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Surface hardening of die steel by superplastic deformation of thermo-sprayed powder alloy ①

WEN Jiu-ba(文九巴)[1], CHEN Shi-pu(陈世朴)[2]
(1. Department of Materials Engineering, Luoyang Institute of Technology, Luoyang 471039, P.R.China;
2. School of Materials Science and Engineering, Shanghai Jiaotong University, Shanghai 200030, P.R.China)

[Abstract] The superplastic forming is an advanced processing technique and has been used in manufacturing some dies, especially extrusion die and forging die. In heavy load condition, the superplastic formed dies often exhibit low service life owing to the low surface strength and poor wear resistance. A commercial cold working die steel GCr15 pre-treated into ultra-fine grain sizes was chosen as the substrate material, on which the surface was thermal-sprayed with the powders of a wear-resistant alloy. At some appropriate temperatures and strain rates, the accommodated superplastic deformation of the substrate and coating occurred and the good cohesion was well performed. The coated layer shows high microhardness values and fairly smooth transition in hardness from substrate to the surface. The wear resistance of superplastically formed specimen has also been improved, compared with the GCr15 steel coated with the same alloy powder and treated by flame remelting.

[Key words] surface hardening; superplastic forming; thermal spray
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1 INTRODUCTION

Dies play an important role in modern manufacturing industry. New processing techniques[1] are being innovated day and day, such as spark erosion, ultrasonic and electron-beam machining, superplastic forming and so on. Their application has remarkably improved the efficiency and quality of the die-making and lowered down the production costs. A variety of the dies used in extrusion, forging, blanking, etc are experienced very severe working conditions of combined heavy load, impingement and friction and they often failed due to caving-in or excessive wear and tear. In order to enhance the hardness and wear-resistance of the die surface, various surface modification methods (e.g. surface coating, deposition, spraying and laser treatment) are used for prolonging their service life.

The present paper suggests a new technique including the thermal spray of wear-resistant alloy powders on surface and the accommodated superplastic deformation of the coating/substrate combination, expecting to well-weld the coating layer with the steel and to strengthen the die surface simultaneously during an easier superplastic die-forming process.

2 EXPERIMENTAL

2.1 Materials and processing

A commercial die steel GCr15 was used as the substrate material, whose nominal compositions are listed in Table 1. The steel bar was machined into rectangular specimens with dimensions of 10.5 mm × 8.0 mm × 17.0 mm. In order to obtain an ultrafine-grained microstructure for the superplastic deformation, the specimens were repeated 3 times by heating at 840 ~ 860 ℃ in salt bath and quenching in oil, and finally tempered at 200 ℃. The resultant grain sizes were about 3 ~ 5 μm.

The steel substrate was firstly blasted with coarse sand. On its 8.0 mm × 17.0 mm surface, the commercial alloy powders (its compositions are also listed in Table 1) were flame sprayed to form about 1 mm thick layer.

Table 1 Nominal compositions of tested die steel and sprayed alloy powders (%)

Material	C	Cr	Mn	Ni	B	Si	Fe
GCr15	1.04	1.55	0.32				Bal.
Alloy powders	1.00	-	-	25	1.5 ~ 3.5	3.0 ~ 5.0	Bal.

2.2 Superplastic deformation tests

The coated steel specimens were compressed at 760 ~ 810 ℃ at different initial strain rates, and the strain rate of $2.5 \times 10^{-4} s^{-1}$ was found to be satisfactory for the accommodated superplastic deformation of both the substrate and the coating.

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2.3 Hardness measurement and wear test

The T1 microhardness tester was used for measuring the hardness distribution from coating to substrate in the coated specimens. The wear resistance was evaluated with an MM-200 test machine using a block-on-ring arrangement in air at room temperature without lubrication. The rings were made of steel GCr15 and heat treated to a hardness of 64 HRC. The wear tests were performed with the load of 196 ~ 588 N at 400 r/min. The mass loss after 40 min test was measured by an analytical balance.

3 RESULTS

3.1 Superplastic deformation of substrate and coating

Fig.1 shows the m values (the strain rate sensitivity upon flow stress) and the R values (the ratio of strain rate between coating and substrate) at the initial strain rates of $2.5\times10^{-4}\ s^{-1}$ as the function of deformation temperature for the coated specimens. The measuring technique of m and R values has been reported elsewhere[2,3]. The substrate steel behaves rather high m values which are higher than 0.3 in the temperature range of 780 ~ 800 ℃ and for the coating the m values are also high in 770 ~ 800 ℃, indicating that the superplastic deformation occurs for both materials at temperatures of 780 ~ 800 ℃. $R>1$ means that the deformability of coating is larger than the substrate's, and vice versa. In particular, at 790 ℃ $R\approx1$, which means that the deformabilities of both materials are similar, resulting in an accommodated deformation. Therefore, a good cohesion was produced between the substrate and coating and the hardened layer formed on the substrate surface.

