The wear resistance of plasma cladding layers on the substrate Hardox450 of middle trough

Xiaobing Yang\textsuperscript{1,2,3} and Junxia Li\textsuperscript{1,2,3}
\textsuperscript{1} Taiyuan University of Technology, Taiyuan 030024, China;
\textsuperscript{2} Shanxi Province Mineral Fluid Controlling Engineering Laboratory, Taiyuan 030024, China;
\textsuperscript{3} National-local Joint Engineering Laboratory of Mining Fluid Control, Taiyuan 030024, China.

Abstract. For the phenomenon of wear failure of the middle trough in the actual conditions, the plasma cladding technique was proposed to repair the surface of middle trough and used to prepare the cladding layer B1 and B2 on substrate Hardox450 of the middle trough. Then, the micro-hardness and wear resistance of the cladding layers and the substrate were compared and analyzed. The results show that the middle trough has a greatly improvement in micro-hardness and wear resistance after the plasma cladding processing, and the wear resistance of the cladding layer B2 is the best.

1. Introduction

As the key component of the scraper conveyor, the middle trough contacts with the scraper, chain, gangue and other parts when bearing the coal bulk, which leads to extrusion force. And then the friction generated when the the scraper and chain carrying the coal bulk, so that it is prone to wear and tear[1][2]. Figure 1 shows the wear picture of the middle trough in the actual production, and it can be seen that the wear on the chain is more serious. The wear of the middle trough caused enormous economic losses to the coal mining industry of our country annually. Therefore, it's necessary to develop surface-modification process to improve the wear resistance of middle trough.

Plasma cladding technology is a kind of surface-modification technology, which can instantaneously melt and remelt the substrate material and alloy powders to form wear-resistant layers
in the same location[3]. A deeply metallurgy combination formed between cladding layers and substrate, and the cladding layers had a high hardness and wear resistance, which greatly extended the service life of middle trough. Plasma cladding technology had the characteristics of low cost, high efficiency and good quality, and it was widely applied in the reinforcement and repair of some components, especially in the middle trough, the nose and the tail of scraper conveyor in coal mines. Figure 2 shows the picture of the middle trough after plasma cladding. In this paper, the plasma cladding technique was used to prepare cladding layers on steel Hardox450. The friction and wear test was carried out on the substrate Hardox450 and cladding layers, focusing on the impacts of plasma cladding on the wear resistance of the middle trough.

2. Friction and Wear Test on Plasma Cladding Layer of Middle Trough

2.1. Experimental Materials and Processing

Hardox450 is a kind of wear-resistant steel plate with high hardness, high strength and high toughness. The steel plate Hardox450 is often used as the substrate of the middle trough in the working condition of excessive wear. The steel plate Hardox450 was chosen as the substrate material in the test. Two Hardox450 steel plates (dimensions: 150mm×60mm×10mm) were selected and its surface was polished with sandpaper(80, 600 and 1200 grit), then the surface-modification was carried out on the steel plates. The alloy power 1 and 2 were used to obtain cladding layer B1 and B2 on steel plate Hardox450 by plasma cladding technology, respectively. The main elements of the alloy powders were Fe, Cr, Nb, Mo, Ni, etc. The main chemical components of the alloy powders are shown in Table 1.

| Power number | Fe(%)  | Cr(%)  | Nb(%) | Mo(%) | Ni(%)  | V(%)   | C(%)   |
|--------------|--------|--------|-------|-------|--------|--------|--------|
| 1            | 15.5~16.0 | 16.5~19.5 | 4.4~4.7 | 0.8~1.0 | 0.75~0.97 | ≤0.9   | <1.6   |
| 2            | 20~20.5   | 20~25   | 5.5~5.8 | 1.5~1.8 | 2.5~2.6 |        |        |

2.2. Experimental Methods and Conditions

The plasma cladding test was carried out by a ZRF-6 numerical control plasma cladding machine. The alloy powders used for cladding were fed by the IGS precise powder feeder, and its grain size was 40-200μm. The flowing rate of delivering powder gas is 10L/min. In order to prevent the oxidization during the cladding process, argon was chosen as the shielding gas and its gaseous flow rate was 16 L/min. The thickness of the cladding layer was about 5mm, and the single cladding width was 60mm. The cladding speed was 150mm/min.

After plasma cladding process, leave them to cool naturally for a period of time. The wire cutting was used to cut the steel plate into small pieces(15mm×15mm×10mm) along the cladding cross-section, ensuring the layers not be destroyed. The test samples of cladding layers after cutting are shown in Figure 3. A MP-2 three-speed metallographic sample grinding machine was used to polish (80, 600 and 1200 grit) the surface of the layers in order to ensure its surface and side face of coating a smooth section. Figure 4 shows the section-cross diagram of the cladding layers.

