

## Effect of powder on properties of low pressure cold spray copper matrix composite coatings

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**Abstract.** Different volume ratios of Al<sub>2</sub>O<sub>3</sub> powder and copper powder are mixed, and a copper-based composite coating is prepared on a pure copper matrix by low-pressure cold spraying technology. The hardness and bond strength of the coating were tested, and the cross-section of the coating was observed and analyzed with a field emission scanning electron microscope. The effect of Al<sub>2</sub>O<sub>3</sub> content in the original powder on the coating performance was investigated. The experimental results show that the copper-based composite coating prepared from copper powder with a particle size range of 10-40 μm has a lower porosity and a denser coating structure. With the increase of the content of Al<sub>2</sub>O<sub>3</sub> in the original powder, both the microhardness and the bond strength of the coating showed a law of increasing first and then decreasing. When the content of Al<sub>2</sub>O<sub>3</sub> was 20%, the coating had the best performance.

### Introduction

Cold spraying technology is a coating preparation technique based on the principles of aerodynamics and high-speed collision dynamics, by sending powder particles into a high-speed air stream. After accelerating to 300-1200 m/s, it impacts the substrate at high speed in a completely solid state, resulting in large plastic deformation and deposition on the surface of the substrate to form a coating [1-3]. Cold spraying is an emerging surface engineering technology in recent years. Compared with thermal spraying such as flame, arc, plasma, and explosion, the biggest process feature is its lower spraying temperature (100-600°C). This feature gives cold spray the following advantages.

(1) The sprayed particles do not melt, and the driving force for phase transformation, oxidation, decomposition, and even grain growth is small. It is suitable for the preparation of metal coatings such as Cu, Ti, Al, and nano and amorphous special coatings.

(2) The thermal effect on the substrate is small and the thermal stress at the interface is relatively low, which helps to improve the interface bonding and obtain a thick coating.

(3) Less energy consumption, conducive to environmental protection. Cold spraying has become a new hot spot in surface engineering research at home and abroad [4-7]. Feng Li et al. applied copper powders with different Al<sub>2</sub>O<sub>3</sub> content, in which the copper powder had a particle size of 30-40 μm, and were sprayed on the surface of copper, aluminum and steel substrates to form a coating by cold spraying technology. The results show that the maximum deposition thickness can be obtained when the content of ceramic phase is 15%, 10% and 25% respectively for three different substrates of copper-aluminum steel. The highest bonding strength of copper matrix occurs in Al<sub>2</sub>O<sub>3</sub> content of 20%, while Al matrix is Al<sub>2</sub>O<sub>3</sub> content of 10%, steel matrix in 25% [8]. The copper powder particle size of 10-40 μm is used in this paper to study the effect of a larger particle size range on the coating performance.

In this paper, low-pressure cold spraying technology is used to mix  $\text{Al}_2\text{O}_3$  powder and copper powder with volume ratios of 10%, 20%, 30%, and 40%, and a copper-based composite coating is prepared on a pure copper substrate. The field-emission scanning electron microscopy was used to analyze the cross-sectional morphology of the copper-based composite coating, and the microhardness and bonding strength were measured simultaneously to study the mechanical properties of the pure copper coating.

## Experimental materials and methods

### Experimental Materials

By using a mechanical mixing method, the copper powder and the ceramic phase powder are mixed in a certain volume ratio, wherein the volume ratio of the ceramic phase powder is 10%, 20%, 30%, 40%, and the number is 1-4#. The microcosmic morphology of the powder is shown in Fig. 1. Fig. 1 shows the microstructure of the powder under scanning electron microscope. Fig. 1a shows the microstructure of the copper powder. The shape of the copper particles can be seen as a dendritic shape. Fig. 1b shows the microscopic shape of the  $\text{Al}_2\text{O}_3$  powder. It can be seen that the  $\text{Al}_2\text{O}_3$  particles are irregularly shaped. The substrate used for the experiment was a copper matrix.

