Study on Stress Properties of Iron Based Cladding Coating under Bending Load

Lifu Xu1,a, Chao Li1,b, Shutao Huang1,c,*, Bo Song1,d
1Shenyang Ligong University, Shenyang 110159, China
Email: a sy_xlf@163.com, b coolboy_tea@163.com, c syithst@163.com,
d Song1990@163.com

Abstract. The finite element analysis was employed to investigate equivalent stress characteristics of iron based cladding coating and substrate, and a three-point bending simulation test was carried out. The coating was set separately on the sides of stretch and press, the distribution and change rule of equivalent stress for different coating thickness were obtained through analyzing the stress state of the coating/substrate system and influence of coating thickness on the interfacial stress. The results show that the maximum stress of the coating/substrate system appears on the coating surface under the bending load; the thicker the coating, the higher the maximum equivalent stress of the coating/substrate system under the same press amount of the punch head.

1. Introduction

The surface cladding technology is a new surface strengthening technology, which the alloy powder with a binder pre-coated on the surface of the parts, and then heated under vacuum conditions, so that it could melt to form coating. The cladding coating is dense and can form metallurgical bonding with substrate. At the same time, the cladding coating has high abrasive resistance, fatigue life and erosion resistance [1, 2, 3]. FeCrAl-alloy has high temperature resistance, anti-oxidation and anti-corrosion property at high temperature, which is commonly used for surface coating of common steel material for high temperature protection [4, 5]. Besides this key features iron aluminizes have a combination of good mechanical properties, low density, low costs and very good availability of the feedstock materials iron and aluminum [6]. In this paper, ABAQUS finite element analysis software was used to study the stress state of the iron-based cladding coating/substrate system and interface in the effect of bending load, At the same time, the influence of coating thickness on stress state was studied, which provided theoretical support for practical application of cladding coating.

2. Numerical Modeling

2.1 Materials and Properties

The substrate material of the cladding coating is 45CrNiMoVA. The cladding coating powdered alloy is FeCrAl, the component content of powdered alloy is shown in Table 1 [4, 7, 8]. The mechanical parameters of the coating and the substrate material are shown in Table 2 [7, 8].

| Element | C | Cr | Si | Al | Fe |
|---------|---|----|----|----|----|
| Contents (%) | 0~0.08 | 20.5~23.5 | 0~0.7 | 5.1~5.7 | margin |
Table 2. Mechanical parameters of substrate and coating

| Materials             | Matrix 45CrNiMoV | FeCrAl |
|-----------------------|------------------|--------|
| Elasticity modulus $E$/GPa | 196              | 220    |
| Poisson's ratio $v$   | 0.29             | 0.3    |
| Tensile strength $\sigma$/MPa | 1488           | 670    |
| Elasticity modulus ratio $E_C/E_S$ | 1               | 1.12   |

2.2 Modeling

To study the equivalent stress distribution of the cladding coating and the substrate under the bending load, three-point bending method was adopted to analyze the finite element of the coating/substrate system. According to the actual working conditions of the coating, it will place the coating in the stretch and compression. The three-point bending model is shown in Figure 1. Model size of the finite element analysis will depend on the standard design of bending test [9]. The rectangular cross-section model was used in which the length of the substrate was 200mm, the width was 20mm, and the thickness was 10mm for studying the equivalent stress distribution of the interface bonding between the coating and the substrate. The length and the width of the coating were identical with the substrate; the thickness was 0.5m, 0.75mm and 1mm for studying the effect of the coating thickness on the stress state. The pressure head radius was 10mm, the basing span was 100mm. The finite element analysis model is shown in Figure 2.

