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Microstructure and mechanical properties of hot forging die manufactured by bimetal-layer surfacing technology

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ABSTRACT

The temperature field and thermal cycling characteristics of a cast-steel matrix die of automobile crankshaft were predicted. The hot forging die was divided into three temperature regions, i.e., surfacing temperature fluctuation region (0–3 mm in thickness), near surfacing temperature gradient region (3–20 mm in thickness) and matrix temperature balanced region (above 20 mm in thickness), and their temperatures were distributed in high, medium and low-tempered temperature zones respectively. The influences of temperature distribution on the microstructure and mechanical properties of the forging die before and after service were studied. The tempered martensite of strengthened layer decomposed and the coarse grain appeared after service. The protruding part of the ribbed slab was easy to propagate fatigue crack, leading to significant decreasing of tensile strength and impact properties. The tempered martensite and lower banite increased in transition layer, the mechanical properties under high temperatures decreased obviously. The strengthening of hardened structure in weld zone was reduced and the coarse grain structure disappeared, this enabled the performance of the weld zone was more stable than the cast-steel matrix layer and the transition layer.

1. Introduction

With the rapid development of power, shipbuilding, aviation and other high-end equipment manufacturing industry, the demand of large hot forging die is increasing. The largest hot die forging press (800 MN) in the word has been put into operation and the working stress of the hot forging die is more than 1000 MPa, and the temperature can be up to 550–750 °C, and the single piece of die weight is 15–75 tons (Zhang et al., 2015a). Traditional large hot forging die is commonly manufactured by homogeneous die material. The forging die used on 750 MN forging press in Soviet Union adopted the combination method of casting and open die forging. The cost of former is lower, but the surfacing layer has low heat treatment hardness, poor wear resistance and short die lifespan. The latter adopted expensive homogeneous material like 5CrNiMo and 5CrMnMo through smelting, casting, forging and machining (Hu et al., 1999). Homogeneous die material manufacturing method used expensive die material for the whole die to meet local performance requirements, and the partial failure would lead to a whole scrap. Moreover, it was hard to control the internal defects in large forging die after forging and heat treatment. Consequently, the whole process had many disadvantages such as high cost, long production period, and low material utilization (Altan et al., 2001). Surfacing welding method used alloy material with a certain performance to clad on parent material surface by means of using heat source to make the parent material obtaining special performance. The Soviet Union applied this method to repair die in early 1950s; the United States used H13 steel welding material to repair die, and the maximum lifespan could be up to 20,000 pieces. Li and Guan (2006) repaired the sleeve axle die by using D397 welding rod and studied the die surfacing welding process. By optimizing the surfacing welding parameters, Sun (2006) found that the lifespan of connecting rod forging die was increased by 60% after using surfacing welding. Luo et al. (2009) used surfacing experiment to investigate the effect of external magnetic field on the performance of surfacing layer. Meanwhile, the progress has been made in the research on welding materials and method. Kim et al. (2012) added Nd and Pr elements into the ferroalloy and studied the corrosion fatigue resistance of 5% iron-based alloy. Zhou et al. (2012) reported that the strength and toughness of surfac-

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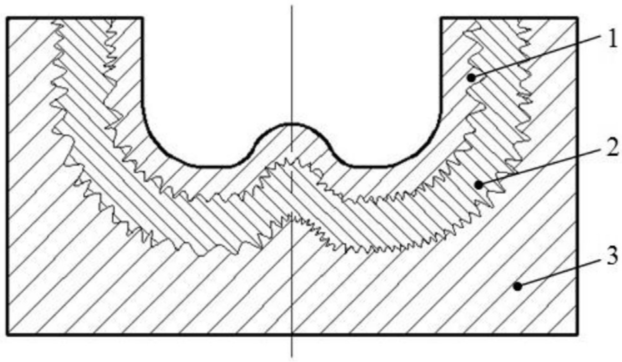

Fig. 1. Section diagram of cast-steel matrix with bimetal-layer surfacing. 1- Strengthened layer; 2- Transition layer; 3- Cast-steel matrix layer.

ing layer were improved by adding Fe-24 wt.%Cr–4.1 wt.%C alloy to ASTM1045 steel. Yu (2004) studied on laser cladding surfacing method of FeNiCrBSi iron-based alloy. Azimi and Shamanian (2010) found that three kinds of Cr powder were deposited in AISISt52 by TIG welding to observe the metallurgy bonding between welding material and parent metal. Liu et al. (2006) adopted plasma spray welding (PTA) to make Fe-Cr-C-Ni powder deposited on the base metal 45 steel and observed its wear resistance. Considering the fusion property between welding materials and parent materials, only the compositions of welding materials that similar to die materials were selected to repair the local failure position in traditional surfacing welding. Therefore, the surface hardness, wear resistance and tempering resistance were not prominent.

