Research and application of smelting process and quality control of high-performance hot work die steel

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In this study, the smelting process, quality control strategy and practical application of high-performance hot work die steel in hot stamping process are discussed in depth. Hot stamping technology is a new type of metal forming process for high-strength steels, which is widely used in the manufacture of automobile body structure parts. The research focuses on the smelting process, quality control and performance characteristics of FYT mold steel. The high strength, wear resistance, thermal stability and toughness requirements of the die steel are realized through the refining smelting process and careful heating treatment. The experimental results demonstrate the wide application of FYT die steel in the hot stamping process, which provides an ideal material choice for the manufacture of automotive parts. The efficient use of die steel in hot stamping process and excellent performance were achieved by optimizing the process and controlling the quality. These studies are of great significance in improving production quality, reducing costs and upgrading the automotive manufacturing process.

Keywords: High-tensile steel hot stamping; Hot stamping tool steel; Electric arc furnace melting; Vacuum degassing method; Quality control.

1. Introduction

High-strength steel hot stamping technology is a new type of metal forming process, which is mainly for high-strength steel and ultra-high-strength steel stamping and forming. This technology is widely used in the field of manufacturing body structure parts for passenger cars, because it can realize vehicle lightweighting and improve the crash strength and safety performance of vehicles [1]. With the increase of plate strength, the traditional cold stamping process is prone to rupture phenomenon in the molding process, which cannot meet the processing process requirements of high-strength steel plate. Hot stamping technology integrates a variety of factors such as forming, heat transfer, and tissue phase change, and its main feature is to take advantage of the high-temperature austenitic state, the plasticity of the sheet material increases, the yield strength decreases, and forming through the die [2]. Commonly used high-strength steel sheet material (such as 22MnB5) forming temperature in the 890-930 ℃, after closing the mold must be rapid cooling (critical cooling rate requirements > 27 ℃), the mold must have to withstand high-temperature thermal fatigue resistance to hot and cold changes. High thermal conductivity die steel can be cooled quickly, which is conducive to improving the strength and hardness of stamped parts, while reducing energy consumption and improving productivity.

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In order to meet these requirements, die steel production must use efficient smelting process, including accurate composition design, optimized melting technology, continuous casting process and careful heat treatment. Nowadays, refining technologies such as electric arc furnace melting, AOD (Argon Oxygen Decarburization), VOD (Vacuum Oxygen Decarburization), and VD (Vacuum Degassing) are widely used to reduce the content of non-metallic inclusions and gases, and to optimize the morphology and distribution of carbides in order to enhance the purity and homogeneity of die steels [3,4]. This study focuses on high-performance die steels, especially FYT die steel, and discusses in depth its smelting process, quality control strategy and its practical application in hot stamping process.

2. Smelting process and quality control of die steel

2.1. *High-strength steel hot stamping process and molds*

High-strength steel hot stamping process is a kind of parallel forming technology in which the high-strength steel sheet is heated above the austenite temperature, and then formed and cooled and quenched by the internal hot stamping die with cooling water channel. The organizational evolution of the forming-phase transformation of a typical hot stamped steel is shown in Fig. 1. Micro alloyed high-strength steel (e.g., 22MnB5) plate, initial state of ferrite + pearlite (tensile strength 650-700 MPa), heated up and held up to 930°C to achieve austenitization, accommodated and then removed from the hot stamping press, rapidly cooled through the martensitic zone to obtain a fine martensitic organization (tensile strength 1500 MPa). During the heating and stamping and forming process, the temperature of the billet changes [5], as shown in Fig. 2. This process has the characteristics of light weight, high strength and relatively low cost, and has become an important way to realize automobile lightweighting and improve the strength and safety of the body.

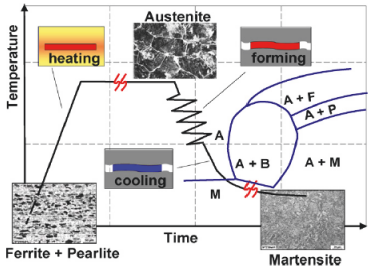

Fig. 1. Hot stamping process and molds for high strength steel

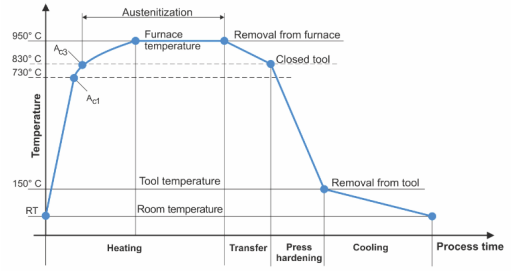

Fig. 2. Temperature change of the sheet for heating and hot stamping process [5]

In a typical hot stamping process, the hot billet out of the furnace temperature of 930 ℃, the upper die closing blank temperature is about 830 ℃, the mold contact with the billet, forming under pressure, the mold in the rapid removal of heat from the billet, until 199-99 ℃ out of the mold. The contact time between the hot blank and the mold is 5-20 seconds, depending on the thickness and shape of the part (blank).

