Annealed microstructure and thermal fatigue properties of Ni60/WC composite layer on H13 steel surface by PTAW

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Abstract: Ni60 coating and Ni60/WC coating were prepared on the surface of H13 steel by PTAW, and some Ni60/WC coatings were annealed. The effect of annealing temperature on the microstructure of Ni60/WC coating was studied. The thermal fatigue test of the coating samples were carried out by a homemade thermal fatigue testing apparatus. The thermal fatigue properties of Ni60 and Ni60/WC coatings were compared. Mainly investigated the performance of Ni60/WC coatings annealed at different temperatures. The results show that the addition of WC reduces the thermal fatigue properties of the Ni60/WC coating. The annealing treatment weakens the crack sensitivity of the Ni60/WC coating and the WC distribution is improved, which is better at 800 °C annealing.

Introduction

H13 steel is a common hot forging die material, be subjected to the thermal load periodically under high temperature. It is easy to fail on the surface, such as wear, thermal fatigue and so on [1],[2]. Thermal fatigue property is an important factor restricting the life of die materials and seriously influences economic efficiency. Therefore, it is of great significance to improve the surface properties of H13 steel dies [3],[4]. Compared with the traditional surfacing technology, the Plasma Transferred Arc Welding (PTAW) has the characteristics of low dilution rate, high efficiency and small deformation of the workpiece. It has obvious advantages in extending the life of hot forging die. Ni60 is nickel based self-fluxing alloy powder with moderate price, low melting point, good formability and excellent high temperature performance [5]. The Ni60/WC composite coating was prepared by adding WC to Ni60. Ni60/WC composite layer can balance the metal toughness and wear resistance, which is superior to the single nickel-based coating [6]-[9].

Because of rapid heating and cooling in the process of PTAW, the brittle ceramic phase easily generates hot cracks on Ni60/WC composite layer and greatly reduces the thermal fatigue property of the materials. Annealing treatment can be used to adjust the microstructure and release residual stress and the coating can obtain excellent properties. Therefore, the effect of annealing temperature on the microstructure and the thermal fatigue properties of the Ni60/WC coating were investigated.

In this paper, Ni60 coating and Ni60/WC composite coating were prepared on the surface of H13 steel by PTAW. Some Ni60/WC composite coatings were annealed and the annealed microstructure was observed. A homemade thermal fatigue testing apparatus carried out the test, and the thermal fatigue properties of the Ni60, Ni60/WC and the annealed Ni60/WC coatings were compared.

Experimental procedure

H13 steel was used as the base material and was cut to a size of 40×110×15 mm. The surface was polished with 80 mesh sandpapers and repeatedly wiped with alcohol to remove oil, then blew dry and put it in a dry box. The coating material was Ni60 alloy powder and WC powder (Table 1), and the ratio of WC was 25%. The alloy powder was placed in a box-type resistance furnace and kept at 120°C for 30 min, then removed impurities with a 100-mesh sieve.

Table1 Composition of Ni60 and WC [wt. %]

Elements	C	B	Si	Cr	Fe	W
Ni60	1.05	3.55	3.85	15.25	3.85	—
WC	3.8	—	—	—	—	96.2

The test equipment is LU-F400-B400-CNC type CNC multi-function powder PTAW machine (Fig.1).The H13 steel plates were placed in holding furnace, kept at 300°C for 2 hours, and then taken out. After the welding finished (Fig.2), one of the samples was air cooled to room temperature, and the other samples were respectively heated to 600 °C and 800 °C in an electric resistance furnace, and then cooled with the furnace. The cross-section morphology of the coating was observed by MR2000 optical microscope, the microstructure of the surfacing layer was analyzed by electron probe X-ray micro analyzer, and the phases were analyzed by the D/MAX-RB12KW X-ray diffractometer (XRD).

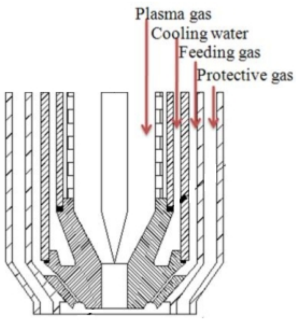

Fig.1 Schematic diagram of PTAW

Fig.2 PTAW coating

Finally, the thermal fatigue specimens were cut into 15×20×10 mm rectangular, then a 100μm wide pre-notch and a 3 mm diameter hook hole were cut by a wire cutter. The surface was polished to remove surface defects, which facilitated fatigue test. The thermal fatigue test was carried out on a thermal fatigue testing apparatus (Fig.3a). The thermal cycle test of multiple samples could be carried out at the same time, which effectively eliminated the influence of external factors. The thermal cycle temperature was changed from 15°C to 750 °C (Fig.3b), the treated samples were placed on the hook with 200 cycles.

