Research on Metallographic Examination of Thermal Spraying Coatings

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Abstract. The metallographic study of thermal spraying coatings was carried out on three double coating samples. ‘ASTM E3 metallographic Sample Preparation Method’ was selected for sample preparation, and coating inspection was conducted according to ‘HB 20195-2014 Metallographic Examination of Thermal Spraying Coatings’. The interface state, cracks and microstructure of the coating analyzed by ‘HB 20195-2014 Thermal Spraying Coating Metallographic Examination’. In combination with Image-Pro Plus quantitative analysis of porosity and unfused particles of coating, the thickness of coating was measured by using pull method. For the first coating, the microstructure, crack, coating thickness and porosity were tested. For the second coating, the microstructure, interface state, cracks, coating thickness, porosity and unfused particles were tested. Through the research on metallographic examination of thermal spraying coating, its hoped to provide some reference value for the examination of other coatings.

1. Introduction
Spraying process is a method in which powder, filament or rod spraying materials are heated to melting or local melting state by a certain form of heat source, and atomized by jet air at the same time, and sprayed on surface of the processed parts to form a spraying layer, so as to improve or change the surface properties of the workpiece [1-2]. Thermal spraying coating, as an important surface engineering technology, has a variety of functions, such as new product manufacturing, old product maintenance, remanufacturing, etc., and is widely used in oil miners, aerospace, Marine, steel, military and other fields [3]. Like as, surface strengthening of drill pipe and plunger parts in the oil industry, heat-resistant and life-extending of aero-engine turbine blades, anticorrosion of Marine equipment, etc. [3-5]. Due to the diverse functions and wide application of spraying coatings, it is necessary to carry out strict assessment of thermal spraying coatings before their service.

In this paper, the porosity, interface state, crack, ratio of unfused particles and microstructure of thermal spraying coating are studied by metallographic examination, which is expected to provide some reference value for thermal spraying coating inspection.

2. General Situation
Thermal spraying process is a surface treatment of metal or non-metal, in which the coated metal is heated to a molten or semi-molten state using an energy source, and the heated particles impact the
pretreatment surface of the workpiece through the process gas or ion flow at high speed, thus forming a special surface coating [6-7]. A schematic diagram is shown in figure 1.

Figure 1. Schematic diagram of thermal spray coating technology.

The analysis of coating metallographic structure is an indispensable part of the thermal spraying coating process, which is conducive to the determination of coating repair quality. So far, there is no set of relevant mature coating metallographic structure analysis methods, and conventional detection methods for reference to metal materials exist [6,8,9]. In order to improve the coating preparation process, optimize the physical and chemical coating performance testing method, promoted the mutual restriction and promotion between coating process and metallographic structure analysis method, this paper uses the thermal spraying coating provided by a company to analyze the metallographic structure, and forms a set of suitable coating metallographic structure analysis method.

3. Sample Preparation
In this paper, samples were prepared and tested according to HB 20195-2014 ‘Metallographic Examination of Thermal Spraying Coatings’ and ASTM E3 ‘Metallographic Sample Preparation Method’. The process flow chart of sample preparation is shown in figure 2. In order to quantitatively analyze the porosity and unfused particles of thermal spraying coating, Image data was processed by using Image-Pro Plus as reference according to technical indexes. The quantitative method is used to guide and formulate the rules for the qualitative evaluation of the thermal spray coating metallography, and finally the metallographic structure analysis and detection method is formed.

Figure 2. Flowchart of preparation of coating metallographic sample.
4. Metallographic Examination

4.1. Observation of Microscopic Features
The coating sample is observed at 50 times without corrosion after polishing. The microscopic features of the coating must be evenly distributed, and area observed must be total length of the section. As see in figure 1.

![Figure 1](image1)

Figure 3 is 50 times metallographic photo of the three sprayed coatings. According to the figure, the above part of the sprayed coating is the first coating (surface layer), the middle part is the second coating (bottom layer), and the bottom part is the substrate. The microstructure of coating is uniformly distributed, and there are no scratches on the polished surface that affect the microstructure evaluation.

4.2. Coating Metallographic Examination

4.2.1. Measurement of Coating Thickness. The thickness of coating was measured under the condition of 100 times magnification of metallographic microscope. In the observation area, the pull wire method was used to measure the coating with uneven thickness. The uniform interval method was used to measure the coating with uneven thickness. Measuring points was 12, and the arithmetic mean value was taken. The measurement results are shown in table 1.

| Test point | Sample 1 | Sample 2 | Sample 3 |
|------------|----------|----------|----------|
|            | First coating | Second coating | First coating | Second coating | First coating | Second coating |
| 1          | 356.5     | 139.7    | 263.1     | 240.3     | 405.7     | 148.7     |
| 2          | 366.1     | 108.3    | 283.6     | 241.2     | 397.3     | 154.7     |
| 3          | 330.6     | 122.1    | 289.0     | 229.0     | 381.4     | 137.2     |

![Figure 3](image2)
4.2.2. Evaluation of Interface State. The representative field of samples’ view was selected to take photographs of the first and second coatings of three samples at 200 times. According to the standard HB 20195-2014 ‘Metallographic Examination of Thermal Spraying Coatings’, the interface pollution, cracks, stratification and other phenomena of the coatings were evaluated.