2.2. *Requirements of hot stamping process on mold materials*

The hot stamping process puts forward extremely high performance indexes for the mold materials. First of all, the die must have excellent thermal strength to withstand repeated thermal shocks at operating temperatures up to 900°C and to prevent cracking due to thermal fatigue. The high thermal strength comes from the reinforcing phases in the mold steel as well as a good grain structure, which help to resist the degradation caused by temperature changes. Secondly, the wear resistance of the die material is crucial, because the contact between the die and the high-temperature metal billet during the hot stamping process leads to strong friction, which requires the die material to maintain its hardness and wear resistance at high temperatures.

Thermal stability is also an indispensable characteristic of die steel, which requires the die to remain dimensionally stable at high temperatures for long periods of time without significant thermal expansion or thermal deformation to ensure the dimensional accuracy of the part. This is often achieved by selecting alloying elements with low coefficients of thermal expansion and by optimizing the microstructure, such as controlling the morphology and distribution of carbides. Toughness is also critical to the quality of the die, as the die may be subjected to shock loads during the hot stamping process, and a tough material prevents sudden fracture under impact.

Hot stamping die steel requirements mainly include the following points: 1) hot stamping die steel needs to have high strength and toughness to withstand high temperatures and high pressures under the huge impact load. High strength can ensure that the mold is not easy to deform in a long period of time, while high toughness can improve the fatigue resistance of the mold, and extend the service life of the mold. 2) During the hot stamping process, friction will occur between the mold and the metal product, so the mold steel is required to have a high degree of abrasion resistance, in order to reduce wear and tear on the performance of the mold and the service life of the impact of the tooling. 3) Hot stamping process, the mold steel needs to be at high temperatures Maintain stable performance. A die steel with good high temperature stability can ensure the dimensional accuracy and surface quality of the stamped part, and improve the production efficiency. 4) The thermal conductivity of the hot stamping die steel has a great influence on its cooling speed and energy consumption. High thermal conductivity die steel can be cooled quickly, which is conducive to improving the strength and hardness of the stamped parts, while reducing energy consumption and improving production efficiency.5) Hot stamping die is prone to thermal fatigue cracks as it works repeatedly at high temperature and high pressure. Therefore, hot stamping die steel should have good thermal fatigue resistance to extend the service life of the mold.

The chemical composition of high-performance hot work die steel FYT301, as shown in Table 1. Tested FYT301 impact work of 340 j, FYT309 impact work of 390 j. The sample hardness of the two steels is HRc47-48.

Table 1 FYT hot stamping die steel composition (w%)

Material type	Average alloy composition (W%)						
	C	Si	Mn	Cr	Mo	V	Supply status
FYT301	0.40	1.00	0.45	5.00	1.50	0.90	soft annealed to approx.180HB
FYT309	0.37	0.50	0.60	4.80	2.40	0.60	soft annealed to approx.180HB

2.3. *Smelting process and heat treatment*

FYT301/ FYT309 hot work die steel is a high chromium, molybdenum and tungsten type hot work steel with good heat resistance, heat fatigue resistance and deformation hardening resistance. Smelting process and quality control are crucial in the manufacturing process. According to the smelting and refining process, the smelting production line of die steel FYT301 and FYT309 is configured as shown in Fig. 3.

The following are the smelting process and quality control points of FYT series mold steel:

(1)Smelting process: The smelting of FYT301/ FYT309 mold steel adopts electric arc furnace or induction furnace, and the purity of the steel is improved by the extra-furnace refining technology (e.g. vacuum degassing, argon protection, etc.). In the smelting process, the chemical composition should be strictly controlled, so that the proportion of carbon, silicon, manganese, phosphorus, sulfur, chromium, molybdenum, cobalt and tungsten and other elements to meet the specified requirements.

