Study on fabrication technology and corrosion resistance of Fe-based amorphous alloy coatings by high-speed laser cladding

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Abstract. In this paper, the AME201 Fe-based amorphous alloy coating was prepared by ultra-high speed laser cladding on the surface of 27SiMn alloy steel. The effects of technological parameters on the surface morphology, micro-structure and dilution rate of coating. Corrosion resistance and weight loss of matrix, AME201Fe coating, 316L coating and Fe901 coating were studied by salt spray corrosion test. The results show that the thickness of AME201Fe coating is mostly affected by powder feeding, laser power and scanning speed have a huge impact on the width of coating, and the dilution rate increased from 0.13% to 29% with the change of laser power, nearly several hundreds of times. The results of salt spray test show that the AME201Fe coating has the minimum weight loss value at each stage compared with the matrix, 316L coating and Fe901 coating, which can play a good role in surface protection because of less internal defects and no grain boundary dislocations.

1. Introduction
The amorphous alloy has excellent physical and chemical properties due to its special micro-structure with long-range disorder and short-range order, no dislocations and grain boundaries. However, the application and popularization of amorphous alloy materials in engineering are limited by room temperature brittleness, fabrication process and size effect[1-2]. Turnbull, Cohen, Inoue and others found[3-5] that amorphous formation required to three conditions: the cooling rate is extremely high, atomic size is vastly different between the components (greater than 12%) with more than three components, the heat of mixing among the major elements is negative, which are favorable for the shape of amorphous phase. Therefore, the ultra-high-speed laser cladding of AME201Fe-based amorphous alloy is chosen, which not only has a high cooling rate to promote the glass transition, but also has a variety of component effects and avoids the size effect, the laser cladding layer and matrix are metallurgical bonding, low cost, compact structure and so on.

In this paper, the influence of process parameters on AME201Fe coating was investigated. Then, amorphous coating was prepared on the surface of 27SiMn alloy steel by optimizing the parameters. Finally, had studied the corrosion resistance and weight loss of matrix and coatings. It provides the corresponding solution for the follow-up engineering application of corrosion protection[6-7].
2. Experimental materials and equipment

2.1. Experimental material
In this experiment, the base material was 27SiMn steel. The composition of 27SiMn steel is listed in table 1. The cladding powder is AME201Fe-based amorphous alloy. The specific composition is shown in table 2 below. The powder size is 16μm ~ 55μm.

| Elements | C   | Si  | Mn  | P   | S   | Cu  | Cr  | Ni  | Mo  | Fe  | Wt.% |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
|          | 0.24~ | 1.10~ | 1.10~ | ≤0.035 | ≤0.035 | ≤0.30 | ≤0.30 | ≤0.30 | ≤0.15 | Bar |

Table 1. The chemical composition of 27SiMn alloy steel

| Elements | C   | Si  | B   | Cr  | Mo  | Fe  | Wt.% |
|----------|-----|-----|-----|-----|-----|-----|------|
|          | 2.12 | 1.25 | 1.95 | 22.41 | 18.3 | Bar |

Table 2. The chemical composition of AME201Fe

2.2. Equipment
The main equipment for laser cladding includes 1 fiber laser, 6-axis industrial robot and 1 powder feeder, special ultra-high speed laser gun 1 set, water cooling and control system in figure 1(a).

Accordind to the requirements of "GBT 10125-2012 artificial salt fog corrosion test", The acetic acid salt spray test (AASS) as shown in figure 1(b). the specific test method is firstly preparing NaCl solution with concentration of 50g/L ± 5g/L and adjusting the PH of the solution to 3.1-3.3 with glacial acetic acid.