Fig.1 Temperature dependence of sensitivity parameter m (a) and strain rate ratio R for coating and substrate (b)

3.2 Hardness and wear resistance

Deformed at 790 ℃ and $2.5\times10^{-4}\ s^{-1}$ and followed by air cooling, the profile of microhardness for the GCr15 steel thermal sprayed with Fe-base wear-resistant coating is shown in Fig.2. The surface hardness reaches up to ~ HV 1 000 and smoothly decreases to that of the substrate.

Fig.2 Microhardness distribution from coating to substrate

Fig.3 is the mass losses as a function of load in the 40 min wear tests, where curves 1 and 2 are the same substrate with thermal sprayed coating but followed by superplastic deformation and by flame remelting respectively. These two kinds of specimens exhibit the similar wear behaviors but the wear resistance of the superplastic deformed specimens is obviously better than that of the remelted one.

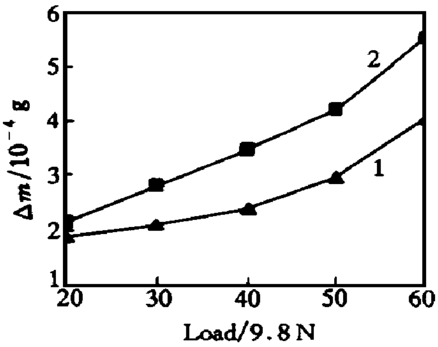

Fig.3 Relationship between mass loss of coating and load for different treatments
1 —Coating superplastically welded at 790 ℃;
2 —Coating remelted by flame

3.3 Microstructure

The optical micrograph of the 790 ℃ superplastic deformed GCr15 steel with coating is shown in Fig.4. The coating layer is dense and homogeneous, no cavity was observed which was inevitably remained after thermal spraying. The coating has been welded onto the substrate. Furthermore, a new (but was not identified) transition layer was found at the interface, by which the well-metallurgical cohesion was formed

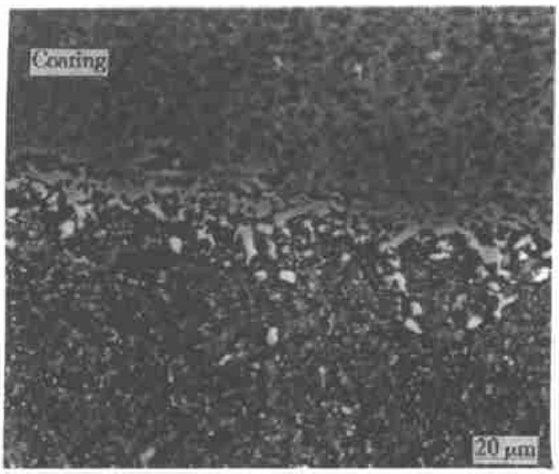

Fig.4 SEM micrograph of coating superplastically welded at 790 ℃

between the substrate and the coating layer.

4 DISCUSSION

The results of present investigation indicate that the m values of the substrate and coating are both higher than 0.3 at 780 ~ 800 ℃ at the initial strain rate of $2.5 \times 10^{-4}\ s^{-1}$. Therefore, it is believable that the accommodated superplastic deformation occurred in such compressive conditions, the fact of $R \approx 1$ means the similar strain rates for both materials. Because of the great difference in the properties of both materials and, thus, in the flow stress and deformability, the nearly equal strain rates are essential for the accommodated deformation.

It is generally recognized[4,5] that the process of superplastic deformation involves the sliding and(or) the rotation of the grains which is adjusted by the motion of dislocation, and is also accompanied by the microscopic diffusion[6~8]. During the superplastic deformation, the microprocesses at the interface region, such as the interdiffusion[9], get much activities[10], resulted from the great difference in crystallographic and chemical compositions between the substrate and coating. Meanwhile, after deforming, the motion of dislocations would also lead to the recrystallization and the formation of new grains across the interface. Therefore, both materials were well-welded to each other and the pores were closed.

The present investigation has suggested that the new processing technique composed of thermal spraying and superplastic deformation can produce a hardened layer on the GCr15 steel, in which many hard particles are precipitated from the coating during the superplastic deformation, and result in remarkable improvement of the surface hardness and wear resistance for the die steels. The technique is supposed to be suitable for the forming of the dies, although the technological details need further studying.

5 CONCLUSIONS

1) By thermal spraying with Fe-base wear-resistant alloy powders onto the surface of ultrafine-grained GCr15 steel, followed with superplastic deformation at temperatures of 780 ~ 800 ℃ and strain rate of $2.5 \times 10^{-4}\ s^{-1}$, the coating is well-welded with the substrate and the hardened layer is formed on the surface.

2) The new processing technique remarkably improves the surface hardness and the wear resistance of GCr15 die steel.

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