(2)cast state organization control: FYT301 / FYT309 die steel cast state organization for its performance and service life has an important impact. In order to obtain ideal casting organization, need to control the casting process parameters, such as pouring temperature, cooling rate, etc.. At the same time, the reasonable design of the chemical composition of the mold steel, in order to reduce the casting state organization of the grain boundary energy, reduce the stress concentration at the grain boundary and the generation of grain boundary cracks.

(3)heat treatment process: FYT301 / FYT309 mold steel heat treatment process has an important impact on its performance and service life. Reasonable annealing, quenching and tempering process can improve the die steel toughness, wear resistance and fatigue resistance.

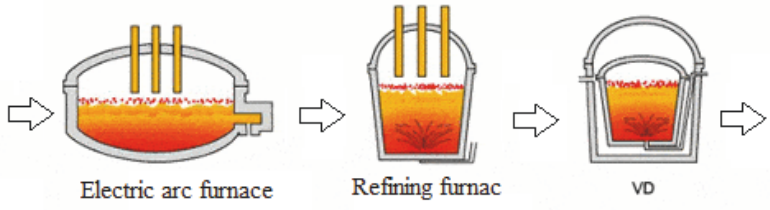

Fig. 3. Tool steel smelting production line schematic diagram

The specific heat treatment process is as follows:

- Annealing: FYT301 / FYT309 die steel using conventional complete annealing or isothermal spheroidal annealing, in order to eliminate internal stresses and improve machinability. Annealing temperature of 850 ~ 900 ℃, after holding the furnace cooling to below 500 ℃, out of the air-cooled.
- Quenching: FYT301 / FYT309 mold steel quenching, can be used in a salt bath furnace, vacuum furnace or mobile particle furnace heating. Quenching process is: 400 ~ 500 ℃ preheating, 650 ~ 840 ℃ preheating, 1020 ~ 1050 ℃ austenitization. According to the requirements of the use of performance, can choose air quenching, oil quenching, gas quenching or graded quenching, graded temperature of 500 ~ 540 ℃.
- Tempering: FYT301 / FYT309 mold steel quenching should be tempered 2 to 3 times to obtain the required mechanical properties. Tempering temperature below 70 ℃, should be carried out as soon as possible to reduce dimensional changes and residual stress. The tempering heating and cooling process should be carried out slowly to avoid re-generation of residual stresses.

2.4. *Quality control of the whole process*

In the manufacturing process of FYT301/ FYT309 mold steel, quality control is the key link. From raw material procurement, smelting, casting, heat treatment to final inspection, it is necessary to strictly control the quality of each link, see Figure 4. specific measures include:

- Procurement of high quality raw materials to ensure that the chemical composition and purity meet the requirements;
- Adopting advanced smelting processes (EAF Electric Arc Furnace Melting, LF Refine and VD (Vacuum Degassing Method)) to improve the purity of steel;
- Optimize grain size and distribution through electroslag crystallizer's control of cast state organization;
- Strictly control the heat treatment process to ensure that the performance is up to standard;
- Conduct comprehensive inspection, including hardness, tensile properties, impact toughness, etc., to ensure product quality.

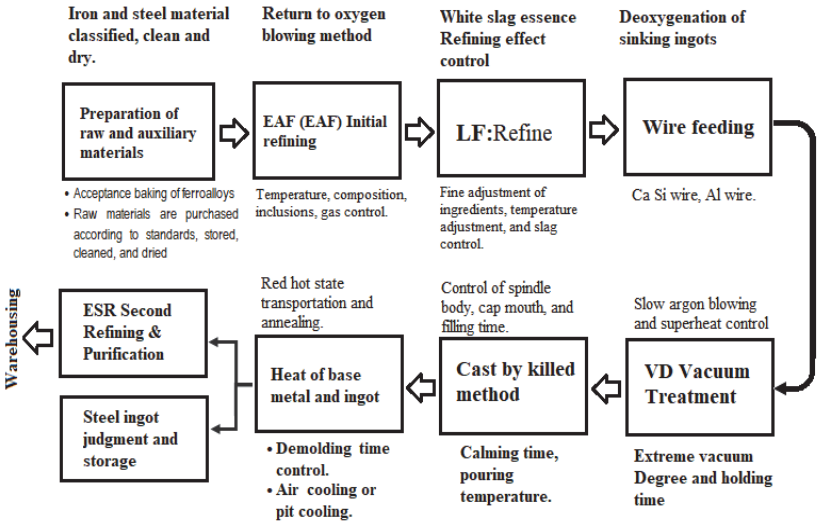

Fig.4. FYT mold steel smelting process and quality control

Through the above smelting process and quality control measures, FYT301/FYT309 mold steel with excellent performance and long service life can be produced.

