Research and application of new high performance hot stamping die steel

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This paper investigates the utilization of advanced high-performance hot stamping die steel in the realm of lightweight automotive body construction, which represents a significant trend in optimizing automotive structures. It delves into the process characteristics of hot stamping high-strength steel and the performance requirements of die materials. The study emphatically analyzes the influence and requirements of 22MnB5 hot stamping steel on the die during the hot stamping process. Furthermore, it delves into the composition design and smelting process of the new die steel D600/D700 by scrutinizing the experimental data. Subsequent to this, friction and wear experiments, along with thermal conductivity tests, were conducted to validate the performance advantages of the new die steel in practical applications. Finally, the tangible impact and economic benefits of the new die steel in the hot stamping process are demonstrated through statistical data from real-world application cases.

Key words: High strength steel; Hot stamping; Die materials; Friction and wear; Car body lightweight.

1. Introduction

In 2023, China witnessed a remarkable surge in the production and sales of new energy vehicles, reaching 9.587 million and 9.495 million, respectively. This represents a year-on-year growth of 35.8% and 37.9%, with the market share reaching 31.6%. Notably, this growth rate surpasses that of traditional fuel vehicles, underscoring the robust competitiveness of new energy vehicles in the market. The pivotal role of lightweight bodies in advancing hot stamping technology for high-strength plates cannot be overstated. Both traditional fuel vehicles and new energy electric vehicles prioritize the manufacture of their body structures through hot stamping with high-strength steel. The difficulty of cold stamping advanced high-strength steel, coupled with the ease of realization in the hot stamping process, has established hot stamping of high-strength steel as the primary forming method for body structural parts [1]. The demand for die steel in hot stamping is underscored by the need for wear resistance at high temperatures, which directly impacts die life and mass production costs, making it a focal point of industry attention.

2. Performance requirements of hot stamping on die materials

In the hot stamping process of high-strength steel, the influence of 22MnB5 on the die is profoundly significant. Initially, the characteristics of 22MnB5 steel in the hot stamping process exert a substantial impact on the utilization and performance of the die. During the hot stamping process of 22MnB5, phase transformation strengthening occurs through rapid

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cooling, enabling the steel to maintain a stable shape during the mold pressure maintenance process. The strength of hot-stamped parts after cooling and strengthening reaches 1300-2000MPa, thereby greatly impacting the life and stability of the die.

Furthermore, the interaction of friction and wear between the blank, part, and die is an indispensable factor in the hot stamping process. The hardness and surface quality of 22MnB5 steel after forming and strengthening directly influence the friction behavior of the die, thereby affecting the degree of wear. By employing a rational design of the friction pair and surface treatment, the friction and wear between 22MnB5 steel and the die can be mitigated, leading to an enhanced service life and processing stability of the die.

Moreover, there exists a close relationship between the cooling rate and thermal conductivity of die steel. The cooling rate of 22MnB5 steel is influenced by the processing environment and process conditions, while the thermal conductivity of die steel determines the heat conduction velocity. Thus, in the hot stamping process, the cooling rate of 22MnB5 steel and the thermal conductivity of die steel need to complement each other to ensure the timely and effective removal of heat from the steel plate, thereby maintaining the processing accuracy and stability of the die.

In summary, the influence of high-strength steel on the die in the hot stamping process is multifaceted, encompassing material properties, the interaction between friction and wear, and the relationship with the thermal conductivity of die steel. A judicious design of die material characteristics, combined with optimized friction pair design and cooling processes, can effectively enhance the service life and processing efficiency of the die, thereby advancing the progress and development of the hot stamping process.

The primary failure modes of hot stamping dies in operation include wear, plastic deformation, cracking, adhesion of metal chips or oxides, as well as corner cracking, as illustrated in Figure 1 [2]. Understanding these patterns and their underlying causes is crucial for the proper design of the mold. The core of the mold parts must possess a certain toughness and sufficient hardness, while enduring high stress near the surface layer. Additionally, sliding contact occurs on the die surface. Typically, the mold is hardened to a certain degree (not reaching the maximum possible hardness), case-hardened (hardening from the surface to a certain depth), and subsequently coated. The coating typically exhibits high hardness, effectively retarding wear.

