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Preparation of Ni60-WC Coating by Plasma Spraying, Plasma Re-melting and Plasma Spray Welding on Surface of Hot Forging Die

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Abstract: In order to produce the hear-resistant inner layer of hot-forging die, the plasma spraying and plasma re-melting and plasma spray welding were adopted. Substrate material was W6Mo5Cr4V2, including 10%, 20%, 30% tungsten carbide (WC) ceramic powder used as coating material to obtain different Nickel-based WC alloys coating. Micro-structure and micro-hardness analysis of the coating layer are conducted, as well as thermophysical properties for the coating layer were measured. The experimental results show that the coating prepared with 70%Ni60, 30%WC powder has the best properties with plasma spray welding, in which the micro-hardness can achieve 900HV, meanwhile it can improve the thermal property of hot-forging die dramatically.

Key words: hot forging die; plasma spraying; plasma re-melting; plasma spray welding; thermo physical properties;Ni60-WC

1 Introduction

Hot-forging die is working in very poor conditions, particularly, in direct contact with the work piece surface. In order to adapt to harsh working environment and improve service life, the material of hot-forging die is desired to be with high toughness and plasticity, small thermal expansion coefficient, good thermal conductivity, excellent mechanical properties and the use of performance, but should have good thermal properties[1].

The cavity damage of hot forging die on surface layer was mainly caused by thermal stress. So for improving the service life of hot forging die, it is the key to reduce thermal stress on the mold cavity surface layer. To solve this problem, gradient materials provides a new way of thinking by thermal stress relief technology. In this paper, plasma spraying, plasma re-melting and plasma welding technology were applied to prepare heat-resistant cermet layer in the hot-forging die mold cav-ity surface[2].

2 Experimental

2.1 Raw materials

The substrate material was W6Mo5Cr4V2; and the sample size was Φ35 mm × 15 mm. The shot peening was used to strengthen the surface before the first sample handling, then high pressure airflow was used to clean surface dust.

Alloy of nickel and cobalt was used in plasma spray and plasma spray welding respectively. Nickel-based alloys not only have excellent oxidation resistance, wear and corrosion-resistant properties, but also have some toughness, whose price is moderate, with series of powder supply[3]. Therefore, Ni60 was chose as bonding materials. The thermal expansion coefficient of WC is small; the thermal conductivity coefficient of which is big enough. It is an ideal heat-shock resistant ceramic material. The particle size of Ni60 powder was −250 - +400 mesh; and the particle size of WC powder was 150-300 mesh.

2.2 Test methods

Table 1 Process parameter of plasma spraying

Material	Argon gas /($L\cdot min^{-1}$)	Current /A	Voltage /V	Spraying span/mm	Powder feed rate /($g\cdot min^{-1}$)
Ni60-SiC	30	450	70	120	14.0

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Table 2 Process parameter of plasma re-melting

Material	Plasma argon gas flow/(m^3/h)	Argon protective gas flow/(m^3/h)	Current/A	Spraying span /mm	Scan width /mm	Melting speed /(cm · min^{-1})
Ni60-SiC	0.8	0.7	95	10	5	35-45

Table 3 Process parameter of plasma spray welding

Material	Plasma argon gas flow /(m^3 · h^{-1})	Argon protective gas flow /(m^3 · h^{-1})	Current /A	Spraying span /mm	Powder feed rate /(g · min^{-1})	Spray speed /(cm · min^{-1})
Ni60-SiC	0.5	0.8	150	10	0.75	45

The coating on substrate (W6Mo5Cr4V2) was prepared with 10%, 20% and 30% WC-Ni60 powder. Parts of the sample were prepared by plasma spraying on the coating layer, and then were obtained by plasma re-melting; in another part of the specimen were prepared by plasma spraying. Process parameters of these three methods are shown in Tables 1-3.

2.3 Characterization

The microstructure of coating was observed by 25800 type scanning electron microscope; micro hardness of coating was testing with a HV-1000 type sclerometer; thermal expansion coefficient was testing with a 0.01HZ-51HZ dynamic mechanical thermal analyzer; thermal conductivity and specific heat capacity was testing with a TC-7000H laser thermal constant tester.

3 Results and discussion

3.1 Coating microstructure

With ratio of 70% Ni60, 30% WC powder, the comparison of plasma spraying, plasma re-melting, and plasma spray welding cross-section of the microstructure was obtained as below.

Rough jagged black lines and empty can be shown in Fig.1 between the coating and the substrate, caused by excessive coarsening during sandblasting surface treatment, so that the spray molten droplets is difficult to be fully filled at the interface, the bonding strength is very unfavorable. There are more black spots in the coating, which is due to the WC having a high melting point in the flow of plasma flame when heating time is shorter, the end of the powder particles melt completely in a semi-melt state formation. Powder during the spraying process and the matrix produced a violent collision, and during the rapid cooling, the liquid metal can not be completely filled with the contact portion of the entire particle, thus to form a pore, most of them are along the distribution of the layer or between grain boundary and reduce the coating combination properties.

