Research on Microstructure and Wear Resistance of Fe-Based Hardfacing Layer Using Plasma Surfacing Technology

SONG Lingling¹, GUO Jian², MA Xiaolei², ZHAO Jingnan²

¹Mechanical and Material School, Tianjin Sino-German University of Applied Sciences, Tianjin 300350, China ;
²College of Mechanical Engineering, Tianjin University of Science & Technology, Tianjin 300222, China
E-mail: jingnanzhao@tust.edu.cn

Abstract. In order to enhance the wear resistance of material surface, the hardfacing alloy is usually deposited on its surface by using plasma surfacing technology (PST). The technology has the advantages of the low dilution rate, small deformation, smooth welding path, food metallurgical combination, and no major defects. In this paper, a Fe-based alloy coating had been prepared by PST, and the structure and properties of surfacing layer had been studied. The results showed that the hardness of surfacing layer was significantly greater than that of the substrate. And the coating layer had a snowflake-like structure. Its Lorraine hardness was up to about 60HRC, and the friction coefficient was about half of the 65Mn after quenching. With the increase of the material hardness, the coating layer has excellent abrasion resistance.

1. Introduction
With the rapid development of modern industry, mechanical parts often work under extremely complicated and demanding conditions, which scrapped the equipment parts easily due to wear, corrosion or abrasion. This requires the materials of equipment parts with good wear resistance, corrosion resistance, high temperature resistance and oxidation resistance under extreme temperature, high pressure and other complex conditions. Therefore, it is important to pay more attention to surface technology and develop surface modification technology (1, 2).

Plasma Surfacing Technology (PST) was developed in the 1960s. Its application area is then further expanded from surface repair to manufacture industry in following 20 years (3, 4). Ever since the 1990s, further researches had been taken on plasma surfacing machines with the rapid development of advanced manufacturing technology. Plasma arc welding is a welding method that takes combined or transferred plasma arc as the heat source and alloy powder or wire as filler metal. In order to obtain desired properties of the surfacing layer, the welding metal and the surface of the substrate need to be melted together into the molten pool, and the condensing to room temperature. The difference between the plasma arc and general mainly lies in that of the general arc is the free arc, while plasma arc compressed in the nozzle and has more characteristics as thermal compression effect, mechanical compression effect, and electromagnetic compression effect (5-8).

Surface coating plays an important role on improving surface properties and prolonging the service life of metal parts (9). The close combination, smooth surface, and superb formation can be obtained by using PST, and macroscopic defects such as cracks are avoided through the this technology. In order to improve the surface wear resistance of materials, the hardfacing alloy tends to deposit on the
surface. Extra special performance such as high-stress wear property can be obtained by adding cemented carbide particles (10).

PST is a kind of welding method to obtain high quality surfacing layer, which uses argon transfer arc as the main heat source to fill metal alloy powder and form a dissolution bath on the surface of the workpiece. According to the different types of the power supply, the plasma arc can be divided into the transfer arc and the non-transfer arc. The transfer arc burns between the electrode and the workpiece, while the non-transferred arc between the electrode and the nozzle. The main difference between them is that the voltaic arc is generally free arc, while the plasma arc is compressed arc. And the plasma arc is influenced by hot compression, mechanical compression and electromagnetic compression in the nozzle, by the influence of which the arc column temperature and energy density greatly increased.

2. Method
The main parameters of powder plasma arc surfacing include welding voltage, current, swing parameter, protective gas flow rate, welding speed and working distance, etc.. Welding voltage has a correlation of working distance: smaller the distance, lower the voltage. The welding current determines the heat input. There won’t be a metallurgical combination of good quality if the welding current is too low since that porosity and micro-cracks will easily happen on the materials. Swing parameters determine the width of the Surfacing path. Protection gas flow will influence the protective effect of the molten pool. Welding speed has a significant influence on the weld thickness and penetration (1, 4).

2.1. Experiment devices and methods
The PST was conducted by using the plasma welding machine of DML-V02BD. In order to increase the bonding strength of the surfacing layer and the substrate, the surface roughness of the material surface was increased through surface sandblasting via the long-empty gp-1 type dry sandblasting machine. The substrate is 65Mn plate, The Fe base alloy powder consist of 80-85%Fe, 8-10%Cr, 2.8-3.2%B, 2-3%Si, 0.9% C.