In this paper, bimetal-layer surfacing on cast-steel matrix was carried out by combining casting and surfacing welding, as shown in Fig. 1 (Li, 2014). The cavity and contour of die was cast firstly by using low cost JXZG02 cast-steel; then, the welding materials with good high-temperature strength and toughness were welded on the matrix to form transition layer and strengthened layer (Zhou et al., 2011). Finally, the die was heat treated and machined. The mechanical properties of forging die were significantly improved by employing excellent high temperature performance of the welding material. Since the die was cast and surface welded according to the profile of die cavity, the manufacturing process and machining allowance were decreased obviously, and the service life and material utilization of forging die were increased significantly. Meanwhile, the surfacing material could be selected specifically according to the service state in different layers of the die, which was beneficial for selecting surfacing alloy materials, enabled high

Table 1
Chemical component of matrix and surfacing alloys.

	C	Si	Mn	P	S	Ni	Mo	Cr	Cu	Al	W	V	Fe
JXZG02	0.28	0.34	1.15	0.02	0.01	0.39	0.25	0.52	0.21	~	~	~	Rest
HC05	0.25	0.74	1.58	0.01	0.01	1.49	1.68	5.51	~	0.22	1.04	0.23	Rest
HC07	0.23	0.78	2.46	0.02	0.01	1.87	1.47	4.58	~	~	~	0.17	Rest

manufacturing flexibility, and extremely suitable for large forging die.

Hot forging die suffers from interaction of mechanical and thermal effect, and complex loading conditions often lead to die failure, such as wear, plastic deformation, fatigue, corrosion, oxidation and surface cracking (Ebara, 2010). Thermal effect is the main influential factor, including alternating stress caused by thermocycling and the microstructure and properties of materials affected by temperature change, and later lead to basic performance changes such as wear resistance, strong toughness, tempering resistance, etc. (Srivastava et al., 2004). The improvement of lifespan of cast-steel matrix with bimetal-layer surfacing forging die is depended on mechanical properties of surfacing layer and the cast-steel matrix's weld zone. Therefore, this paper focuses on the comparison of microstructure and mechanical properties of cast-steel matrix with bimetal-layer surfacing forging die on a hot die forging press before and after service; the temperature distribution and heat transfer characteristics of die surface layer, and near surface layer and matrix were analyzed by DEFORM 3D. Then, the evolution of microstructure and mechanical properties of surfacing layer and weld zone were revealed to provide important guidance for material selection and functional layer design of large cast-steel matrix with bimetal-layer surfacing on hot forging die.

2. Experimental materials and welding process

2.1. Experimental materials

In this study, JXZG02 was used as the matrix material of forging die. According to the different requirements of each surfacing layer, the material of strengthened layer and transition layer were respectively surfacing electrode HC05 and HC07. The chemical component of these three surfacing layers was listed in Table 1.

2.2. Surfacing process

JXZG02 die matrix should be cleaned (deoil and derusting) and preheated before surfacing, and the dried electrodes were placed in

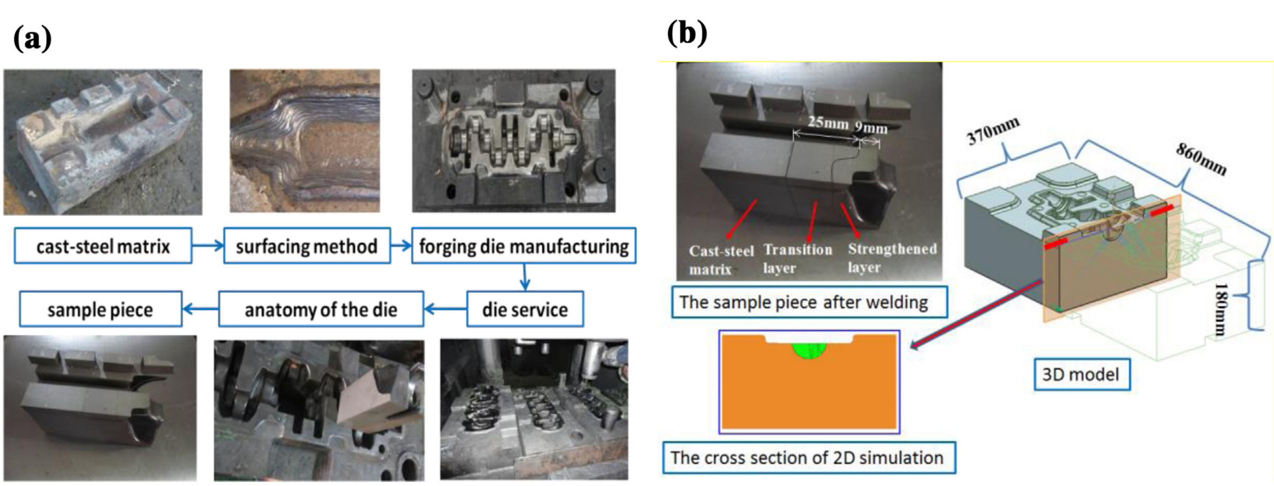

Fig. 2. Die manufacturing processes and sampling. (a) Die manufacturing processes; (b) Sample and simulated section.