MATEC Web of Conferences **21**, 08001 (2015)
DOI: 10.1051/matecconf/20152108001

Bimetal-gradient-layer surfacing of forging die manufacturing based on cast-steel substrate

Jiansheng Zhang[a], Jie Zhou, Fei Gao, Zhu Su, and Shun Lu

College of Materials Science and Engineering, Chongqing University, No.174 Shazhengjie, Shapingba district, Chongqing 400000, China

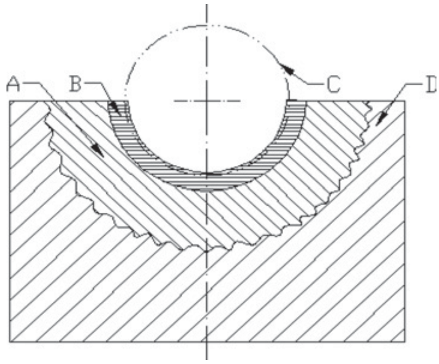
Abstract. To solve problems encountered in manufacturing forging die used on large-scale hydraulic press with traditional method, such as poor forging penetration, long cycle, high cost, etc, a new method of mold making was put forward, which adopted casting steel as substrate and used two surfacing layers– the bimetal-gradient-layer(BGL)– on the working area of die cavity to make forging die. Firstly, the processes and materials were chosen according to the operating requirements of equipment and BGL surfacing samples were prepared. Then, properties analyses of samples were conducted. The application experiment was done on 50MN hydraulic press. The results showed that this method could shorten the manufacturing cycle and reduce cost apparently; properties between substrate and surfacing layers transited smoothly; the properties of die manufactured by BGL surfacing method could meet the requirements of 50 MN hydraulic press well, which justified the new method's effectiveness.

1. Introduction

Dies play a key role in the fast-developing industries such as aerospace, automotive, machinery etc., and the demand is still increasing. The biggest die-forging hydraulic press around the world has been put into use in China and its forging die can weigh 65 $\sim$ 100 tons for each one. The traditional method to manufacture hot forging die is to machine forged modules of 5CrNiMo or H13 and to do surface treatment such as nitriding, carburizing, shot peening etc. to extend the service life of dies (Albertin et al. 2001; Bagherifard et al. 2013; Chen 2002). However, this method has many defects such as low material utilization, large amount of finishing, long production period, high cost and so on (Ciancaglioni et al. 2012), which impedes the upgrading of products and lowers the competition ability.

In this paper, a new BGL surfacing method was put froward to manufacture large-scale molds, shown in Fig. 1. The new method is expected to substitute die steel with "casting steel + BGL surfacing" and the strengthening layer that has high strength and hardness is welded along the cavity profile based on casting steel (Girish et al. 2013). This new method can lower the cost of mold making considerably and shorten the manufacturing cycle and improve the dies' service life. The hardness of die cavity can be HRC45-50, which is much higher than 5CrNiMo forging die. The process of BGL surfacing method is as

[a] Corresponding author: zhangjiansheng@cqu.edu.cn



A——Layer 1: transition layer with moderate strength and hardness;
B——Layer 2: strengthening layer with high trength and hardness;
C——Mold cavity contours;
D——Cast-steel substrate

Figure 1. Sketch of BGL surfacing method.

Table 1. Chemical composition of three kinds of materials.

Composition	C	Si	Mn	P	S	Cr	Ni	Mo	W	Cu	V	Co	Fe
JXZG	0.35	0.36	1.57	0.017	0.005	0.28	0.12	0.08	~	~	~	~	The rest
JXHC1	0.16	0.60	1.33	0.03	0.007	6.40	1.86	1.82	1.58	~	0.17	0.05	The rest
JXHC2	0.30	0.82	1.87	0.01	0.005	7.20	1.57	1.93	4.32	0.04	0.25	0.17	The rest

following: casting → heat treatment (normalizing and high-temperature tempering) → rough machining → the BGL surfacing(including preheating, surfacing and tempering after welding) → finish machining → grinding or polishing → inspection. Processes such as open die forging and the corresponding heat treatment of traditional method can be cancelled. Although surfacing and other relevant processes have to be added, this method approves to be highly cost efficient and promising.

To use this new method on large-scale hydraulic press (300MN and 800MN), scale-ration application experiments were done on 50MN hydraulic press in this paper. The materials and processes that met the operating requirements of 50MN hydraulic press were chosen and BGL surfacing samples were tested to analyze the properties. Following the way we designed, the BGL surfacing method could be used to manufacture forging dies for materials with bigger forming load and higher deformation temperature(such as titanium alloys, high temperature alloys etc.) in near future.