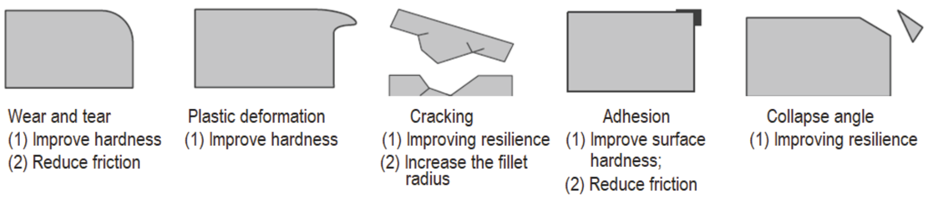

Fig. 1 Main failure modes and countermeasures of molds.

The performance requirements of hot stamping on die materials can be summarized as follows:

- High compressive strength to mitigate plastic deformation

- High hardness at high temperatures to minimize die wear
- Sufficient toughness to prevent fracturing
- Good weldability, facilitating maintenance and design modifications
- High thermal conductivity to facilitate rapid cooling and quenching of parts, thereby enhancing thermal stability and productivity

3. Research on new hot stamping die steel

3.1. *High Wear Resistance Requirement for Hot Stamping Dies*

To design hot stamping die steel with high wear resistance, several key factors must be comprehensively considered. Firstly, the selection of materials with high hardness is essential, such as the addition of carbide and other hard phases, to enhance material hardness, wear resistance, and reduce friction and wear. Simultaneously, while improving hardness, it is crucial to ensure that the material possesses a certain level of toughness to prevent brittle fracture and cracking, thereby improving the die's service life. Furthermore, wear resistance is a pivotal characteristic, necessitating the selection of alloy elements and additives with superior wear resistance to enhance material wear resistance and reduce surface wear. Additionally, the thermal conductivity of the material must be taken into account to ensure effective heat dissipation and maintain processing accuracy and stability. In the composition design and material selection, careful attention should be paid to the selection of appropriate alloy elements and additives to achieve high wear resistance and hardness, while ensuring the processing performance and thermal conductivity of the materials. Therefore, the physical properties and composition design of hot stamping die steel with high thermal conductivity and high wear resistance require comprehensive consideration from various aspects to ensure stable performance in complex processing environments.

3.2. *Composition design of new die steel D600/D700.*

To cater to diverse users and product batch requirements, two high-performance hot stamping die steels were developed [3]. D600 is a long-life die steel suitable for mass production applications, and its material composition is presented in Table 1. On the other hand, D700 is designed for medium-life applications, specifically developed for medium and small batch hot stamping production, and its material composition is detailed in Table 2.

Table 1 Composition (w%) of new mold steel D600

C	Si	Mn	Cr	Mo	V	Al	Fe
0.47-0.53	0.20-0.60	0.20-0.60	4.20-4.80	2.90-3.30	0.50-0.70	0.00-0.04	Bal.

Table 2 composition of new die steel 700 (w%)

C	Si	Mn	Cr	Mo	V	Al	Fe
0.40-0.45	0.20-0.50	0.30-0.60	6.20-6.80	1.20-1.40	0.60-0.90	0.00-0.04	Bal.

3.3. *Smelting and manufacturing process*

The smelting and manufacturing process of D600/D700 wear-resistant and long-life/medium-life die materials is outlined below:

(1) The smelting process involves the use of an electric arc furnace with an eccentric configuration. It is crucial to maintain the alkalinity CaO/SiO at approximately 3% during the electric arc furnace smelting process to ensure the stability of the chemical environment within the furnace and the uniformity of the alloy composition.

(2) The alloying process to adjust the alloy composition and enhance the material properties is conducted in the medium-frequency furnace as part of the refining process.

(3) Further enhancement of the material's purity and uniformity is achieved through the refining process outside the furnace and vacuum degassing.

