Influence of Ni addition on Abrasive wear behaviour of plasma-sprayed Duplex stainless steel coatings

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Abstract: Many austenitic and ferritic stainless steels have a higher yield and ultimate tensile strength than duplex steels. The extent to which this is true is determined not only by the alloy's composition but also by how it is treated. This increased strength is usually accomplished without sacrificing the alloy's hardness, as long as the alloy does not contain any of the harmful phasing elements. Thus an attempt is made to study the duplex stainless steel being plasma sprayed on a substrate and study its microstructure, hardness, and abrasive wear resistance. The primary objective is to study the abrasive wear resistance of duplex stainless steel coatings on 316 stainless steel. Ni percentage in coatings is varied at the coating stage in weight percentages of 7.0, 7.5, and 8 % and to study its effect on the wear rate of the coatings. The composition of the coatings is confirmed using XRD. A two-body abrasive wear test is carried out to determine the wear rate of the coatings with varying percentages of Ni and varying loads. Besides, the coatings are characterized by optical microscopy. Weight loss measurements of the tested samples are carried out and the data obtained is analyzed through weight loss plots. Also, weight loss data is used to further calculate the wear rate which is analyzed using wear rate plots. Finally, the microhardness of the coatings is determined.

Keywords: Duplex stainless steels, Abrasive wear, Optical microscopy

1. Introduction

In the chemical and petrochemical industries, duplex stainless steel (DSS) grades are widely used. The key advantages of duplex stainless steels are their excellent resistance to oxidation, corrosion, and stress corrosion, as well as their superior mechanical properties [1-4]. These alloys have general corrosion rates that are similar to, if not lower than, austenitic stainless steel. In dilute sulfuric acid, these alloys have the same or lower general corrosion rates as austenitic stainless steels. This is true for dilute hydrochloric acid as well as caustic solutions used in the pulp and paper industry. Any of these alloys can also be used in organic acid environments. As compared to austenitic stainless steels, many of these alloys have better pitting and crevice corrosion resistance [5-7].
Duplex stainless steels (DSS) exhibit excellent resistance to transgranular and intergranular stress corrosion cracking. Depending on the environment, the composition of the alloy and its microstructure determine the resistance towards corrosion [2]. Instead of austenitic or ferritic stainless steel sometimes Duplex stainless steels which possess excellent mechanical properties are utilized. The hardness of ferrite decreases with decreasing temperature, but since it is only a part of a two-phase alloy, the ductile-to-brittle transformation is not as sharp as in ferritic stainless steels.

Since ferrite has a lower coefficient of expansion and higher thermal conductivity than austenite, the more ferrite present, the lower the coefficient of expansion and the higher the thermal conductivity of the duplex stainless steel. Duplex stainless steels are usually very weldable; in particular, duplex weld metal is used in austenitic stainless steels [8-12]. However, there is no research reported on the microstructure, hardness, and abrasive wear resistance of plasma-sprayed DSS coatings. In light of the above, an attempt was made in this study to investigate the microstructure, toughness, and abrasive wear resistance of plasma-sprayed DSS coatings with varying Ni content. and its influence on microstructure, hardness, and abrasive wear resistance.

2. Materials and Methods

Stainless steel (316 grade) substrate was taken in the plate form of dimensions 76 × 25 × 4 mm. The substrate 316 SS was pretreated and sandblasting was done. DSS grade S31500 (3RE60) in form of wire was coated on the substrate by wire arc spray process at Center of Excellence in Corrosion & Surface Engineering (CECASE) labs, NIT, Trichy. The schematic representation of the wire arc spray process is shown in figure 1. The wire spray process is well explained in the literature elsewhere. After the spray process, the samples are cleaned in acetone and weighed, using a digital balance. To confirm the duplex nature of the coatings XRD was performed on the coatings and the sample coated with 7.0 wt% Ni is shown in figure 2. X-ray Diffraction studies were performed using a Rigaku D/Tex Ultra diffractometer with a Cu Kα radiation of 1.5405 Å. The scanning angle (2θ) ranged from 30° to 120° with a step size of 0.02° and counting time of 2 s/step. The diffraction patterns obtained were indexed and compared with the ICDD-PDF standard data.

Vickers microhardness equipment (Matsuzawa MMT-X7 B type, Japan) was used to measure microhardness by performing indentations at a loading force of 100 gf and holding time of 15 s. The samples were polished to remove slight undulations before taking the microhardness tests. At least 5 measurements were conducted and the average microhardness values for the samples are shown in Table 1. Figure 3 shows the optical microscopic image of the indentation on the coated sample.
2.1 Two-body abrasion test
Before the wear examination, all of the samples were thoroughly washed with acetone and weighed. The tests were conducted on a two- and three-body abrasion testing device provided by DUCOM Instruments, Bangalore, India. Figure 4 depicts the abrasive wear test setup. A spinning wheel with a chlorobutyl rubber beading on its outer surface makes up the apparatus. The sample holder is constructed so that the sample to be examined is pressed against the spinning rubber wheel and that the applied load can be changed. The rubber wheel is set to turn at a steady speed of 200 revolutions per minute. The abrasive medium is 60-micron silica sand, which is fed between the contact surfaces of the rubber wheel and the sample as shown in figure 4.