![Figure 1. Three-point bending model of cladding coating](image1.png)

![Figure 2. Finite element analysis model of three-point bending](image2.png)

The bonding state of the coating and substrate at the interface is significant factor, which affecting the finite element simulation results. Application of vacuum cladding technology, the micrographs of the FeCrAl alloy powders were welded on the substrate, as shown in Figure 3. It was observed that the coating was tightly combined with the substrate, and the bright white areas of the interface bonding were the miscible regions between the coating and the substrate. It was indicated that the cladding coating and substrate belonged to the metallurgical bonding, which was in conformity with other research literatures [10, 11]. The interface bonding between the cladding coating and the substrate were defined as tie. The size of the finite element model mesh was 0.25mm×1mm×1mm, and the element type was hexagonal elements with 8 nodes. The full restraint was applied on the both basing. The pressure head uniformly reduced. The displacement loads was applied on the pressure head, and loading speed was 0.05mm/s.
3. Results and Discussion

3.1 The Stress State of Coating/Substrate System under Bending Loads

When the displacement of the pressure head was 0.5mm, the stress distribution of different thickness coatings under the stretch and the press conditions is shown in Figure 4 and Figure 5.

Figure 3. Interface structure between the cladding coating and the substrate.

Figure 4. Equivalent stress distribution of stretching FeCrAl coating
It was observed that the stress values of the top and the bottom surfaces of the coating/substrate system were the highest under the bending loads, and the stress values of near the neutral surface approached zero. The maximum stress values of the coating/substrate system appeared coating surface under the coating stretch and the press. The equivalent stress distribution diagram at the interface bonding between the coating and the substrate was magnified for analyzing the stress distribution conditions at the interface bonding between the coating and the substrate. It was observed that owing to the Elasticity modulus and the Poisson's ratio and other physical parameters of the coating and the substrate were different, the stress of the coating was always greater than the substrate, which had significant difference. The coating thickness was 0.5mm, the stress difference values of the coating and the substrate was maximum; the coating thickness was 1.0mm, the stress difference values of the coating and the substrate was minimum. The thicker the coating, the smaller the stress difference values of the coating and the substrate, the stress transition from the substrate to the coating was more gentle, the equivalent stress distribution of the coating and substrate was more uniform.

In order to analyze the equivalent stress distribution conditions of the coating/substrate system under the different descending distance of the pressure head, the descending distance of the pressure head was 0.3mm, 0.4mm, 0.5mm. Under the different descending distance of the pressure head, the maximum stress curve line of the coating/substrate system of the different coating thickness is shown in Figure 6. It was observed that when the coating thickness was the same, the greater the descending distance of the pressure head, the greater the maximum stress of the coating/substrate system. When the descending distance of the pressure head was the same, the thicker the coating, the greater the maximum stress of the coating/substrate system. In the elastic change phase of the coating/substrate system, the stress of the system was proportional.
3.2 The Effect of the Coating Thickness on the Stress at Interface Bonding

In order to analyze the force conditions of the interface bonding between the coating and the substrate, the paper selected suitable units for stress analysis as shown in Figure 7.

![Selected elements](image)

(a) Stretched coating                          (b) Compressed coating

Figure 7. Selected elements

The mesh of the interface bonding between the coating and the substrate was magnified and then selected analysis units at the coating and the substrate. The two units were selected at the two flanks of the interface bonding, the unit 1 was near the unit of the interface substrate, and the unit 2 was near the unit of the interface coating.

When the descending distance of the pressure head was 0.5mm, the stress distribution of the interface bonding at the stretched coating is shown in Figure 8, and the stress distribution of the interface bonding at the compressed coating is shown in Figure 9.

![Figure 8](image)

(a) Coating thickness 0.5mm (b) Coating thickness 0.75mm (c) Coating thickness 1mm

Figure 8. Enlarged drawing of equivalent stress distribution of stretching FeCrAl coating

![Figure 9](image)

(a) Coating thickness 0.5mm (b) Coating thickness 0.75mm (c) Coating thickness 1mm

Figure 9. Enlarged drawing of equivalent stress distribution of compressing FeCrAl coating
It was observed that the coating was in the stretch and the compression, the stress of unit1 was always less than the stress of unit2. Near the interface bonding, the stress of coating was always greater than the stress of substrate. Inside of the substrate, the distribution of the equivalent stress was uniform and the transition was gentle, which shown that the equivalent stress inside the coating and the substrate was uniformly varying, the interface bonding between the coating and the substrate had obvious stress mutation.