(4) Finally, the formation of the D600 wear-resistant and long-life die material meeting the specification requirements is accomplished by pouring the electrode blank.

4. Test and application of new die steel

The friction and wear experiment is based on simulating the wear of materials under external forces and friction. These experiments can be conducted using various friction testing machines, such as rotating discs and ball discs [4]. Given the nature of the hot stamping process, which involves the contact, deformation, and sliding of the real hot blank with the mold, special emphasis is placed on conducting sliding wear experiments to simulate the wear of materials under sliding friction.

4.1. *Test of Thermal Friction Coefficient*

The friction and wear tests of D600/D700 were conducted using the UMT Tribolab high-speed and high-temperature friction testing machine (see Figure 2). The sliding wear test was performed to simulate the wear of materials under sliding friction, and the block sliding wear test was selected.

In accordance with the standard test method of the instrument, the pins (upper die) made of two different die steels D600 and D700 are shown in Figure 3. The hot stamping 22MnB5 steel plate, one with AlSi coating on the surface and the other without coating, is welded to the lower module by laser, as depicted in Figure 4. Please refer to Table 3 for the experimental scheme and the experimental parameter settings.

It is evident from data figure 5 that the friction coefficient remained relatively stable in the first 10 seconds of the experiment, with virtually no significant fluctuations. However, as time progressed, when D600 and D700 die steel were rubbed against the AlSi-coated plate at 700 °C, the friction coefficient exhibited an abnormal peak within the first

500 seconds, reaching a maximum value of 1.2-1.35, as depicted in Figure 6. Subsequently, over the following 700 seconds, the friction coefficient stabilized. An analysis of the dramatic change was conducted, revealing that the coating peeled off during the friction process and accumulated on the surface of the test piece, forming accumulation bulges. This hindered the relative movement of the friction pair, resulting in an abnormal increase in friction and the friction coefficient.

Table 3 Test scheme for friction and wear test

22MnB5	Mold material	Temp.	Load/MPa	Area of contact mm^2	Press N	Speed mm/s	Time min
Uncoated	D600	600	5	7.07	35.34	15	20
	D700	600	5	7.07	35.34	15	20
AlSi coated	D600	600	5	7.07	35.34	15	20
	D700	600	5	7.07	35.34	15	20
Uncoated	D600	700	5	7.07	35.34	15	20
	D700	700	5	7.07	35.34	15	20
AlSi coated	D600	700	5	7.07	35.34	15	20
	D700	700	5	7.07	35.34	15	20

Fig. 2 Umttribolab high speed and high temperature friction tester

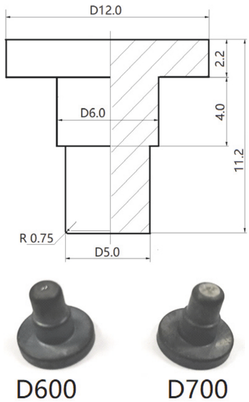

Fig. 3 size and physical photos of friction head

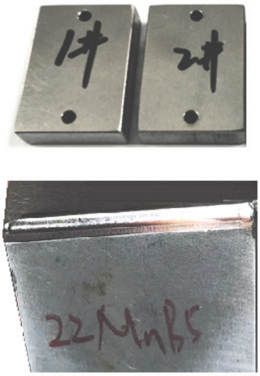

Fig. 4 photos of the lower module and the tested steel plate welded on the module surface

In the actual hot stamping process, the hot stamping of parts lasts for a short time of 0-10 seconds before the experiment. It is more accurate and credible to describe the friction behavior between the die and the sheet metal in the hot stamping process. The friction test results are summarized in Table 4.