In order to identify the difference of the material hardness on substrate and hardfacing layer, Rockwell hardness tests were taken on both of the materials. Indentation hardness tests were performed using a electronic MH-6 micro-hardness tester, which can be accurate to 0.01 HRC. The load was set at 100 N and the test duration was set at 10 s. There are 3 tests on each material, and then the average value of the tests was calculated as the final experimental data. The tested specimen size is 20 mm x 8 mm x 8 mm.

Before the surfacing test, the base material of 65Mn material was pretreated. Sand blasting machine was first used to give sand blasting on the substrate surface, in order to remove oil pollution and impurities, meanwhile it increases roughness and bonding strength. The pretreated base material was then overlaying welded with Fe-based powder. Heat treatment was given after welding, and then wire cutting followed after air-cooling in order to test the hardness and observe the morphology of the tissue.

TESCAN VEGA3-SCAN electron microscope and EDS spectroscopy analyzer were used to test the microstructure morphology of the coating and the composition of various phases. The abrasion resistance analysis was used to test the friction coefficient and wear loss of the composite coating and 65Mn materials using the HRS-2M reciprocating friction wear tester. The grinding wheel has a rotational speed of 250 r/min, the wear test is 180min, and the quality loss of the material is measured in real time. The measurement can be accurate to 0.1 mg.

2.2. Maintaining the Integrity of the Specifications
The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and
others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

3. Results And Discussion

Plasma arc welding technology was used to prepare Fe-based coating on the 65Mn substrate. Side observation was given by electron microscopy after wire cutting, as shown in figure 1. It can be clearly seen that the surfacing layer and the substrate formed quite well metallurgical combination.

![Figure 1. The metallurgical combination of matrix and coating](image)

3.1. Hardness analysis

The Rockwell hardness tests of substrate and hardfacing layer were conducted, as shown in figure 2. Results of the 3 groups of substrate and hardfacing layer were 42.10, 38.50, 43.4053, 65, 62.40, and 65.73 HRC, respectively, as shown in table1. The average hardness of the hardfacing layer is 60.59 HRC, while the average hardness of the substrate is only 41.3 HRC. It is obvious that the hardness of the surfacing layer is better than the substrate.

| Hardness | Coating layer (HRC) | Matrix layer (HRC) |
|----------|---------------------|--------------------|
| 1        | 53.65               | 42.10              |
| 2        | 62.40               | 38.50              |
| 3        | 65.73               | 43.40              |
| Average  | 60.59               | 41.3               |

![Figure 2. The hardness test of the surfacing layer](image)

The coating microstructure and morphology were observed by the electron microscope, as shown in Figure 3(a, b). Figure 3(a) shows the microstructure of the substrate and figure 3(b) shows the morphology of the surfacing layer. It can be seen that the coating is mainly composed of a grey matrix, hexagonal particles, lath-shaped particles, oxide, and pore structure. Among that the dark gray hexagonal particles and plate-like particles deposited on the gray substrate, the black hole is pore and part of the black dots for oxide impurities.
Figure 3. The structure and morphology of the matrix and the coating (a) morphology of substrate material. (b) Microstructure of surfacing layer.

3.2. Wear resistance analysis

Figure 4 shows the friction coefficient test on the substrate and the coating. The figure is a time-dependent contrast line graph about friction coefficient of the 65Mn substrate and that of Fe coating after quenching. Plasma surfacing Fe powder coating friction coefficient is significantly lower than that of 65Mn. It was almost half of the 65Mn friction coefficient after quenching. It means that the prepared coating layer has greatly enhanced the wear resistance of the substrate.

Figure 4. Comparison chart of friction coefficient

The wear loss of the surfacing layer was measured by HSR-2M reciprocating friction and wear test machine. The change law of the sample wear rate and time was shown in Tab.2 and figure 5. As shown by the graph, the wear rate increases with time. The wear rate was relatively high of 65Mn, it increased linearly with the increase of wear time. Compared with 65Mn, the wear volume was about 1mg of plasma surfacing coating at 30min. Then it increased in the amplitude of miniature 2mg~4mg in 45-90 min. However after 120min, the wear volume increased straightly and rapidly. If the sample surface contains more CrC hard phase, the better wear resistance and smaller changes of wear loss it will be. With the extension of time, the wear scar grew deeper to the coating layer. Then the hard particle content would reduce, and the wear resistance became poorer so that the wear rate increased significantly.