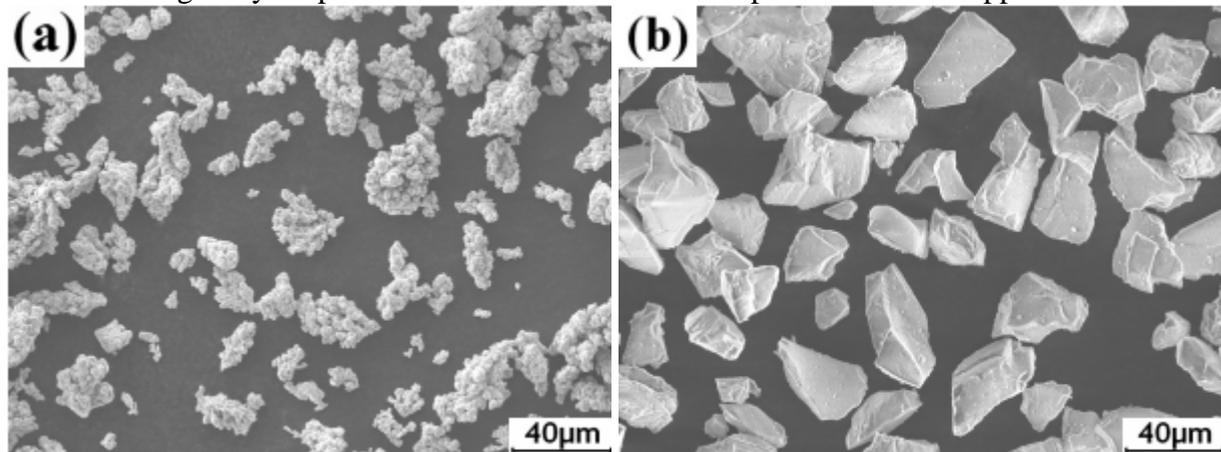


Figure 1 Powder micromorphology (a: copper powder, b:  $\text{Al}_2\text{O}_3$  powder)

### Cold spraying process

The experiment was conducted using the GDU-3-15 low pressure cold spray system produced in White Russia. Spraying process parameters: spraying temperature is  $300^\circ\text{C}$ , carrier gas is compressed air, pressure is 0.7MPa, spraying distance is 10mm.

### Analytical methods

In this experiment, the JSM6700F field emission scanning electron microscope was used to observe the cross-sectional morphology of the copper-based composite coating.

Microhardness test was carried out on the surface of the coating with a HV-1000 microhardness tester. The loading load was 1.96 N and the loading time was 15 s. Each sample was taken at 3 points for testing, and then the average value was taken as the final experimental result.

In this experiment, the paired parts of the spray bar and the 45 bar with the same material were bonded together with epoxy resin and allowed to stand at room temperature for 48 hours. The tensile strength of the coating was tested using Shimadzu's ability tester. The test speed was 1 mm/min and the load was 2000 N. Each group was tested 5 times and the average value was taken as the final test result.

## Results and analysis

### Coating microstructure

Figure 2 shows the cross-sectional microstructure of four cold-sprayed copper coatings. It can be seen that the particle is tightly bound to the matrix, and the junction is inlaid with  $\text{Al}_2\text{O}_3$  particles (shown by the yellow arrow). Compared to other spraying, particles in the cold spraying process are

more likely to obtain high speed [9]. The copper particles with a larger particle size range produce intense plastic deformation. The copper particles with smaller particle sizes can effectively fill the pores, and the resulting coating microstructure is more dense. Image software was used to analyze the pores (shown by the red arrow) in the coating. The results were 0.70%, 0.52%, 0.59%, and 0.64% in order. It can be seen that as the content of  $\text{Al}_2\text{O}_3$  in the original powder increases, the porosity in the coating first decreases and then increases. This is because the  $\text{Al}_2\text{O}_3$  particles can promote the plastic deformation of the copper particles, and have a concretion effect on the particles deposited in the early stage; With the increase of the content of  $\text{Al}_2\text{O}_3$ , the degree of work hardening of the coating is higher, the denser the structure, and the stronger the bonding of the coating. However, when the content of  $\text{Al}_2\text{O}_3$  is 40%, the  $\text{Al}_2\text{O}_3$  particles in the coating also increase, too much  $\text{Al}_2\text{O}_3$  particles on the coating erosion effect, resulting in coating porosity.