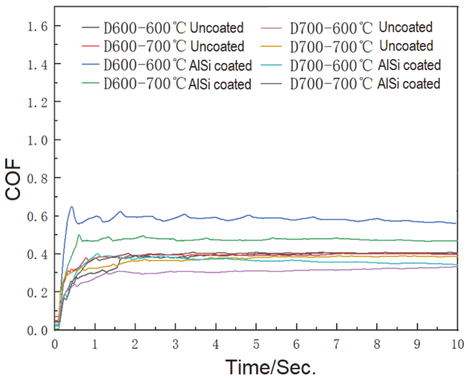

Fig. 5 Friction factor of friction and wear test in the range of 0-10 seconds

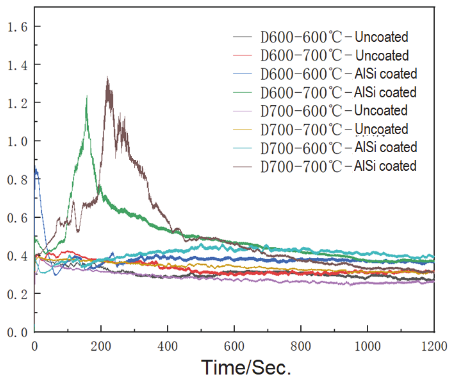

Fig. 6 Friction factor of friction and wear test in the range of 0-1200 seconds

Table 4 Friction test data of different coatings and D600/D700 (hardness of test piece: HRc52-55)

22MnB5	Temperature	D600 (0-10sec.)	D700 (0-10sec.)
Uncoated	600 °C	0.29963	0.26402
	700 °C	0.30938	0.32609
AlSi coated	600 °C	0.37649	0.42132
	700 °C	0.41384	0.38082

Based on the experimental test data provided above, the following observations can be made:

- At a stable temperature, the average friction coefficient of the two types of die steel and the AlSi-coated plate is higher than that of the uncoated steel.
- The friction coefficient of D600 on the 22MnB5AlSi-coated plate undergoes significant changes at 600 °C, which may be attributed to experimental error caused by the friction path being obstructed by the falling off of the AlSi coating during repeated motion friction.

4.2. *Thermal conductivity test*

The thermal conductivity test utilizes laser heating (Type LFA467HT), and the thermal conductivity of D600/D700 at 400°C and 600°C is presented in Table 5. As the temperature increases, the thermal conductivity of D600 decreases by 10%, while the thermal conductivity of D700 experiences a slight decrease of less than 3% from 400°C to 600°C.

Table 5 thermal conductivity of D600/D700

Test temperature	Thermal conductivity w/(m*k)	
	D600/58hrc	D700/54hrc
400 °C	31.8	26.75
600 °C	28.6	26.04

4.3. *Application cases*

Since its introduction for hot forming in 2016, a significant number of early service dies have completed their life cycle. Based on the application data statistics, the new die steel D600/D700 has demonstrated the capability to meet the current mass production life requirements and has exhibited favorable cost-effectiveness.

For the hot stamping of AlSi-coated sheet 22MnB5, numerous instances have been recorded where parts with general forming difficulties (such as ordinary A-pillar, front and rear anti-collision beam plates, etc.) have undergone more than 800,000 stamping cycles [5]. Similarly, for difficult-to-form parts (such as cross beams, front and rear longitudinal beams, central channels, etc.), there have been numerous cases with more than 500,000 punching cycles.

In the case of 22MnB5 uncoated sheet, there have been numerous instances of parts with general forming difficulties (such as ordinary A-pillars, front and rear bumpers, etc.) undergoing more than 500,000 stamping cycles. Furthermore, for difficult-to-form parts (such as cross beams, front and rear longitudinal beams, central channels, etc.), the demand for more than 300,000 strokes can be sustained through local replacement of inserts.

5. Summary

In summary, the research and application of new high-performance hot stamping die steel have demonstrated that the new die steel D600/D700 exhibits excellent wear resistance and thermal conductivity, meeting the requirements of lightweight automobile bodies. It provides crucial support for the advancement and development of the hot stamping process. In practical application, the new die steel has proven to meet the life requirements of mass production and has achieved favorable cost-effectiveness. Therefore, the new high-performance hot stamping die steel holds broad application prospects in the field of automobile manufacturing and signifies a positive contribution to the advancement of the automobile industry.

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