effective process countermeasures, is of great significance for improving casting quality, reducing production costs, and enhancing the competitiveness of enterprises.

1. Classification and Characteristics of Common Casting Defects

1.1 Porosity-Related Defects

Porosity-related defects are relatively common among casting defects and have a significant impact on casting quality. Gas porosity is a typical type of such defects. Subsurface gas pores are mostly pear-shaped and are often hidden inside the casting before machining, becoming visible only after machining. This type of porosity disrupts the continuity of the internal structure of the casting and reduces its compactness^[1]. Surface gas pores are usually circular or elliptical and appear as obvious open pores that can be directly observed by the naked eye. Their presence not only affects the appearance of the casting but may also act as stress



concentration sites, thereby reducing the strength of the casting. Blowholes are another manifestation of gas porosity; they are irregular in shape with rough surfaces and similarly weaken casting performance. Shrinkage cavities and shrinkage porosity also belong to porosity-related defects. Shrinkage cavities are relatively concentrated and have rough surfaces, generally occurring in hot spots of the casting. Hot spots are regions that solidify last during the solidification process. Because the molten metal in these areas cannot be sufficiently fed during shrinkage, shrinkage cavities are formed. Such cavities can seriously impair the load-bearing capacity of the casting and reduce its service safety. Shrinkage porosity, on the other hand, consists of fine and dispersed pores, which are commonly found in thick sections. In these thick sections, the molten metal has a longer solidification time, making it prone to the formation of fine dispersed pores during solidification. These pores reduce the compactness and mechanical properties of the casting.

1.2 Surface and Internal Inclusion Defects

Surface and internal inclusion defects impair the cleanliness and uniformity of castings. Sand holes are regular cavities formed by sand particles embedded in the casting surface and are relatively conspicuous on the surface. Sand holes not only affect the surface appearance quality of castings but also reduce surface strength and wear resistance, leading to increased wear during service. Slag holes are irregular defects caused by slag or oxide inclusions. If slag removal during melting is incomplete, slag or oxides may be entrained into the molten metal and form slag holes during solidification. Slag holes damage the internal structure of castings and reduce their compactness and corrosion resistance. Oxide inclusions are layered defects formed by the entrapment of oxide films from the molten metal surface. During pouring, if the surface oxide film is not removed in time, it can be entrained into the casting, forming oxide inclusions. This type of defect leads to delamination within the casting and reduces its mechanical properties and toughness.

1.3 Crack-Related Defects

Crack-related defects pose a serious threat to the safety and reliability of castings. Hot cracks form at the final stage of solidification, when the casting is in a high-temperature and brittle state. The fracture surface

of hot cracks is dark gray and lacks metallic luster. Their presence makes the casting prone to fracture along the crack under load, thereby reducing its load-bearing capacity. Cold cracks occur after the casting has cooled to an elastic state and are characterized by clean fracture surfaces with metallic luster. The formation of cold cracks is often associated with internal stresses within the casting. When these stresses exceed the strength limit of the casting material, cold cracks are generated. Cold cracks may cause sudden fracture of castings during service, leading to serious consequences.

1.4 Shape and Dimensional Defects

Shape and dimensional defects affect the assembly accuracy and service performance of castings. Cold shuts and misruns are defects formed when molten metal fails to fuse completely. Cold shuts appear as through seams, while misruns result in incomplete castings. Both defects prevent the casting from achieving the designed shape and dimensions, thereby impairing assembly and application. Distortion and warpage are geometric deviations caused by non-uniform cooling. During cooling, different sections of the casting shrink inconsistently, resulting in distortion and warpage. These defects can lead to excessive or insufficient clearances between the casting and mating parts, adversely affecting assembly accuracy and service performance (distortion causes the casting dimensions to deviate from drawing requirements and, in severe cases, may lead to insufficient machining allowance or scrapping). White iron formation and hard spots are hard and brittle microstructures formed due to excessively rapid local cooling. Such microstructures deteriorate the machinability of castings and increase machining difficulty and cost.

2. Systematic Analysis of Defect Causes

2.1 Material Factors

The composition and cleanliness of molten metal play a fundamental role in casting quality. Excessive gas content in molten metal cannot be fully released during solidification, leading to the formation of gas porosity and related defects within the casting. The presence of impurity elements must not be overlooked. Different impurities have varying effects on casting performance: some reduce strength, others impair toughness, and some may even induce cracking. The properties of

molding sand and core sand are also critical factors^[2]. Insufficient strength of molding sand may cause mold collapse during pouring, resulting in dimensional deviations of the casting. Poor permeability hinders gas evacuation, increasing the likelihood of gas porosity. Excessive gas evolution from the sand during solidification can prevent gas escape, forming gas pores or blowholes. The quality of coatings and binders also affects casting quality. Coatings with poor venting properties obstruct gas discharge, while insufficient refractoriness may cause decomposition or burning at high temperatures, generating impurities that reduce melt cleanliness and lead to oxide inclusions.