Table 2. Comparison Table Of Wear And Loss

| Wear time (min) | 30  | 60  | 90  | 120 | 150 | 180 |
|-----------------|-----|-----|-----|-----|-----|-----|
| 65Mn (mg)       | 1.1 | 3   | 4.1 | 6.05| 9   | 11  |
| surfacing layer (mg) | 1.1 | 2.8 | 3   | 4.05| 5.9 | 7.9 |
Figure 5. Comparison chart of wear and loss

4. Conclusion
In this paper, plasma welding technology was utilized to prepare Fe-based composite coatings on 65Mn substrate. The specimen coating formation looked smooth and without major defects. The welding layer was uniform and had a compact structure. The surfacing layer and the substrate formed an excellent metallurgical combination.

The hardness of the surfacing layer reached 60HRC, much higher than the hardness of the 65Mn base material, which is about 40HRC. And the friction coefficient was approximately half of the 65Mn after quenching. The average wear amount was reduced by 1/3, and the coating had better wear resistance much better.

The PST is a simple and feasible way to effectively improve the wear resistance of the mechanical parts and prolong its service life. Therefore, it could be applied to strengthening the structure surface and improve the quality of work in industry.

Acknowledgment
The authors would like to gratefully acknowledge the financial support provided by Tianjin Key Laboratory of Integrated Design and On-line Monitoring for Light Industry & Food Machinery and Equipment, China under the Grant 2017LIMFE01, Tianjin Municipal Education Commission, China under the Grant 2017KDYB20, and Tianjin Natural Science Foundation Grant 17JCYBJC42400.

References
[1] Hou QY, Gao JS, and Zhou F. “Microstructure and wear characteristics of cobalt-based alloy deposited by plasma transferred arc weld surfacing” J. Surface and Coatings Technology, vol.194, pp.238-243, 2005.
[2] Liu YF, Mu JS, Xu XY, and Yang SZ, “Microstructure and dry-sliding wear properties of TiC-reinforced composite coating prepared by plasma-transferred arc weld-surfacing process”, Materials Science and Engineering: A, vol.458, pp.366-370, 2007.
[3] Dong Lihong, Zhu Sheng, Xu Binshi, and Du Zeyu, “Development of wear and corrosion resisting powder Plasma-arc surfacing,” Weld, pp.6-9, July 2004.
[4] M. Young, The Technical Writer’s Handbook. “Optimization design of composite powder composition of plasma arc surfacing” Journal of Materials Protection, vol.37, pp.7-8, July 2004.
[5] YANG Kun-yu, “Based on the working process of welding methods and equipment curriculum design”. Journal of Mechanical professional education, pp. 57–59, 2012.
[6] KANG Jian-xin, GUO Li-jie, and GAO Fa-ming, “HAZOP analysis of gas fractionation unit based on process simulation”. Journal of Yanshan University, vol. 38, pp.189–196, May 2014.
[7] LU Jian-bo,YAO Sun, LOU Song-nian, DU Ze-yu, and LI shao-qing, “Coat Components Optimization and Wearability for Plasma Transferred Arc Processing,” Materials for
Mechanical Engineering, vol.30, pp.35–37, Mar 2006.

[8] DENG Yuan-jiang, PAN Hou-hong, and LUO Tao. “Comparison between Two Methods of Plasma Arc Powder Automatic Surfacing on Valve,” Journal of Chongqing Institute of Technology, vol. 21, Nov 2007

[9] Zhao J, Wong KS, Shrotriya P. Hybrid CO2 laser waterjet heat (LWH) treatment of bindered boron nitride composites with hardness improvement. Ceramics International. 2017;43(11):8031-9.

[10] Zhao J, Shrotriya P., “Increase the hardness of polycrystalline cubic/wurtzite boron nitride composite through hybrid laser/waterjet heat (LWH) treatment” Advances in Applied Ceramics, vol. 1-8, May 2017