Research on Anti-cavitation Coating Performance of Shipping Fluid Machinery

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Abstract: In this paper, micro-nano-structure and nano-structure WC-based coatings were prepared by supersonic flame spraying technology for the cavitation of fluid mechanical parts. We used SEM and XRD to analyze the coating structure, mechanical properties and electrochemical properties. We also studied the cavitation’s mechanism of the coating in 3.5% NaCl simulated seawater medium. The results show that the micro-nano structure WC-10Cr-4Cr coating prepared by supersonic flame spraying has a micro-nano structure and added 4% Cr element, while the nanostructure WC-12Co coating is prone to have decarburization during the preparation process, resulting in generating a certain amount of W to reduce the hardness of the coating. Therefore, the micro-nano structure WC-10Cr-4Cr coating has better porosity, micro hardness and crack toughness properties. In the simulated seawater cavitation environment, the coating has more excellent anti-cavitation performance.

1. Introduction
With the development of national marine engineering, the development of marine oil and gas has attracted extensive attention. Marine oil and gas drilling platforms, offshore floating platforms and transportation equipment are subjected to cavitation, erosion and corrosion. In this environment, the cavitation damage of centrifugal pumps and other overcurrent components is exacerbated, making these devices more likely to lose control. The research on the anti-cavitation of overcurrent parts has been widely concerned by researchers around the world, but there is a little research on anti-cavitation materials in corrosive media. Since cavitation is only carried out on the surface layer of the material, with the development of surface engineering technology and coating materials (especially in nano coatings), coating treatment has become the most effective way to solve the problem of cavitation.

The cavitation phenomenon generally occurs in industries such as shipping fluid machinery, marine drilling platforms, and marine floating platforms. Typical components of cavitation in the shipping industry are shipping propeller blades, diesel engine bushings, and pump impellers. In the offshore drilling platform system, drilling pumps, centrifugal pumps and delivery pumps will have severe cavitation damage, reducing the efficiency of oil development and transportation. The energy industry also faces huge challenges. For example, components such as turbine blades and desulfurization circulating pumps cause component failure due to cavitation, which reduces the service life of the equipment and may even cause downtime and maintenance. This means that it may result in huge economic and energy losses[2].
Recently, the anti-cavitation materials researched around the world are nano materials. WC-Co is a cermet composite coating material composed of WC ceramic and Co metal. WC has high hardness, strength, and thermal conductivity, and the material has good wear resistance; Co has good toughness, and it is one of the metals with excellent anti-cavitation properties. Therefore, the WC-Co cermet coating has excellent anti-cavitation performance and has become a focus of application research in recent years \[^{[3]}\].

Traditional spraying methods could cause changes in the composition, performance and structure of nanomaterials, while supersonic flame spraying has the characteristics of high speed and low temperature. Therefore, the coating prepared by it has many advantages, such as low porosity and better corrosion resistance. In addition, the oxide boundary of this coating is low, and the hardness, toughness and wear resistance of the coating are better\[^{[4-5]}\].

Based on the above characteristics, supersonic flame spraying is suitable for spraying metal powder, alloy powder, mixed powder and carbide powder, especially for metal alloys and carbides with bonding phase. Therefore, in this paper, a nanostructure WC-12Co coating and a micro-nanostructure WC-10Co-4Cr coating were prepared by supersonic flame spraying technology, and the structure and anti-cavitation performance of these coatings were studied.

2. Materials and methods

2.1 Materials

The spray powder uses a nano-structured WC-12Co powder and a micro-nano-structured WC-10Co-4Cr powder. The powder characteristics are shown in Table 1. The base material of the sprayed sample is Q235 steel.

| Powder type | Product No. | Manufacturing method | Nano WC size (μm) | Micron WC size (μm) | Micro-nanosized particle ratio | Powder size (μm) |
|-------------|-------------|---------------------|------------------|-------------------|-----------------------------|-----------------|
| N1 WC-12Co  | Agglomeration sintering | 0.2-0.3 | - | 0/100 | 10-45 |
| M1 WC-10Co-4Cr | Agglomeration sintering | 0.2-0.3 | 2.5 | 70/30 | 20-53 |

There are two main chemical components of WC-based spray powder. One is hard WC, and the other is metal Co (Cr). The wettability of the two is very important. Excellent wettability will greatly enhance the consolidation effect of the relatively hard WC particles in the coating, so that the coating has higher hardness and excellent wear resistance. In this paper, the D-max / 2550 (XRD, Cu Kα radiation in JEOL) X-ray diffractometer was used to analyze the two powders.
Figure 1. XRD patterns of the two WC powders

The main physical image of the two powders can be obtained by XRD analysis of the spectrum. From Figure 1, it can be seen that the parameters of the micro-nanostructure WC-10Co-4Cr powder and the nanostructure WC-12Co powder material are different. The micro-nano structure WC-10Co-4Cr powder is mainly WC and Co, and there is also a Co3W3C phase, which is due to the strong affinity of Cr and C in the WC-10Co-4Cr powder. During the sintering process, Cr and C will be combined in a small amount, resulting in a partial carbon deficiency in the WC-10Co-4Cr powder, thereby forming a small amount of carbon-depleted phase Co3W3C. The main phases in the nanostructured WC-12Co powder are the WC and Co phases, and basically no new phases are generated. The powder maintains good performance during the preparation process.