2.2 Process Design Factors

The design of the gating system has a significant influence on casting quality. The cross-sectional area of runners must be properly designed. If the area is too small, the filling rate of molten metal is slow, which can result in misrun defects; if it is too large, excessive flow velocity may entrain gas and impurities, leading to gas porosity and slag holes. An unreasonable filling path can hinder smooth metal flow and cause defects such as cold shuts. Insufficient slag-blocking capability allows impurities to enter the mold cavity, forming slag-related defects. The design of risers and chills is crucial. Low feeding efficiency of risers may cause shrinkage cavities and shrinkage porosity, while inadequate chilling effects make it difficult to achieve directional solidification, resulting in distortion and warpage. Mold and cavity design should not be neglected. Poor layout of venting channels makes gas discharge difficult, leading to gas porosity, while non-uniform temperature distribution in the mold can cause deformation and cracking of the casting.

2.3 Operation and Equipment Factors

Control of pouring temperature and pouring rate has a major impact on casting quality. Excessively high pouring temperatures increase gas absorption in the molten metal, making gas porosity more likely. Conversely, excessively low pouring temperatures reduce fluidity, leading to misruns and cold shuts. Pouring too quickly tends to entrain gas and impurities, while pouring too slowly may cause premature cooling and solidification, impairing mold filling. The condition of mold preheating and cooling systems also affects casting quality. Insufficient mold preheating results

in a large temperature difference between the molten metal and the mold, which can easily cause cracking. Malfunctions in the mold cooling system lead to non-uniform cooling, resulting in distortion and warpage. The standardization of mold assembly operations is equally important. Incomplete removal of loose sand may allow sand particles to enter the mold cavity, forming sand hole defects. Inadequate fixation of sand cores can cause displacement during pouring, adversely affecting the shape and dimensional accuracy of the casting.

2.4 Environmental and Storage Factors

The storage conditions of raw materials have a potential impact on casting quality. Excessive humidity can cause metal materials to rust and molding sand to absorb moisture, thereby affecting melt cleanliness and sand properties. Extremely high or low temperatures may alter the physical and chemical properties of raw materials, ultimately influencing casting quality. Preheating treatment of sand cores and molds prior to use should also be carefully controlled. Insufficient preheating results in low temperatures of sand cores and molds, increasing the risk of cracking due to large thermal gradients during pouring. Excessive preheating, however, may damage sand cores and molds, impairing casting formation quality. The preheating temperature of sand cores is generally controlled within the range of 180–220 °C, while mold preheating temperature depends on mold material and casting requirements and is typically set between 150–300 °C.

3. Process Countermeasures and Optimization Strategies

3.1 Countermeasures for Porosity-Related Defects

Gas porosity is one of the most common porosity-related defects. To effectively control gas porosity, optimization of the gating system is the core technical approach. Inclined pouring allows molten metal to enter the mold cavity smoothly, reducing gas entrapment, while bottom pouring can prevent direct impingement of molten metal on the top of the mold cavity, thereby lowering the risk of gas entrapment. Improving the permeability of molding sand is also crucial. This can be achieved by selecting molding sand with appropriate particle size, reasonably controlling sand compaction, and reducing gas-generating substances, so that gases can be discharged smoothly

from the mold cavity^[3]. Strict control of coating venting performance should not be neglected. Coatings with good venting properties enable rapid gas escape, and appropriate particle size ensures uniform coating coverage, reducing the risk of gas porosity. Control of shrinkage cavities and shrinkage porosity should follow the principle of directional solidification. Rational arrangement of risers and chills is essential. Risers provide supplementary molten metal to compensate for solidification shrinkage, while chills accelerate local cooling, promoting sequential solidification and preventing the formation of shrinkage cavities and shrinkage porosity. Risers should be placed at hot spots of the casting (generally above or adjacent to the hot spot, with an appropriate distance maintained). The thickness of chills is typically determined based on casting wall thickness and is generally 0.5–1.0 times the wall thickness. Adjustment of coating thickness and spraying uniformity is also important. Excessively thick or uneven coating layers hinder heat transfer and affect the solidification sequence; therefore, coating thickness should be moderate and uniform. The coating thickness is generally controlled within the range of 0.3–0.8 mm. The use of chill blocks or heat-dissipating fins can accelerate local cooling, allowing critical areas of the casting to solidify first and preventing shrinkage defects. Chill blocks are usually made of copper alloys with high thermal conductivity, while the spacing of heat-dissipating fins is determined according to casting requirements and is typically 10–30 mm.

