Development and Performance Evaluation of Hot Stamping Die Steel with Long Service Life

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Abstract. This paper presents a new developed hot stamping die steel with long service life. According to high thermal conductivity and high wear resistance required by hot stamping, the composition and content of alloy elements are scientifically designed by analyzing the influence of each alloy element on the material properties. In composition design, the content of Cr, Mn and Si is reduced, and the content of C, Mo and V is appropriately increased. The optimized heat treatment process is also adopted. After testing, the hardness and cross shock resistance of the die steel have been significantly improved. The service life of the hot stamping die using this steel reaches 530k to 610k strokes.

Keywords: Die steel · Hot stamping · Service life

1 Introduction

With the increasing energy crisis and environmental problems, vehicle light weighting has become an inevitable path for the sustainable development of auto industry. The high reinforcement of the car body can not only reduce the weight of the body, but also improve the safety. It is the best way to realize the lightweight of the car body and improve the crash safety at the same time.

Hot stamping is to heat the steel sheet to above 900 °C for austenitization, and then quickly send it into a die with a cooling system for stamping and quenching, and the microstructure of the sheet is transformed to martensite, thereby ultra-high strength parts are obtained. During the stamping process, the die directly contacts with the blank, and the high temperature of sheet material heats sharply up the forming surface of the die, and the surface generates compressive stress, which requires die steel to have high thermal strength and thermal stability. When the stamping parts are taken out, the temperature of the die drops sharply, which is very easy to produce thermal fatigue, and die steel is required to have good high temperature fatigue resistance. During the service process, the die is also subjected to huge shock loads, so it must also have excellent toughness. In addition, the die will also appear to be rough during the stamping process, which requires die steel to have sufficient hardness.

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Currently popular die steels are 1.2367 and 7Cr steel, with a service life of up to 300k strokes. 1.2367 has good thermal fatigue performance and toughness, its wear resistance and thermal conductivity are still poor; 7Cr steel has good wear resistance, but poor thermal fatigue resistance and thermal conductivity. Therefore, it is necessary to improve the existing hot stamping die steel material and its manufacturing method to provide a special die steel with a good combination of wear resistance and thermal conductivity.

This paper presents a new developed hot stamping die steel with long service life. Its composition and process were rationally designed, its microstructure, quenching hardness and cross shock resistance were tested, and the service life of several hot stamping die made of this die steel was counted.

2 Design of Alloy Element Composition

C is a necessary element to ensure the hardness of the steel, and it is the most economical design criterion to increase the hardness by appropriately increasing the C content. On the basis of the traditional thermal strength steel 4Cr5MoSiV1, in order to further improve the red hardness and thermal conductivity [1], the Mo content is increased from the ordinary 1.10–1.75% to 3%. In order to ensure the thermal fatigue performance, it is necessary to make the carbides highly dispersed, to prevent the appearance of large-grained carbides, to make the high-temperature carbide particles rounded. To prevent the formation of a large number of V-series carbides, the V content is reduced from 0.80–1.20% to 0.55%. Silicon will promote the development of dendrites in the steel ingot, aggravate the segregation of steel, and affect the fatigue performance. However, considering the deoxidation requirements, Si is controlled at 0.27%. Cr will form M6C. This carbide is unstable during use. Although it can be refined during production, it will grow and coarsen after a period of use. Due to the absorption of surrounding C by Cr, the matrix will be depleted of C, the hardness will be reduced, and the fatigue life will be affected, but too low Cr will reduce the rust resistance. Therefore, the Cr content should be appropriately reduced from 4.75–5.50% to below 4.5%. Mn will not only promote the precipitation of MnS inclusions, but also increase the overheating tendency of the steel, but it will help deoxidation, so Mn is controlled at 0.30%.

3 Die Steel Samples and Performance Evaluation Methods

The presented die steel, which is named D600, is mainly composed of the following elements (mass fraction, %): C, 0.47–0.51%; Si, 0.25–0.30%; Mn, 0.25–0.30%; Cr, 4.20–4.50%; Mo, 2.90–3.10%; V, 0.50–0.60%; Al, 0.01–0.03%; Fe and other inevitable impurities. 3 samples are tested and their chemical compositions are shown in Table 1.

The heat treatment process of the samples is heating to 1050–1080 °C, and oil cooling and quenching to 50–80 °C [2].

Quenching hardness was tested with a Rockwell hardness tester. JB-w750e-l shock test machine (Fig. 1) was used to test the unnotched cross shock energy. The die steel is adopted by several hot stamping dies, and their service life are counted.