2. Experimental details

2.1 Materials selection

Based on the production cost and the operating requirements of equipment, we chose JXZG casting steel (designed by Chongqing Jiepin High Tech. Development Co.Ltd) as substrate material. JXHC1 and JXHC2(designed by Chongqing Jiepin High Tech. Development Co. Ltd) were chosen as welding wires. Table 1 shows the composition of JXZG, JXHC1 and JXHC2.

2.2 Surfacing process

JXZG should be preheated before surfacing process and the temperature for preheating was 450 °C ± 20 °C and the heating temperature speed was 80 °C/h. After 10 hours' heat preservation (He 2000), we used Dimension 812 welding machine to do surfacing. The protective gas was argon and carbon dioxide (volume ratio was 4:1). Table 2 shows the parameters of surfacing process. The last step was to temper it at 550 °C and to cool it in furnace.

Table 2. Process parameters of surfacing.

Welding machine	welding voltage/V	welding current/A	inter-layer temperature/°C	welding speed/ mm · s^{-1}	wire diameter/mm
Dimension 812	26	130	300 ± 20	3	2.4

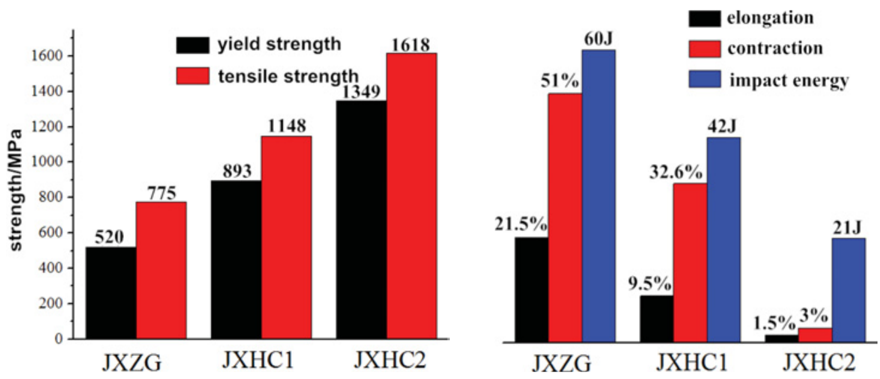


Figure 2. Mechanical properties of the substrate and two surfacing layers.

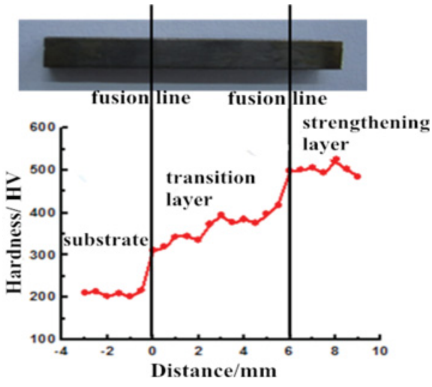


Figure 3. Hardness distribution curve of sample.

2.3 Properties analysis

2.3.1 Mechanical properties analysis

The mechanical properties of JXZG, JXHC1 and JXHC2 at room temperature are shown in Fig. 2.

From Fig. 2 we can see that the mechanical properties grew gradiently and had a smooth transition between substrate and two surfacing layers, which helped the fusion process of JXZG and JXHC. The strengthening layer had high strength and high wear resistance, which could meet the working requirements of die cavity and prolong the service life (Zhang 1996). The ductility and toughness of substrate were good enough while it was much cheaper than conventional die steel.

2.3.2 Microhardness analysis

The welding line between JXZG and transition layer(JXHC1) was chosen as a starting point and hardness tests were done every 0.5 mm to the substrate direction and the surfacing layers direction. From Fig. 3 we can see that a more relaxative hardness gradient developed during BGL surfacing process because of the existence of transition layer. In addition, as binder, the carbon content of transition

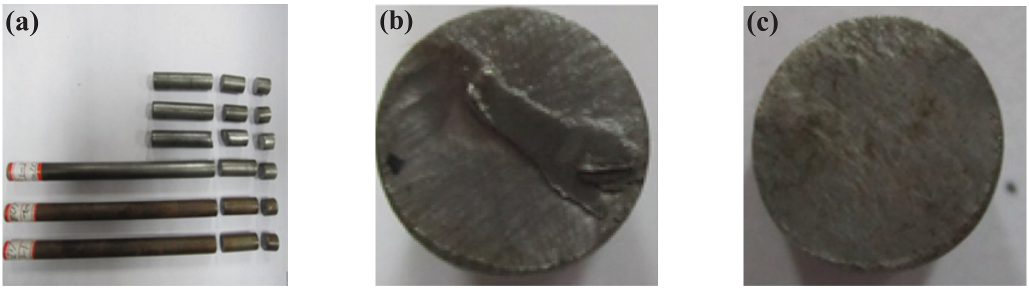


Figure 4. Shear fracture morphology: (a) samples (b) the interface between JXZG substrate and JXHC1 transition layer; (c) the interface between transition layer and JXHC2 strengthening layer.