2.2 Method

The spraying sample is prepared by JB2000 supersonic flame spraying equipment. In order to prevent the coating temperature from being too high during the spraying process, the coating is prepared by indirect spraying. The quality of the substrate before spraying directly affects the quality of the coating, and it has the greatest impact on the bonding strength between the coating and the substrate. The pretreatment of the surface of the substrate is particularly important. The purpose is to improve the bonding between the substrate and the coating, thereby improving the quality of the coating.

Before spraying the sample, clean the sample surface with acetone, and then roughen the sample surface with 60-mesh corundum. The thickness of the coating after spraying is about 0.5mm. The coating after spraying is processed by grinding. The thickness of the coating after processing is about 0.4mm and the surface roughness is Ra≤0.8μm. The spraying parameters mainly include the flow rate of kerosene and oxygen, the spraying distance, the length of the spray gun and the moving speed of the spray gun. The optimized spraying process parameters are shown in Table 2. As can be seen from Table 2, the optimized two WC-based coating preparation process parameters are basically the same.

| Powder type | Gun Length (inch) | Kerosene flow (GPH) | Oxygen flow (SCFH) | Powder feed rate (g/min) | Spray distance (mm) |
|-------------|------------------|---------------------|-------------------|------------------------|---------------------|
| N1          | 6                | 6.5                 | 2000              | 75                     | 380                 |
| M1          | 6                | 6.5                 | 1950              | 75                     | 380                 |

3. Research on coating performance

3.1. Analysis of coating microtopography

The surface morphology and microstructure of the coating were observed with S-570 and JSM6700F
scanning electron microscope (SEM), and the phase analysis was performed with D5000 X-ray diffractometer (XRD).

It can be seen from Fig. 2 that the nanostructure WC-12Co coating and the micro-nanostructure WC-10Co-4Cr coating have different degrees of melting and different surface texture structures. The melting condition of the micro-nano WC-10Co-4Cr coating is excellent. Some of the carbide particles have been melted, and some of the unmelted carbide particles are coated with Co in an irregular shape. The WC particles in the micro-nano WC-10Co-4Cr powder are composed of nanometers and micrometers. Due to the small size, large surface area and high activity of the nano-WC particles, a large part has been melted, and the nano-WC particles will be filled in the micro-melted or semi-melted micro-WC particles after melting to form a multi-scale structure. This multi-scale WC-10Co-4Cr coating has small porosity, strong impact resistance and excellent toughness, and this coating can well prevent the occurrence of cracks during the cavitation process. The particles of nano WC-12Co powder are easier to melt, and the melted particles are easy to agglomerate together to form the shape of large particles.

It can be seen from Fig. 3 that the interface between the coating and the substrate clearly shows tiny jagged protrusions. This is because the speed of the supersonic flame reaches more than 3 times the speed of sound, and the coated particles impinge on the substrate under such high air flow, causing the
substrate to undergo large deformation and form pits. In addition, it shows that the bonding between coating and substrate is mainly mechanical bonding. WC-based coatings have fewer pores, indicating that the coating is denser and has lower porosity.

3.2. Coating phase analysis
The phase composition of the coating can characterize the performance of the coating. The comparative study of the phase structure of the WC-based coating is of great significance for further understanding of the thermal melting and solidification process of the powder during the spraying process.

It can be seen from Figure 4 that the micro-nano structure WC-10Co-4Cr coating produced only a small amount of W2C phase. This shows that during the spraying process, their WC particles did not decompose significantly, and in addition to a certain amount of W2C phase, the nanostructured WC-12Co coating also generated a certain amount of W phase, which shows that during the preparation process of the coating, there is a certain decarburization phenomenon. The Co and Co3W3C phases which are present in the micro-nano structure WC-10Co-4Cr powder disappear. This is because the Co3W3C phase is a metastable phase, which will decompose to generate a small amount of Co and WC phases in the high-temperature flame stream during the spraying process. The decomposition products react with oxygen to form a small amount of W2C phase.

3.3. Analysis of coating porosity, micro hardness, crack toughness
The porosity, microhardness and crack toughness of the coating are important indicators to measure the quality of the anti-cavitation coating, which has a direct impact on the performance of the anti-cavitation coating used in fluid machinery.