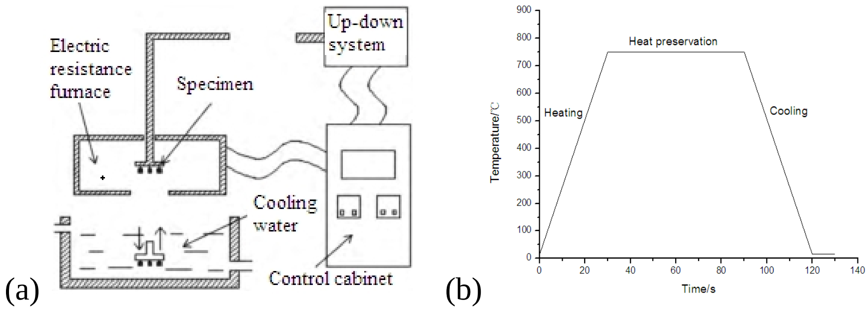

Fig.3 Schematic and process diagram of homemade thermal fatigue testing apparatus
(a) Schematic diagram (b) Process drawing

Results and discussion

Annealed structure and discussion. Figure 4a shows the cross-sectional scattering morphology of the as-welded coating. It can be seen that a 10μm bond was formed between the substrate and coating, indicating that the binding between the substrate and the coating was well. After annealing at 600°C (Fig.4b), there is no crack at the bottom of the coating. It indicates that the annealing treatment effectively weakens the sensitivity of the coating crack, and the WC particles in the bottom spread to the middle of the coating. After annealing at 800 °C (Fig.4c), no crack occurred at the bottom of the coating, a few amount of WC particles diffused, the black nickel-rich phases in the middle of the coating are distributed uniformly, and the large black nickel-rich phase is refined.

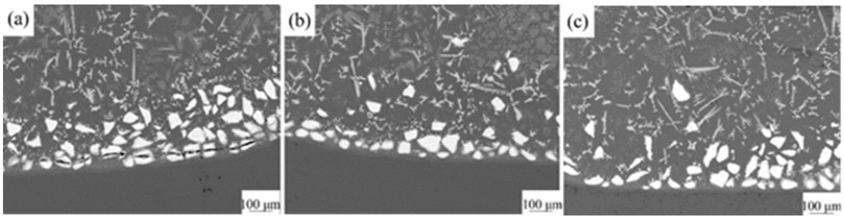

Fig.4 Cross-sectional scattering morphology of samples at different annealing temperatures
(a)as-welded coating (b) annealing after 600℃ (c) annealing after 800℃

It can be seen from Fig.5a that the Ni60/WC coating structure in the as-welded state is mainly composed of gray-white block crystals and coarse petal-like dendrites in the periphery. Agglomeration occurs between the petal-like dendrites, and white eutectic structures are distributed between the dendrites. Figure 5b shows the coating structure after annealing at 600°C without significant changes. After annealing at 800°C (Fig.5c), the petal-like dendrites are refined, the dendrite agglomeration disappears, and the coating structure is finer.

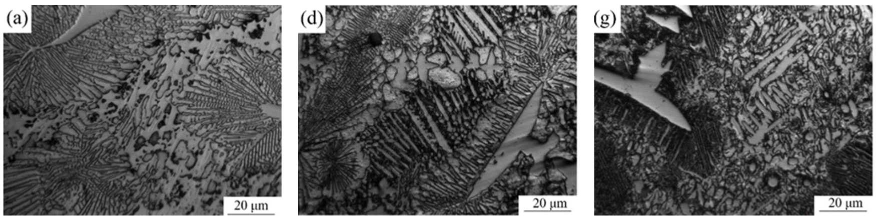

Fig.5 Microstructure of Ni60/WC coating after annealing at different temperatures
(a) Welded state (b) Annealing at 600℃ (c) Annealing at 800℃

Figure 6 is an XRD pattern before and after Ni60/WC coating annealing. After PTAW, the coating is mainly composed of phases such as (Ni, Fe), Cr4Ni15W, Ni17W3, Ni2Cr3, Cr23C6, and WC. The existence of metal eutectic phases such as Cr4Ni15W and Ni17W3 indicates that the mixed powders decompose under the irradiation of plasma beam. In addition, the phases composition of the coating changes little after annealing at 600 °C and 800 °C. Therefore, it is considered that the annealing temperature has little influence on the phase composition of the coatings.