The cross-section microstructure of the re-melting layer with 30% WC plasma is illustrated in Fig.2. Re-melted layer organization is small closely interconnected; a certain degree of dilution of the matrix are on the cladding. There are a lot of pores among organization, which reduces the hardness of the organization.

The thin flat crystal ribbon between the coating and the substrate is shown in Fig.3 in the sections of 30% WC plasma spray layer. The bright white flat crystal is γ-Ni composition observed in the metallurgical microscope, which proves a good metallurgical bond between the substrate and the spraying layer. Black particles are observed on the boundary of the substrate and coating; and these are not completely melted WC particles.

3.2 The micro-hardness of coating

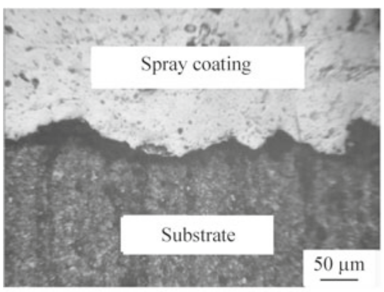

Fig.1 Microstructure of plasma spraying layer

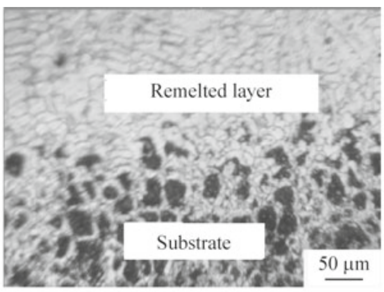

Fig.2 Microstructure of plasma re-melting layer

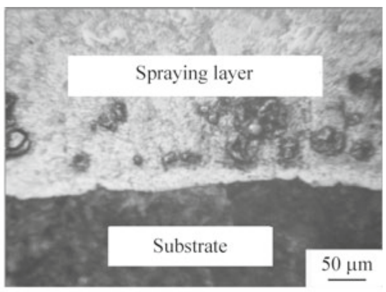

Fig.3 Microstructure of plasma spray welding layer

The micro-hardness curves of plasma spraying, re-melting and spray coating are respectively illustrated in Figs.4-6, with 10% WC, 20% WC and 30% WC powder.

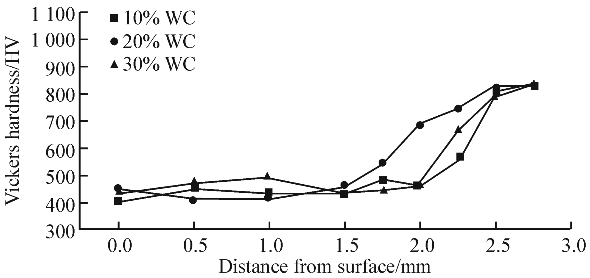

Fig.4 The micro-hardness distribution of plasma spray layer

As shown in Fig.4 trends of micro-hardness curves of three kinds of spray coating are consistent. With the increase of the distance from the surface, the micro-hardness first increases gradually, and suddenly decreases, and then arrives at the matrix hardness. The reason of hardness drop points is that plasma spray coating appears layered structure. The reason of different drop point position is the different depth of spraying coating and the different interface.

With the increase of WC content, the micro-hardness of the coating layer increases, so increasing WC content will improve the micro-hardness of the coating layer. But the hardness of the sprayed coating is less than the hardness of the matrix, so not it play a strengthen role. The micro-hardness of coating is low, which may be that WC spray coating of carbide particles is coarse, centralizing, and the less dispersive.

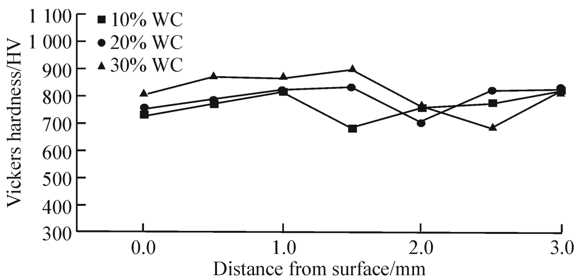

Fig.5 The micro-hardness distribution of plasma re-melting layer

Re-melted layer micro-hardness curves trend of the three powders can be seen from Fig.5. The hardness curve is flat on the coating section, lower than 500HV. There is a suddenly rise on the junction of the coating and substrate, which reaches the hardness of the matrix. Coating hardness is less than 500HV, which is much lower than the hardness of the matrix, it can not play a role in strengthening the matrix.

The micro-hardness curves trend of three kinds of spray welding is consistent, as illuminated in Fig.6. From the Fig.6, it can be seen that the hardness of surface reaches 900HV, then gently decreases to the hardness of the substrate. It can be conclude that the spray-welding method is better to used to strengthening the substrate under reasonable WC powder ratio.