|   | Sample 1 First Coating | Sample 1 Second Coating | Sample 2 First Coating | Sample 2 Second Coating | Sample 3 First Coating | Sample 3 Second Coating |
|---|------------------------|-------------------------|------------------------|-------------------------|------------------------|------------------------|
| 4 | 344.9                  | 103.9                   | 235.9                  | 242.1                   | 388.2                  | 141.1                  |
| 5 | 359.4                  | 135.9                   | 278.4                  | 232.3                   | 391.2                  | 151.0                  |
| 6 | 378.4                  | 127.5                   | 276.1                  | 277.5                   | 379.3                  | 135.8                  |
| 7 | 358.7                  | 93.1                    | 273.8                  | 257.1                   | 391.3                  | 168.4                  |
| 8 | 338.9                  | 135.7                   | 267.7                  | 229.1                   | 408.0                  | 141.1                  |
| 9 | 355.0                  | 161.7                   | 299.6                  | 216.9                   | 385.9                  | 135.2                  |
| 10| 386.3                  | 142.7                   | 355.6                  | 232.2                   | 396.7                  | 116.1                  |
| 11| 358.0                  | 175.6                   | 328.5                  | 260.1                   | 408.0                  | 139.5                  |
| 12| 352.6                  | 172.5                   | 305.7                  | 273.1                   | 405.0                  | 149.5                  |
|   | **Average**            | **134.9**               | **288.1**              | **244.2**               | **394.8**              | **143.2**              |

Figure 4. Metallographic photograph of spray coating. (a: sample 1 first coating, b: sample 1 second coating; c: sample 2 first coating, d: sample 2 second coating; e: sample 3 First coating, f: sample 3 Second coating)
According to figure 4, the surface of the first coating of test sample 1 has cracks (as shown in figure 4(a)). The comparative method is used to evaluate the interface pollution, and the interface pollution degree of the second coating and the matrix is 20%. The interface separation between the second coating and the matrix appeared in sample 2 (as shown in figure 4(d)). Sample 3 has no cracks and no interface separation phenomenon, and the microstructure distribution is uniform. The contamination degree of the interface between the second coating and the matrix is 20%.

4.2.3. Evaluation of Porosity and Unfused Particles. According to standard HB 20195-2014 ‘Metallographic Examination of Thermal Spraying Coatings’, the percentage content of pores in coatings is given in 12 grades (1%, 2%, 3%, 5%, 7%, 10%, 12%, 15%, 18%, 20%, 25% and 30% respectively). For unfused particles, only two kinds of criteria are given, namely coarse and fine unfused particles. Due to the visual comparison error of the comparison method, and the ratio of unfused particles needs more detailed data. Therefore, adopted the standard HB 20195-2014 ‘Metallographic Examination of Thermal Spraying Coatings’ with the Image Pro-Plus software to examine the porosity of the first coating and porosity and unfused particles of the second coating of samples.

The coating photos of the three test samples were cropped and the largest rectangular area was selected for detection. The test results of first coating and second coating were shown in figure 5 and figure 6 respectively.

![Figure 5](image)

**Figure 5.** The porosity of the first coating. (Left: Metallographic photograph of the first coating; Right: Porosity photograph)

The porosity of first coating was detected in an appropriate area. As can be seen from figure 5, a total of 2006 pores were detected in sample 1, with an average pore area of 12.23μm² and a porosity (area ratio) of 19.185%. A total of 1041 pores were detected in sample 2, the average pore area was 12.23μm², and the porosity (area ratio) was 19.351%. A total of 1677 pores were detected in sample 3, the average pore area was 16.31μm², and the porosity (area ratio) was 17.531%.

Figure 6 shows the detection results of the second coating, mainly including unfused particles and pores. The porosity detection is mainly calculated by using the color difference recognition of the software according to the evaluation standard HB 20195-2014, and the unfused particles are calculated by using the software after stroke.
As can be seen from figure 6, a total of 165 pores were detected in sample 1, with an average pore area of 0.891μm² and a porosity ratio (area ratio) of 9.317%. A total of 30 unfused particles were detected, with an average particle area of 1.658μm² and an unfused particle ratio (area ratio) of 3.134%. A total of 1758 pores were detected in sample 2, with an average pore area of 6.097μm² and an area ratio of 11.321%. A total of 111 unfused particles were detected, with an average particle area of 37.554μm² and an area ratio of 4.403%. A total of 750 pores were detected in sample 3, with an average pore area of 8.123μm² and an area ratio of 9.415%. A total of 337 unfused particles were detected, with an average particle area of 4.925μm² and an area ratio of 2.565%.

5. Conclusion
Metallographic examination of thermal spraying coatings of the three samples was carried out, and the results were as follows:

1) The average thickness of the first coating of sample 1 was 357.1μm and the average thickness of the second coating was 134.9μm. The surface of the first coating is cracked, and the contamination degree of the interface between the second coating and the matrix is 20%. The porosity of the first coating is 19.185%. The porosity of the second coating is 9.317%, and the proportion of unfused particles is 3.134%.

2) The average thickness of the first coating and the second coating of sample 2 were 288.1μm and 244.2μm respectively. There is no crack on the surface of the first coating, but interface separation occurs between the second coating and the matrix. The porosity of the first coating is 19.351%. The porosity of the second coating is 11.321%, and the proportion of unfused particles is 4.403%.

3) The average thickness of the first coating and the second coating of sample 3 were 394.8μm and 143.2μm respectively. There is no crack in the coating and no interface separation phenomenon. The microstructure distribution is uniform. The contamination degree of the interface between the second coating and the matrix is 20%. The porosity of the first coating is 17.531%. The porosity of the second coating is 9.425% and the proportion of unfused particles is 2.565%.

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