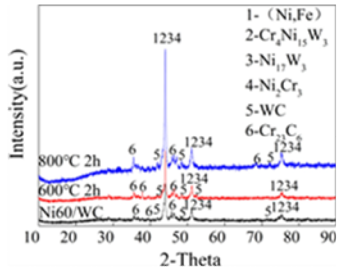

Fig.6 XRD pattern before and after Ni60/WC coating annealing

Thermal fatigue crack and discussion. Figure 5 shows the microstructure of Ni60 and Ni60/WC coatings after 200 thermal cycles. The surface crack propagation of Ni60 coating exhibits secondary crack characteristics, and there are not obvious crack at the cross section. After 200 thermal cycles, the surface morphology is blackened overall, the crack is coarse and there are secondary cracks. The cross-section cracks have a network-like feature, the cracks mutually expand, and spalling phenomenon occurs at the combined areas.

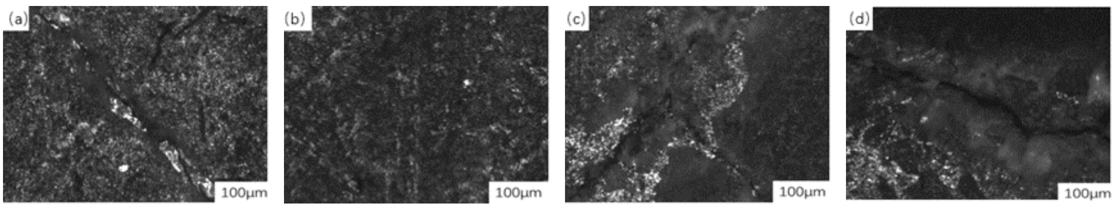

Fig.7 Micromorphology of Ni60 and Ni60/WC coatings after 200 thermal cycles
(a) Ni60 surface (b) Ni60 cross-section (c) Ni60/WC surface (d) Ni60/WC cross-section

Figure 8 shows the cross-sectional morphology of the Ni60/WC coatings annealed at different temperatures after 200 thermal cycles. There are two rough cracks in the cross section of the coating annealed at 600°C, spalling phenomenon and a secondary crack propagation appeared around the coarse crack. After annealing at 800°C, there is no crack at the junction of the coating and the substrate, and transverse cracks appear around the WC particles.

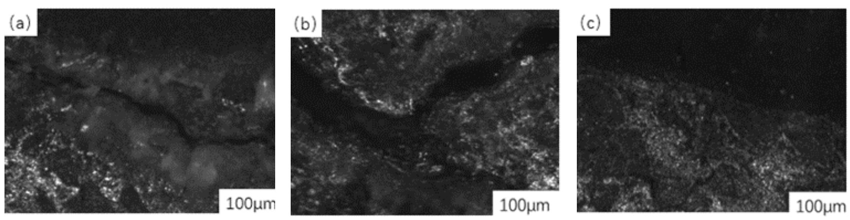

Fig.8 Cross-sectional morphology of Ni60/WC coatings after different annealing treatments after 200 thermal cycles (a) not heat treated (b) 600°C annealing (c) 800°C annealing

Conclusions

(1)The Ni60/WC coating structure in the as-welded state is mainly composed of gray-white block crystals and coarse petal-like dendrites, and white eutectic structures are distributed between the dendrites. After annealing at 800 °C, the petal-like dendrites in the coating are refined and the structure distribution is finer.

(2)The Ni60/WC coating without annealed is mainly composed of phases such as (Ni, Fe), Cr4Ni15W, Ni2Cr3, Ni17W3, Cr23C6, and WC. Annealing at 600 °C and 800 °C has little influence on the phase composition of the Ni60/WC coating.

(3)After thermal fatigue test, the Ni60 coating generated a secondary crack at the joint between the coating and substrate, and expanded to the hardened zone. The addition of WC reduced the thermal fatigue properties of the Ni60 coating. Due to the difference in thermal expansion coefficient, the Ni60/WC coating had more cracks near the welding fusion line and WC aggregation area, and expanded toward the heat affected zone.

(4)The annealing treatment improves the mechanical properties of the Ni60/WC coating and the matrix combine zone after the thermal fatigue test. The 800 °C annealed coating had better performance, and the surface cracks were relatively least.

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