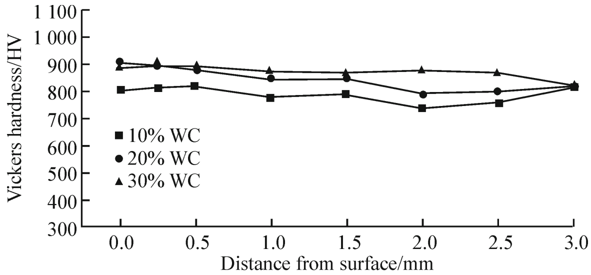

Fig.6 The micro-hardness distribution of plasma spray welding layer

3.3 Thermal stress parameters

3.3.1 The thermal expansion coefficient of the coating

The general stress in forging die is the most sensitive to the change of thermal expansion coefficient. To produce little elastic deformation in the work process of forging die, thermal expansion coefficient α should be a little value. The thermal expansion coefficient of substrate material W6Mo5Cr4V2 is 11.2 × 10^{-6} K^{-1}; WC is 6.2 × 10^{-6} K^{-1}; and Ni60 is 18 × 10^{-6} K^{-1}.

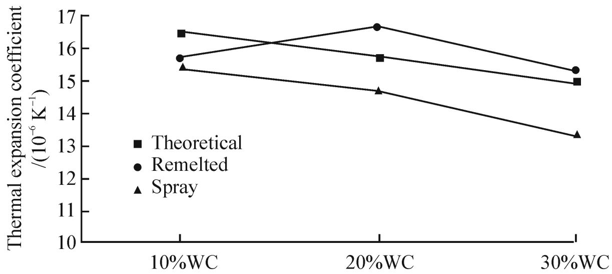

Fig.7 Thermal expansion coefficient of WC sample at 600 ℃

To get the coating with expansion coefficient similar to the matrix material, theoretically, WC content should be increased. As is shown in Fig.7, it can be concluded that the actual thermal expansion coefficient of re-melting is more than theoretically value. The one of spray welding is less. So plasma re-melting is not significant to improve the coating.

On plasma spray welding layer, the coating of three proportions of powder is similar. The actual value of the three is lower than the theoretical value. With the increase of WC, the heat expansion coefficient decreases gradually to the matrix. Among three proportions of powder, the heat expansion coefficient of spray welding coating with 30% WC powder is the least.

3.3.2 The heat capacity and thermal conductivity

The specific heat capacity of forging die material should be a larger value. The specific heat capacity is inverse ratio to WC content.

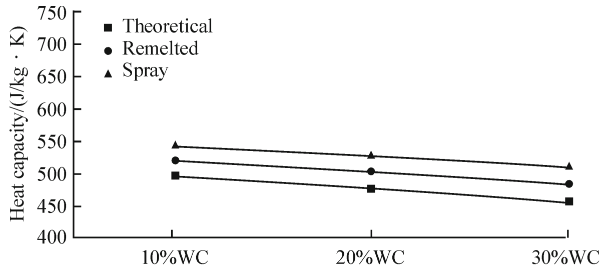

Fig.8 Heat capacity of WC sample at 600 ℃

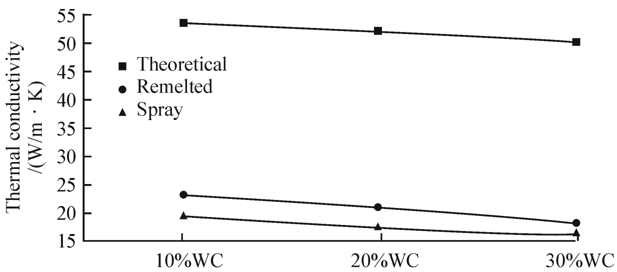

Fig.9 Thermal conductivity of WC sample at 600 ℃

As is shown in Fig.8, the heat capacity of spray coating is much more than the substrate, which makes against combination of the coating and the substrate. The heat capacity of re-melting and spray welding coating is similar to the substrate, which increases with the decrease of WC content. By comparison of three proportions of powder, the specific heat capacity of 10% WC powder coating is the largest. As can be seen in Fig.9, the thermal conductivity of plasma re-melting and spraying welding is much smaller than the theoretical value; the theoretical and actual values of the spraying coating layer were closer.

4 Conclusions

From the microstructure, micro-hardness, thermal expansion coefficient, the heat capacity and thermal conductivity of the three proportions of WC powder obtained samples of the three methods of spraying, re-melting, spray-welding analysis, it can be concluded as follows:

a) The cladding by spray-welding method is uniform and compact. The hardness of the cladding by the spray-welding is the most, and that by the re-melting is the least. The specific heat capacity of re-melted layer and spraying layer is close to the matrix, inverse ratio to the WC content.

b) The thermal conductivity of plasma re-melting and spraying welding is much smaller than the theoretical value; the theoretical and actual values of the spraying coating layer are closer.

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