3.2 Countermeasures for Inclusion Defects

Prevention of sand holes should start with improving sand core quality. Enhancing surface strength and curing integrity of sand cores can reduce the risk of sand particle detachment during pouring. The surface strength of sand cores should generally be no less than 1.5 MPa, and curing time should be determined according to core material and size to ensure complete curing. Standardized mold assembly operations are equally important. Before mold assembly, floating sand on the surfaces of the mold cavity and sand cores should be thoroughly removed to prevent sand particles from entering the cavity and forming sand holes. Compressed air can be used for cleaning, with pressure controlled within 0.3–0.5 MPa. Control of slag holes and oxide inclusions requires a combination of

measures. Installing ceramic foam filters can effectively intercept slag and prevent it from entering the mold cavity. The pore size of ceramic filters is generally selected based on the size of impurity particles in the molten metal, with commonly used pore sizes ranging from 10 to 30 pores per inch (ppi). Optimization of the melting process is also essential. Degassing, refining, and slag skimming operations should be carried out to remove gases and impurities from the molten metal, thereby reducing the sources of slag holes and oxide inclusions. Degassing is typically performed using nitrogen or argon, refining time should not be less than 15 minutes, and slag skimming should be conducted 2–3 times. The use of teapot ladles or slag-blocking ladles can reduce secondary oxidation of molten metal during pouring, thereby lowering the probability of oxide inclusion formation.

3.3 Countermeasures for Crack Defects

Structural optimization is a critical measure for crack prevention. Abrupt changes in section thickness should be avoided, and fillet transitions should be adopted to reduce stress concentration and lower the likelihood of crack formation. The fillet radius is generally determined according to casting wall thickness and is typically 0.2–0.5 times the wall thickness. The addition of anti-cracking ribs can help disperse stresses, resulting in a more uniform stress distribution under load and enhancing crack resistance. The width of anti-cracking ribs is usually 0.3–0.8 times the casting wall thickness, while the height is generally 1–2 times the rib width. Process adjustments also play a significant role in crack control. Cooling rate should be carefully controlled, and either simultaneous solidification or directional solidification should be selected according to casting characteristics to reduce thermal stresses caused by non-uniform cooling. Simultaneous solidification is suitable for thin-walled castings, whereas directional solidification is more appropriate for thick-walled castings. Adjustment of mold operating temperature and draft angle is also important. An appropriate mold temperature can reduce thermal stress caused by temperature differences between the casting and the mold, while a reasonable draft angle facilitates demolding and prevents cracking during mold release. Mold operating temperature should be determined based on casting material and requirements,

and the draft angle is generally controlled within 1–5°. Stress-relief annealing of complex castings can further improve crack resistance by releasing residual internal stresses. The stress-relief annealing temperature is generally controlled within the range of 500–650 °C, and the holding time is determined according to casting thickness, typically 1 hour for every 25 mm of thickness.

3.4 Countermeasures for Shape and Dimensional Defects

Improvement of cold shuts and misruns should focus on enhancing the mold-filling capability of molten metal. Increasing pouring temperature and pouring rate can improve molten metal fluidity, enabling it to fully fill the mold cavity. On the premise of avoiding defects such as gas porosity, the pouring temperature can be moderately increased by 20–50 °C, and the pouring rate can be increased by 0.1–0.3 m/s. Enlarging the cross-sectional area of ingates and shortening the filling path can reduce heat loss and flow resistance during filling, thereby preventing cold shuts and misruns. Casting distortion can be controlled by adopting anti-deformation design. Based on the shrinkage behavior of the casting, a certain amount of counter-deformation is preset during mold design to compensate for shrinkage and reduce deformation. Optimization of process layout, including rational positioning of gating, risers, and chills, ensures uniform stress distribution during solidification and reduces deformation risk. Elimination of white iron formation and hard spots requires adjustment of carbon equivalent and inoculation treatment. An appropriate carbon equivalent improves the microstructural properties of castings and reduces the tendency toward white iron formation. Effective

inoculation treatment refines grains, enhances casting toughness, and eliminates hard spots. Slowing down local cooling rates through the use of special sands or insulating materials can prevent the formation of hard and brittle microstructures caused by excessively rapid local cooling, thereby ensuring uniform casting quality.

Conclusion

Control of casting defects is a critical aspect of casting production. Through a systematic analysis of defect causes and the implementation of targeted process countermeasures from multiple perspectives—including materials, process design, operation and equipment, as well as environmental and storage conditions—the occurrence of various defects such as porosity, inclusions, cracks, and shape and dimensional deviations can be effectively reduced. Continuous optimization of casting processes and strict control of production stages can steadily improve casting quality, thereby meeting the urgent demand for high-quality castings in mechanical manufacturing.

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