3. Study on fabrication technology and corrosion resistance of coatings by high-speed laser cladding

3.1. Effect of fabrication technology on coating formation
In order to study the affect of processing parameters on the formation of AME201Fe coatings, a series of cladding parameters were carried out according to table 3.
Table 3. Variation in process parameters

| number | Laser power (kW) | Scan speed (mm/s) | Powder rate (g/min) | Focal length (mm) |
|--------|------------------|-------------------|---------------------|------------------|
| 1      | 1.5              | 200               | 25                  | 15               |
| 2      | 2                | 200               | 25                  | 15               |
| 3      | 2.5              | 200               | 25                  | 15               |
| 4      | 1                | 100               | 5                   | 15               |
| 5      | 1.5              | 150               | 25                  | 15               |
| 6      | 1.5              | 250               | 25                  | 15               |
| 7      | 1.5              | 200               | 15                  | 15               |
| 8      | 1.5              | 200               | 20                  | 15               |
| 9      | 1.5              | 200               | 25                  | 15               |
| 10     | 1.5              | 200               | 25                  | 5                |
| 11     | 1.5              | 200               | 25                  | 10               |
| 12     | 1.5              | 200               | 25                  | 15               |

Figure 2. Different fabrication technology of coating forming size and its macro-morphology

The cross-sectional geometric dimensions of coatings are calculated by Image J, figure 2(a)(b)(c)(d) is obtained from the statistics of melting height and melting width under different process parameters. figure 2(a)(b) when other factors are constant, the width of coating will increase with the enhance of laser power, but the coating height does not change much. In figure 2(c), the coating height is a linear relationship with powder rate, but the width of coating does not change much. The main reason is that the increase of the powder feeding rate, the mass of the powder entering the molten pool enhances in the unit time, which causes the height of coating to be improved according to the principle of mass conservation[8].

3.2. Effect of fabrication technology on cross-section morphology
Figure 3(a) is the cross-section morphology of different laser power under low magnification. From the drawing, it can be found that the whole coating is formed well, the shape is semi-ellipse, the inner
structure is compact and there is no obvious defect. At the surface of base material has obvious interface, and the melting ratio of base material increases with the upgrade of laser power.

Figure 3. Cross-sectional morphology of coatings with fabrication technology

Figure 3(b) shows the cross-section morphology of coatings increases from 100 mm/s to 250 mm/s. As the scanning speed improves, the deposition thickness of coating decreases and the melting ratio to the base metal drops. It was also found that there were cracks in the coating at low scanning speed, which was related to the high linear energy and the enhance of dilution conductivity, resulted in the excessive thermal stress between the matrix and the coating[9].

3.3. Effect of laser parameters on coating dilution

The cross-section and the thickness of AME201Fe coating is used to calculate the dilution rate by the area method, the results are shown in figure 4. When the laser power is increased from 1.0 kW to 2.5 kW, and the dilution is increased from 0.13% to 29%, nearly several hundreds of times. The coating dilution at different scanning speeds is calculated in figure 4(b). Compared with figure 4(a), it was found that the dilution rate decreased slightly with the enhance of scanning speed[10].

3.4. Experimental analysis on salt spray corrosion of different laser cladding coatings

The initial state of the salt spray corrosion samples was obtained by using the Yageli cold-set rubber seal as shown in figure 5(a) below and the salt spray corrosion samples of weight were recorded by electronic balance. Then placed in a acetic acid salt spray test (AASS) chamber at 35 °C, the samples were weighed after 24h, 72h and 120h, as shown in figure 6.
Figure 5. The macro-morphology of the samples after 120h. It can be seen from the graph that the salt spray corrosion for 120h has caused the surface corrosion to some extent, and the base material has the most serious corrosion\textsuperscript{[11]}.

Figure 6. Weight loss statistics of salt spray corrosion

According to the samples quality was measured in different time periods. As can be seen from figure 6, it can be clearly seen from the diagram that the AME201Fe coating prepared by the experiment has the minimum weight loss value at each stage compared with the matrix and 316L and Fe901. AME201Fe-based amorphous coatings have a good corrosion resistance because of less internal defects and no grain boundary dislocations. Therefore, Fe-based amorphous coatings show little change in weight loss and can play a good role in surface protection\textsuperscript{[12-13]}.

4. Conclusions
- Among the four parameters, the thickness of AME201Fe coating is most affected by powder feeding, and the width of coating is mainly affected by laser power and scanning speed.
- The laser power and scanning speed have a major impact on coating dilution. The dilution rate is proportional to the laser power, and inversely proportional to the scanning speed. The dilution rate increased from 0.13% to 29% with the change of laser power.
- The results of salt spray corrosion test show that AME201Fe coating has the lowest weight loss value. This is because Fe-based amorphous coatings have characteristics of less internal defects and no grain boundary dislocations.

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