The wear tests were conducted with a constant load of 5 N and 8 N for 3 minutes and 30 seconds. The diameter of the spinning rubber disc and its rotation speed (RPM) was used to measure the sliding time and velocity.
3. Results and Discussion

3.1 XRD analysis
The samples subjected to XRD are analyzed for the composition of the coatings. Figure 2 reveals the XRD pattern obtained for the 7% Ni added coating. Almost all the samples with varying Ni content showed a similar pattern and confirmed the dual-phase normally present in the duplex stainless steels. The presence of ferrite and austenite phases confirmed that the coatings are similar to duplex stainless steels.

3.2 Microhardness test
The microhardness values obtained for the uncoated and coated samples are listed in table 2. The values indicate a slight increase in the Hv value for an increase in Ni percentage. This may be attributed to the fact that the addition of Ni increases the strength and toughness of the materials. Figure 5 graphically represents the variation of hardness to Ni percentage.

![Figure 5. Variation of Hv Vs DSS coatings](image)

| Sample | Hardness value (HV) | Average value | Standard deviation |
|--------|---------------------|---------------|--------------------|
| Uncoated | 313, 321, 311, 317, 318 | 316 | 4 |
| Coated with 7wt% Ni | 320, 321, 325, 322, 326 | 322.80 | 2.588 |
3.3 Two-body abrasion test

The weight difference between the samples before and after the experiments was determined. The wear rate of various samples was calculated by converting the weight loss in grams into the basic wear rate (mm³/mm). The samples are examined for the effect of Ni addition on the wear rate of the coatings. The values of the test sample under 5N and 8N loads are described in Table 2. The wear mass loss of DSS coatings as a function of Ni content is shown in table 2. The wear mass losses of the coatings initially decrease as the Ni content increases. As compared to the uncoated sample, the wear mass loss of the DSS coating with 8wt% Ni in the coating has the lowest weight loss (0.054 gm), which is 40% less. The values indicate that the wear rate increases marginally as the applied loads' increase. However, the coating with the highest Ni content showed the lowest wear rate once again.

| Coated with 7.5wt% Ni | 322 | 323.6 | 1.673 |
|-----------------------|-----|-------|-------|
|                       | 322 |       |       |
|                       | 324 |       |       |
|                       | 326 |       |       |
| Coated with 8wt% Ni   | 324 | 325.8 | 1.303 |
|                       | 326 |       |       |
|                       | 327 |       |       |
|                       | 327 |       |       |

Figure 6. Variation of Wear rate

Figure 6 depicts the difference in wear rate as a feature of Ni percentage in various samples. The wear scars on the samples show that the wear is more abrasive at first. The wear mechanism then shows mixed results as the Ni percent increases due to the ductility imparted by Ni. It begins off as an abrasive and then turns into an adhesive in samples.
Table 2. Wear Test Results

| Sample                | Initial weight (gm) | Final weight (gm) | Weight loss (gm) | Volume loss (mm³) | Wear rate (mm³/mm²) |
|----------------------|---------------------|-------------------|------------------|-------------------|---------------------|
|                      |                     |                   |                  |                   |                     |
| **5N load**          |                     |                   |                  |                   |                     |
| Uncoated             | 58.954              | 58.724            | 0.23             | 26.744            | 3.723               |
| Coated with 7wt% Ni  | 62.517              | 62.427            | 0.09             | 10.465            | 1.457               |
| Coated with 7.5wt% Ni| 62.528              | 62.444            | 0.084            | 9.767             | 1.360               |
| Coated with 8wt% Ni  | 60.591              | 61.537            | 0.054            | 6.279             | 0.8743              |
| **8N Load**          |                     |                   |                  |                   |                     |
| Uncoated             | 60.869              | 60.393            | 0.476            | 55.348            | 7.706               |
| Coated with 7wt% Ni  | 61.527              | 61.362            | 0.165            | 19.186            | 2.671               |
| Coated with 7.5wt% Ni| 62.421              | 62.281            | 0.14             | 16.279            | 2.266               |
| Coated with 8wt% Ni  | 61.943              | 61.835            | 0.108            | 12.558            | 1.748               |

4. Conclusions
Wire arc spray technique was used to successfully prepare duplex stainless steel coatings of grade S31500 on an SS316 steel substrate. The following are the findings reached as a result of the research:
1) An increase in Ni percent causes dual phases such as ferrite and austenite to emerge in the coating during the wire arc spray process, according to XRD research.
2) As the wt% of Ni in the DSS coatings increased, the microhardness of the coatings increased.
3) The tribological properties of the DSS coating were superior. The coating with a higher Ni percentage demonstrated the best wear resistance in terms of wear mass loss. With a rise in Ni wt percent, the wear mechanisms changed from abrasive to adhesive wear with grooving and ploughing.

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