Under the different descending distance of the pressure head and the different thickness of the coating, the unit of the interface bonding between the coating and the substrate was subject to stress. The stress curve is shown in Figure 10 and Figure 11.

![Stress curves](image)

**Figure 10.** The curve of equivalent stress distribution of stretching FeCrAl coating

![Stress curves](image)

**Figure 11.** The curve of equivalent stress distribution of compressing FeCrAl coating

4. Conclusions

(1) The stress analysis of the FeCrAl welding coating/substrate system bending test shown that the coating was set separately on the sides of stretch and press, the maximum equivalent stress of the coating and the substrate appeared in the coating surface. When descending distance of the pressure head was the same, the maximum equivalent stress at the stretched coating was greater than the maximum equivalent stress at the compressed coating.

(2) When descending distance of the pressure head was the same, the thicker the FeCrAl cladding coating, the greater the maximum equivalent stress of the coating and substrate system. On the
contrary, when descending distance of the pressure head was the same, the thicker the coating, the smaller the equivalent stress value of the interface bonding between the coating and the substrate.

(3) We need to consider two factors in the actual design of the coating thickness: the maximum equivalent stress of the coating and substrate and the equivalent stress value of the interface bonding.

5. Acknowledgements

This study is financially supported by the Natural Science Foundation of Liaoning Province (No. 20170540789).

6. References

[1] Wang X P. Comment on the progress of the surface coating technology [J]. Total Corrosion Control, 1996, 10 (2): 8-12.

[2] Wang J Y and Ni X H. Investigation on Interface between Base Metal and Coating Made by Means of Vacuum Fusion Sintering [J]. Development and Application of Materials, 2002, 17 (3): 15-8.

[3] Liu X B, Liu H Q, Liu Y F, He X M, Sun C F, et al. Effects of temperature and normal load on tribological behavior of nickel-based high temperature self-lubricating wear-resistant composite coating [J]. Composites Part B Engineering, 2013, 53 (7): 347-54.

[4] Zhang Z L. High temperature behaviors and aluminum diffusing mechanism of containing aluminum coatings produced by thermal spray [D]. Shenyang university of technology, 2007, 33-42.

[5] Vignesh S, Shanmugam K, Balasubramanian V et al. Identifying the optimal HVOF spray parameters to attain minimum porosity and maximum hardness in iron based amorphous metallic coatings [J]. Defense Technology, 2017 (13), 101-10.

[6] Thiem P G, Chorny A, Smirnov I V, et al. Comparison of microstructure and adhesion strength of plasma, flame and high velocity oxy-fuel sprayed coatings from an iron aluminum powder [J]. Surface & Coating Technology, 2017 (324), 498-508.

[7] Zhu R S. Investigation on Self-fluxing Alloy Powders [J]. Powder Metallurgy Industry, 2000, 4(2):7-14.

[8] Bolelli G, Candeli A and Koivuluoto H. Microstructure-based thermo-mechanical modeling of thermal spray coatings. [J]. Materials & Design, 2015, 73:20-34.

[9] Wang P, Liu W P, Dong L, et al. Interpretation of GB/T 232-2010 “Metallic Materials Bend Test” [S]. Beijing: General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of the People's Republic of China, 2011.

[10] Lu J B. Study on performance of vacuum sintered Ni-based coating [J]. Surface Technology, 2006, 35 (6): 25-6.

[11] Tao H W. Research and analysis of Co-based, Ni-based coating by high frequency induction and vacuum cladding [D]. Qingdao Technological University, 2012, 13-4.