![Figure 3. The test samples of cladding layers after cutting](image)

The experimental subjects included the substrate Hardox450, the cladding layer B1 and B2. The MFT-R4000 multi-functional tester was used to carry out reciprocating friction and wear test, with the bearing steel ball GCr15(d=6mm). The friction distance was 5mm and the reciprocating time was
1200s. In order to improve the accuracy of the experimental results, the experimental data is usually obtained by averaging three measurements under the same conditions[4][5].

3. Micro-hardness of the Plasma Cladding Layer on Surface of Substrate Hardox450
The HVS-1000Z Digital Micro Vickers Hardness Tester was used to measure micro-hardness on surface and cross section of the substrate Hardox450, cladding layer B1 and B2. The micro-hardness on surface of the substrate Hardox450, cladding layer B1 and B2 are shown in Table 2. It is obvious that the micro-hardness of the two cladding layers are higher than that of the substrate Hardox450, and the hardness of the cladding layer B2 was the largest, which was approximately 5 times that of the substrate Hardox450.

Table 2. The vickers hardness of the substrate Hardox450, cladding layer B1 and B2

| Material     | Hardness(HV) |
|--------------|--------------|
| Hardox450    | 203.7        |
| B1           | 986.6        |
| B2           | 1025.8       |

The micro-hardness distribution curves on the cross section of cladding layers B1 and B2 are shown in Figure 5. Seen from Figure 5, the average micro-hardness of the cladding layer B1 was lower than that of B2 on the substrate Hardox450. From the surface of the cladding layer B1 and B2 to the substrate, the micro-hardness of the cladding layers decreased. At 3000μm away from the surface of the cladding layers, the hardness of the cross-section of the two cladding layers declined rapidly. Because of significant differences in hardness between the cladding layers and the substrate, the bonding interface was inherently a weak zone, so that the hardness value decreased rapidly here, which shows that the lower hardness substrate Hardox450 had a lower dilution rate of the cladding layer[6-9].

4. Wear Resistance of Plasma Cladding Layers on Surface of Substrate Hardox450

4.1. Effect of Different Load on Wear Resistance of the Cladding Layer
When the sliding speed was 50mm/min, the friction and wear tests were carried out under the applied load of 30N, 40N, 50N, 60N and 70N, respectively. The changing tendency on the friction coefficient of the substrate Hardox450, cladding layer B1 and B2 under the different load was shown in Figure 6. As can be seen from Figure 6, the friction coefficient of the substrate, cladding layer B1 and B2 varied differently under different load. With the load increasing, the friction coefficient of the substrate and cladding layer B1 increased first and then decreased, and the friction coefficient reached the maximum when the load was 40N. The abrasive and wear debris increased frictional resistance in the process of reciprocating friction, so the friction coefficient increased first. However, with the load increasing, the
friction heat leads to a lubricating film formed on the contact surface of the friction pair, so friction coefficient decreased gradually. Overall, the friction coefficient of the substrate Hardox450 was obviously greater than that of the cladding layers, as a whole, under the same conditions, the friction coefficient of the substrate Hardox450 was larger than that of the cladding layers B1 and B2, and its maximum reached 1.5 times that of cladding layer B2. Also, the friction coefficient of cladding layer B1 was greater than that of cladding layer B2 as a whole.

![Figure 6. The changing tendency on the friction coefficient of the substrate Hardox450, cladding layer B1 and B2 under the different load.](image)

![Figure 7. The changing tendency on the wear rate of the substrate Hardox450, cladding layer B1 and B2 under the different load.](image)

The changing tendency on the wear rate of the substrate Hardox450, cladding layer B1 and B2 under the different load was shown in Figure 7. As can be seen from Figure 7, the wear rate of cladding layer B1 and B2 increased with the load increasing. This is because that with the increase of the load, more and more wear debris and abrasive grains generated and gradually accumulated on the surface of the cladding layers, thereby intensifying its wear. With the increase of load, the wear rate of the substrate Hardox450 increased first and then decreased; when the load ranged from 30N to 50 N, the wear rate changed little; when the load was greater than 50N, the wear rate gradually increased with the load increasing. This is because more and more wear debris, produced by the counterpart with high hardness cutting Hardox450, was rolled repeatedly to bring adhesive wear. As a whole, under the same conditions, the wear rate of the substrate Hardox450 was greater than that of the cladding layers B1 and B2, and the wear rate of the cladding layer B1 was greater than that of B2.