3. Performance and application of FYT mold steel

3.1. *Performance characteristics*

FYT die steel is unique in hot stamping process with its excellent comprehensive performance. Its microstructure characteristics for high performance has laid a solid foundation. First of all, FYT die steel has a uniform and stable carbide distribution, which is attributed to the refined smelting process, which includes precise composition design and the application of refining technology. The uniform distribution and proper morphology of the carbides contribute to the wear resistance and thermal stability of the material, enabling it to maintain its hardness and resistance to plastic deformation at elevated temperatures.

A comparison table of the performance parameters of FYT301/309 die steel and H13 (4CrMoSiV1) is shown in Fig. 5. FYT series can be widely used in the manufacture of hot stamping dies for structural parts of automobile bodies with good overall performance and cost-effectiveness.

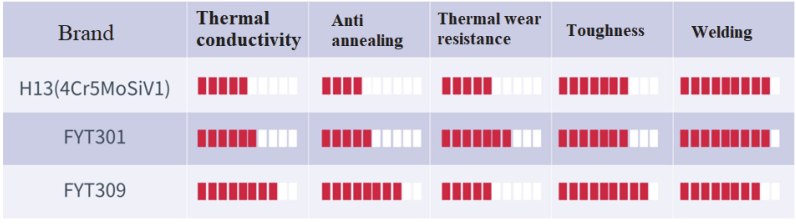

Fig. 5. Comparison of application parameters between FYT301/309 mold steel and H13 (4CrMoSiV1)

3.2. *Application areas*

FYT mold steel has a wide range of applications in the hot stamping forming of automotive body structural components and laser welded plate hot stamping forming. Several typical applications are as follows:

(1) 2-piece B-pillar hot stamping mold in one die. In the process of using the hot stamping mold made of FYT301/309 steel, the shape and size of the mold can be adjusted to make the B-pillar have good strength and stiffness, and the high wear resistance of FYT301/309 steel makes the mold have a long service life and reduces the frequency of mold replacement.

(2) One mold, two pieces of A-pillar hot stamping die: A-pillar is an important structural part of the front part of the car, which is of great significance to the safety and stability of the vehicle. The hot stamping die made of FYT301/309 steel can ensure good molding effect of A-pillar in the stamping process, and improve the strength and stiffness of A-pillar at the same time.

(3) Body front door ring. At present, multi-component integrated hot stamping has become an important development direction, it uses laser welding plate technology, the different forming strength of the plate, according to the mechanical properties of the body door ring needs, welding with, has obtained the comprehensive advantages of mechanical properties and lightweight. Through the use of FYT301/309 steel hot stamping molds, can produce door rings with excellent performance, reduce costs and meet the strict standards of the automotive industry.

(4) Rear Tailgate Beam. Rear tailgate beam is a key structural member of the rear body, which plays an important role in the stability and safety of the vehicle.The hot stamping die made of FYT301/309 die steel can ensure that the rear tailgate beam obtains the ideal shape and size during the stamping process, and at the same time improves its strength and stiffness.

4. Conclusion

In this study, the smelting process, quality control strategy of high-performance die steels, especially FYT die steel, and its practical application in hot stamping process have been thoroughly discussed. Through careful analysis, we understand the special requirements of hot stamping process on die materials, such as high strength, wear resistance, thermal stability and toughness, and how these properties affect the service life of the die and the quality of the product.FYT die steel significantly improves these key properties by virtue of its uniform carbide distribution, fine grain structure and optimized heat treatment.

In terms of smelting processes, high-performance hot work die steels employ the importance of advanced technologies such as electric arc furnace melting, LF refining and VD in reducing the content of non-metallic inclusions and gases, and optimizing carbide morphology. Heat treatment processes, such as pre-hardening, quenching and tempering, are key to achieving specific properties of the die steel, while surface strengthening

techniques play a decisive role in improving the wear resistance and resistance to thermal fatigue of the die.

In most cases, the optimum tool steel for hot stamping can only be an optimum compromise for all these requirements. Standard hot work tool steels often reach their limits when faced with these demands. fYT301 has a good combination of properties that make it suitable for hot stamping and forming dies for high tensile steel plates. TYT309 has excellent thermal conductivity, temper resistance and is suitable for complex hot forming dies.

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