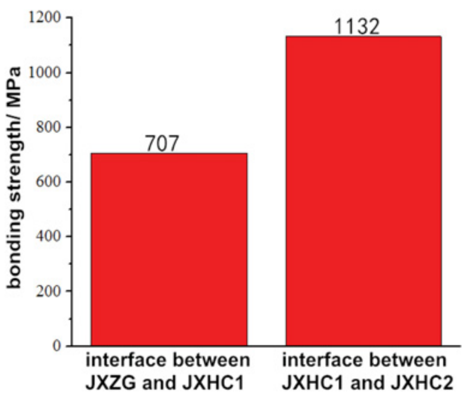


Figure 5. Bonding strength.

layer was moderate, which decreased the carbon migration. Therefore, the softening of substrate and hardening of surfacing material near the fusion line were avoided.

2.3.3 Bonding strength analysis

Figure 4 shows the shear fracture morphology. The fracture mechanism between substrate and JXHC1 was quasi-cleavage fracture and the fracture mechanism was dominated by brittle fracture between JXHC1 and JXHC2 (Zhou 2011). Figure 5 shows the boding strength of different materials.

The bonding strength between substrate and JXHC1 was 707 MPa, which was higher than the tensile strength of cast-steel substrate and could prevent the BGL surfacing structure from dropping out or cracking effectively. Meanwhile, the bonding strength between JXHC1 and JXHC2 was 1132 MPa, as shown in Fig. 5. The gradient growth of bonding strength was of great importance in avoiding failure resulted from huge properties difference between dissimilar materials, which ensured the reliability of surfacing structure.

3. Results and discussion

3.1 Forging simulation and results

Figure 6 shows the model of a undercarriage crossbeam produced on 50MN hydraulic press and its bottom die of pre-forging process.

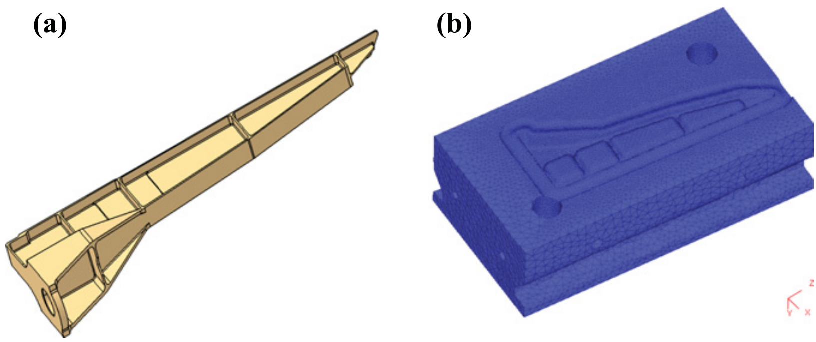


Figure 6. FEM model: (a) undercarriage crossbeam; (b) bottom die of pre-forging.

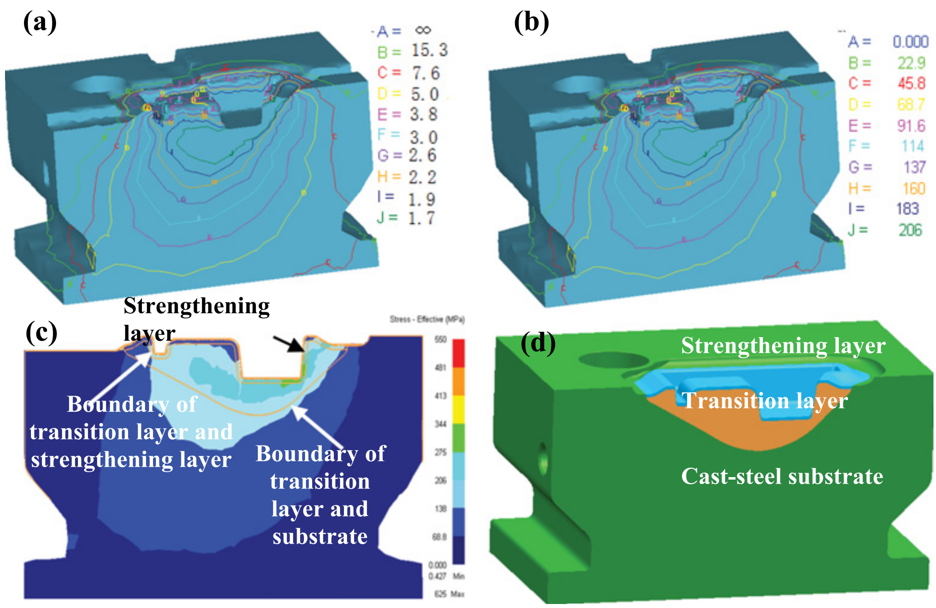


Figure 7. BGL surfacing: (a) security coefficient; (b) allowable strength; (c) outline curve; (d) structural model.