4.2. Effect of Different Sliding speed on Wear Resistance of the Cladding Layer

When the applied load was 70N, the friction and wear tests were carried out under different sliding speed of 50 mm/min, 90 mm/min, 130 mm/min, 170 mm/min, and 210 mm/min, respectively. The changing tendency on the friction coefficient of the substrate Hardox450, cladding layer B1 and B2 under the different sliding speed are shown in Figure 8. With the increase of the sliding speed and reciprocating friction times, the friction coefficient of the substrate Hardox450 increased first and then decreased, and it reached the maximum when the sliding speed was 140mm/min. The friction coefficient of the cladding layer B1 and B2 generally decreased, and the friction coefficient of the cladding layer B2 was the smallest. Although the change on the friction coefficient of the cladding layer B2 was slightly fluctuated, the fluctuation range remained about 0.02.

The changing tendency on the wear rate of the substrate Hardox450, cladding layer B1 and B2 under the different sliding speed are shown in Figure 9. As can be seen from Figure 9, as the sliding speed increase, the wear rate of the substrate Hardox450, cladding layer B1 and B2 generally decreased. The wear rate of the substrate was significantly greater than that of the the two cladding layers, and the wear rate of the cladding layer B2 changed less with increasing sliding speed. As can be seen from Table 1, the cladding layer contains a small amount of soft phase metal, which have a
lubrication effect in the process of reciprocating friction, reducing the friction coefficient and wear rate of the cladding layer.

Figure 8. The changing tendency on the friction coefficient of the substrate Hardox450, cladding layer B1 and B2 under the different sliding speed.

Figure 9. The changing tendency on the wear rate of the substrate Hardox450, cladding layer B1 and B2 under the different sliding speed.

4.3. Analysis on Wear Mechanism of the Cladding Layer
In order to investigate the wear mechanism of Hardox450, cladding layer B1 and B2, a JSM-IT300 scanning electron microscope was used to observe their wear morphology[10]. Figure.10 shows the wear morphology on the surface of the substrate Hardox450, cladding layer B1 and B2 after the reciprocating friction which lasted 1200s when the load was 30N and the sliding speed was 210mm/min.

Figure 10. Wear morphologies of substrate Hardox450, the cladding layer B1 and B2: (a) Hardox450, (b) B1, (c) B2
As can be seen from Figure.10, the wear of the substrate Hardox450 was the most serious. The wear of the cladding layer B1 and B2 was obviously less than the former, and the wear of the cladding layer B2 was the least. Fig (a) shows the wear morphology of the substrate Hardox450[11-13]. In Fig(a), there was a large area of exfoliations and cracks on its surface. After a long period of rolling, the removal of material was accumulated and adhered, so the main wear mechanism of the substrate Hardox450 were adhesive wear and abrasive wear. Fig (b) shows the wear morphology of the cladding layer B1. As can be seen from Fig (b), there was a small amount of abrasive, wear debris and a slight furrow with a few pits on its surface, so the wear mechanism of the cladding layer B1 were slight adhesive wear and abrasive wear. Fig (c) reveals the wear morphology of the cladding layer B2. It can be seen from Fig (c) that there was a small amount of abrasive and wear debris with not obvious furrow on its surface, so the wear mechanism of the cladding layer B2 was abrasive wear. Combining the changing tendency of wear rate and friction coefficient in Fig.6-9, it can be concluded that the use of plasma cladding technology can improve the wear resistance of the substrate and extend its service life, and the wear resistance of the cladding layer B2 is better.

5. Conclusion
In view of the wear failure of the middle trough, the plasma cladding technique was used to prepare the cladding layer B1 and B2 on steel plate Hardox450. After the plasma cladding processing, the middle trough has a greatly improvement in micro-hardness and wear resistance. The cladding layers had anti-friction effect, with lower friction coefficient and wear rate than the substrate. With the change of load and sliding speed, friction coefficient and wear rate of cladding layers changed little. The wear resistance of the cladding layer B2 is best. The wear resistance of the middle trough were improved by the plasma cladding. Also, the the relative contents of some elements of alloy powders were optimized and controlled to improve the friction-wear properties of the substrate properly. The plasma cladding can be widely used in the surface-modification of middle trough and reduce the waste of the resources, which have significant economic and social profit.

Acknowledgments
The research are supported by the NSFC- Shanxi coal based low carbon joint fund focused on supporting project(Grant No.U1510205). The author gratefully acknowledged the helpful discussions with the research group and colleagues of Taiyuan University of technology.

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