The microhardness of the coating was measured using an "HVS-1000" digital microhardness tester with a load of 200g. For the measurement of the porosity of the coating, the Axiovet 40 MAT scanning electron microscope was first used to scan the coating, and then five areas of 200X scanning electron microscope photos were taken from different areas of the coating cross section, and the photos were imported into IQmaterials software for calculation. Finally, the gray scale method is used to measure the porosity. The cracking toughness of the coating was tested with Huayin HV5 small load Vickers hardness tester, and the load was 5kg.

The porosity, microhardness and crack toughness of the two WC coatings are shown in Table 3. As can be seen from Table 3, the porosity of both WC-based coatings is very low, because both powders contain nano-sized WC particles. During the spraying process, the nano-sized WC particles have a large contact area and are melt more fully, thereby reducing the porosity of the coating. The micro-hardness of both WC-based coatings is very high. This is mainly due to the high hardness W2C phase generated during the spraying of WC powder, which significantly increases the microhardness of the coating. The
The micro-hardness of the nanostructured WC-12Co coating is low. This is because the spraying temperature is too high, which causes some WC particles to decompose and decarbonize to form the W phase, reducing the hardness of the coating. The cracking toughness of both WC-based coatings is good, mainly because the powder has nano-WC particles, and the formed coating grains are fine. In addition, the number of grains per unit volume inside the coating is large, and the deformation is more uniform, delaying the formation and propagation of cracks. Therefore, the two WC-based coatings have good crack toughness.

### Table 3. Porosity, microhardness and crack toughness of the two WC-based coatings

| Coating No. | Porosity (%) | Microhardness (HV$_{0.2}$) | Cracking toughness (MPam$^{1/2}$) |
|-------------|--------------|-----------------------------|-----------------------------------|
| N1          | 0.36         | 1311                        | 5.56                              |
| M1          | 0.26         | 1020                        | 4.85                              |

### 4. Experimental research and mechanism analysis of coating cavitation

The cavitation test uses J93025 ultrasonic vibration cavitation test device. The test method refers to the GB / T8363-86 method. To simulate the seawater environment, the test medium is 3.5% NaCl solution. The cavitation loss weight of the sample is weighed by TG328 electronic balance, accurate to 0.1mg.

Figure 5 shows the cavitation test curves of two WC-based coatings. It can be seen from the figure that the cavitation volume of the two WC-based coatings increases linearly with time, but the slope of the cavitation curve of the nanostructured WC-12Co coating is large, which means that the cavitation rate is high. The anti-cavitation performance is worse than the micro-nano structure WC-10Co-4Cr coating. The cavitation rate curve is shown in Fig. 6. From the figure, it can be clearly seen that the nano-structure WC-12Co coating has a stable cavitation rate of about 1.3 mm$^3$/h, while the cavitation rate of micro-nanostructure WC-10Co-4Cr coating in the stable period is about 0.15 mm$^3$/h, which is only about 1/8 of the nanostructure WC-12Co coating. And from Fig. 6, it can be observed that the cavitation rate of micro-nanostructure WC-10Co-4Cr coating has a downward trend in the post-test stage.

It can be seen from the analysis in Table 3 that the micro-nanostructure WC-10Co-4Cr coating is superior to the nanostructure WC-12Co coating in all aspects. For example, the low porosity allows the material to form fewer cavitation sources. Due to its high hardness and good crack toughness, it not only has high impact resistance, but also has good resistance to plastic deformation. In the early stage of cavitation, the source of cavitation reduced, and the strong intergranular bonding force delays the fracture and shedding of intergranular tissue. In addition, due to the presence of 4% Cr, the corrosion resistance of the coating is improved, and the effect of electrochemical corrosion near the source of cavitation is greatly reduced, which makes the corrosion resistance of the coating significantly improved. Also, the powder forms the CoCr composite metal bonding phase during the spraying process. This metal bonding phase has better performance than Co, which improves the hardness and plays a buffering role. Therefore, under the simulated seawater environment of 3.5% NaCl, the micro-nano structure WC-10Co-4Cr coating has more excellent resistance to cavitation.
5. Conclusion
Through experimental research and analysis, the following main conclusions are as follows.

1) The WC-based powder contains nano-WC particles and is prepared by supersonic flame spraying technology, so the two WC-based coatings have good porosity, micro hardness and crack toughness properties, but in comparison, the micro-nano structure WC-10Co-4Cr coating has better performance.

2) The nanostructured WC-12Co coating not only contains W2C, but also has a certain amount of W phase, indicating that there is decarburization in the coating preparation process, which reduces the hardness of the coating.

3) Under the simulated seawater environment of 3.5% NaCl, the stable cavitation rate of the micro-nanostructure WC-10Co-4Cr coating is only about 1/8 of that of the nanostructure WC-12Co coating. This means that the microstructure significantly enhances the anti-cavitation performance of the WC-based coating in the simulated seawater environment.

4) The micro-nano structure WC-10Co-4Cr coating exhibits excellent anti-cavitation performance under simulated seawater environment, and it is expected to be applied to the cavitation-prone parts of fluid machinery in seawater environment.

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