The forming process of a undercarriage crossbeam was simulated on Deform-3D. The forming of undercarriage crossbeam was difficult because of its high web and thin wall structure. Therefore, AISI-H13 steel (homogeneous material) was used as the mold material in our simulation firstly to achieve the temperature field and stress distribution of this mold under working condition. Then, by combining simulation results and properties of materials and recommended value of safety coefficient, the three-dimensional models of cast-steel substrate and surfacing layers were obtained, as shown in Fig. 7.

Following the way we design above, the BGL surfacing method can be used to manufacture forging dies for bigger equivalent stress and higher deformation temperature.

3.2 Trail production

Figure 8 shows the bottom die manufactured by BGL surfacing method and one forging produced on it. The forgings produced have passed dimension and performance inspections and the forging die was intact after service. Compared with the forging die of 5CrNiMo, the service time of BGL surfacing die

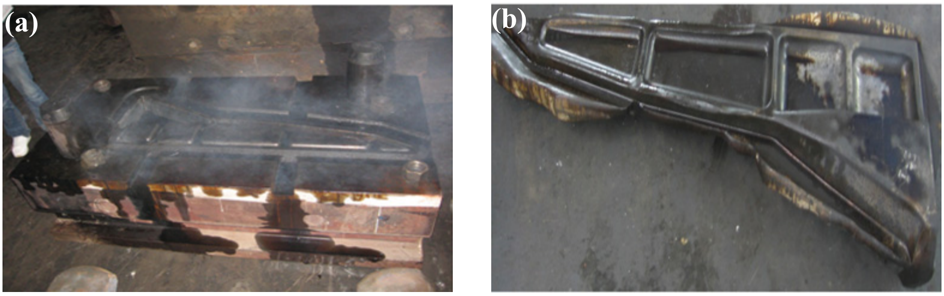


Figure 8. (a) The BGL surfacing die; (b) forging.

was prolonged and the manufacturing cost decreased by 20 $\sim$ 30%. The main failure was fatigue wear on surface of die cavity while collapse, flaw or crack was not found. The trial production has proved BGL surfacing method's effectiveness in manufacturing forging die.

4. Conclusions

- A new method of mold making is put forward in this paper, which is highly cost efficient and promising.
- The composition and microstructure of BGL surfacing samples transit smoothly between cast-steel substrate and two surfacing layers.
- The properties of BGL surfacing structure can meet the working requirements of 50 MN hydraulic press under working condition.
- The new method can shorten the manufacturing cycle apparently and prolong the die's life-span, which is pretty promising.

This research was supported by grants from the National Natural Science Foundation of China (No. 51275543) as well as Special Funds for Major Projects of China's Ministry of Science & Technology (2012ZX04010-081).

References

[1] Albertin E., Sinatora A. 2001. Effect of carbide fraction and matrix microstructure on the wear of cast iron balls tested in a laboratory ball mill, Wear, **2**(50): 492–501
[2] Bagherifard S., Fernandez P.I., Ghelichi R. 2013. Fatigue behavior of notched steel specimens with nanocrystallized surface obtained by severe shot peening, Materials & Design, **45**: 497–503
[3] Chen Z.N. 2002. Handbook on welding. Beijing:China Machine Press, 141–172
[4] Ciancaglioni I., Donnini R., Kaciulis S. 2012. Surface modification of austenitic steels by low-temperature carburization, Surface and Interface Analysis, **447**(8): 1001–1004
[5] Girish B.M., Vitala H.R., Satish B.M. 2013. Effect of nitriding on corrosion behavior of graphite reinforced aluminum alloy composites, Corrosion Engineering Science and Technology, **48**(1): 51–54
[6] He J.J. 2000. Precision casting processes of casting dies, Foundry, **49**(3): 156–159
[7] Zhang H.J., Dai J.W., Zhu Y.R. 1996. Investigation on low temperature temper embrittlement of 20Cr2NiA steel, Physical testing and Chemical Analysis Part A(Physical testing), **32**(6): 11–14
[8] Zhou J., Lu S. 2011. A method of dual metal layer manufacturing mold based on cast-steel substrate: China, ZL200910104604. X[P]