Table 1. The chemical compositions of die steel samples.

Samples	C	Si	Mn	Cr	Mo	V	Al	S	P
1	0.47	0.25	0.29	4.32	2.97	0.55	0.016	0.002	0.009
2	0.49	0.26	0.30	4.32	3.00	0.52	0.019	0.002	0.010
3	0.47	0.27	0.30	4.27	2.97	0.52	0.022	0.002	0.010

Fig. 1. JB-w750e-l shock test machine.

4 Results and Analysis

4.1 Metallography and Mechanical Properties Analysis

D600 die steel is smelted by electroslag re-melting, the material purity is uniform, the steel ingot is completely annealed, and the structure is very uniform and small after sufficient forging (as shown in Fig. 2). The annealed metallography reaches the AS2 level in the North American Die Casting Association (NADCA) standard, which is excellent (AS1-9 is qualified). The good structure ensures the stability of the performance of the mold material. D600 has higher wear resistance and high temperature red hardness than ordinary hot die steel due to the increase of C and Mo in chemical composition. The quenching metallography has reached the AS3 level, which is also excellent.

The Rockwell hardness of the D600 samples is higher than 55 HRC (see in Table 2). Compared with H13, it has obvious advantages in hardness. The hardness of the samples is relatively consistent, indicating the good uniformity of the steel.

The unnotched cross shock energy are all better than 330 J (see in Table 2). Compared with H13, the shock energy is increased by 57.1–64.3%.

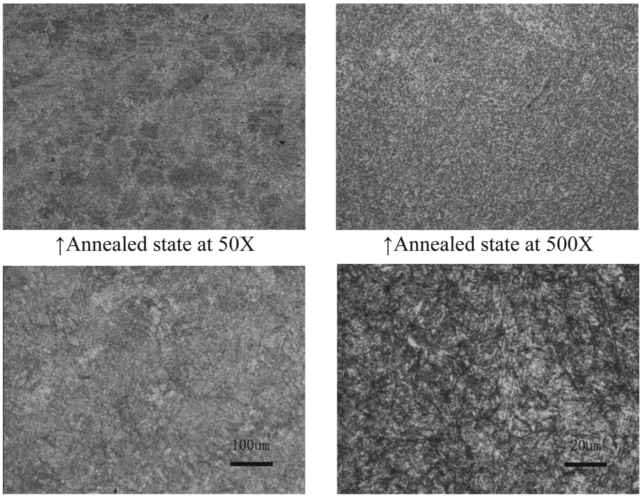

Fig. 2. D600 metallography (mainly pearlite at annealed stated, mainly acicular martensite at quenched state).

Table 2. Metallography and mechanical properties.

Samples	Metallography		Quenching hardness/HRC	7 × 10 unnotched cross shock energy/J
	Annealed	Band segregation		
1	AS3	SA1	56	338
2	AS4	SA1	56.5	345
3	AS3	SA3	55	330
H13	/	/	44–52	210 (at 51HRC)

Due to the reasonable heat treatment and quenching temperature, all alloy elements are dissolved, and in the rapid cooling and quenching, they become a small high-toughness fine needle-like martensite structure and a small amount of dispersed carbides, so the die steel obtains high toughness, high wear resistance, and high red hardness, and it is very suitable for high temperature and harsh hot stamping service conditions.

Table 3. Die service life.

Die case	Service life/strokes
B-pillar die	560k
Die of Front and rear anti-collision beams	610k
Die of A-pillar lower panel	530k

Fig. 3. Die of B-pillar and A-pillar lower panel.

4.2 Die Service Life

D600 die steel is used in the manufacture of several dies, and they are used for the production of various vehicle parts. According to the product production quantity and technical evaluation, the service life of these dies will reach 530k to 610k strokes (see in Table 3), which is able to better meet the production needs of hot stamping die in the entire life cycle and reduce die costs (Fig. 3).

5 Conclusion

This paper presents a new developed hot stamping die steel with long service life. According to high thermal conductivity and high wear resistance required by hot stamping, the composition and content of alloy elements are scientifically designed by analyzing the influence of each alloy element on the material properties. In composition design, the content of Cr, Mn and Si is reduced, and the content of C, Mo and V is appropriately increased. The optimized heat treatment process is also adopted. After testing, the hardness and cross shock resistance of the die steel have been significantly improved. The service life of the hot stamping die using this steel reaches 530k to 610k strokes.

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