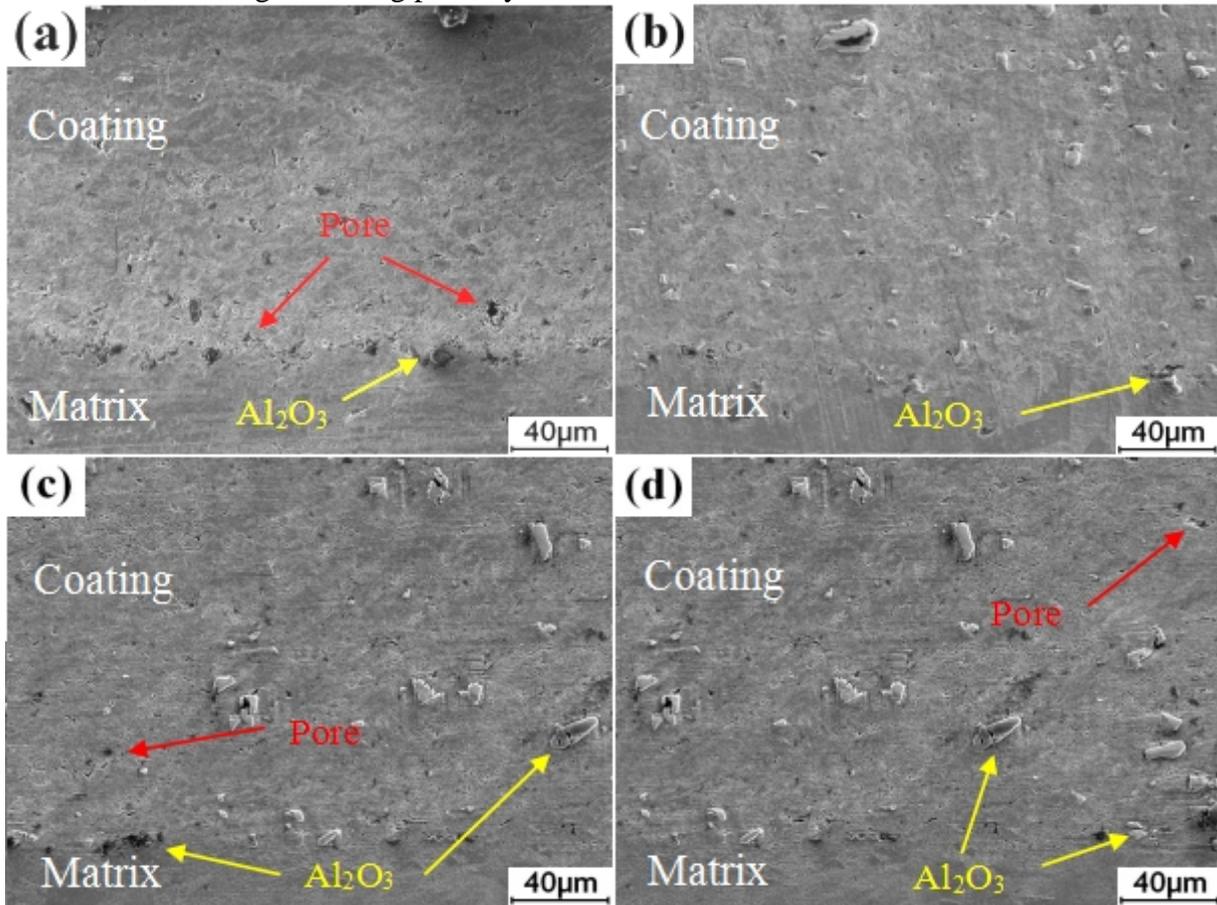


Fig.2 Cross-section microstructure of copper-based composite coating (a) 10%  $\text{Al}_2\text{O}_3$ , (b) 20%  $\text{Al}_2\text{O}_3$ , (c) 30%  $\text{Al}_2\text{O}_3$ , (d) 40%  $\text{Al}_2\text{O}_3$

### Coating hardness

The coating hardness is an important indicator reflecting the mechanical properties of the coating, and the porosity in the coating is one of the important factors affecting the hardness of the coating [10]. Microhardness tests were performed on the surface of four cold-sprayed copper coatings. The test results are shown in Figure 3.

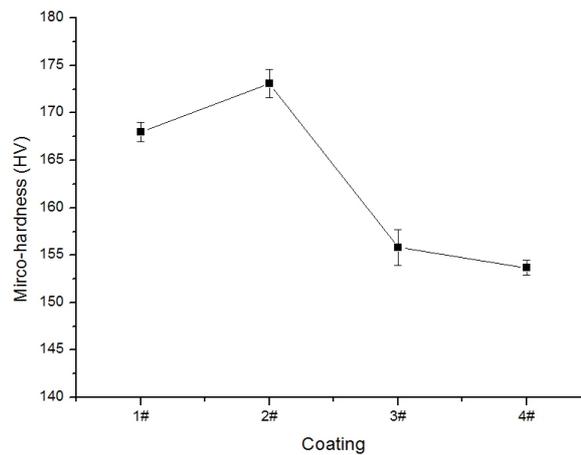


Fig. 3 Surface microhardness of cold-sprayed copper coating

It can be seen from Fig. 3 that the particle size of the copper powder in the original powder is in the range of 10-40 $\mu$ m. When the content of Al<sub>2</sub>O<sub>3</sub> is 20%, the microhardness of the coating reaches the highest value, and the value is 173.1HV. With the increase of the content of Al<sub>2</sub>O<sub>3</sub> in the original powder, the microhardness of the coating surface increased first and then decreased. According to [8], the maximum hardness of the coating made of copper powder with a particle size range of 30-40  $\mu$ m is 157.6 HV, which shows that a larger particle size difference in the copper powder can give a coating with a higher hardness.

### Coating bond strength

The bonding strength test was performed on the surface of four cold sprayed copper coatings. The test results are shown in Figure 4.

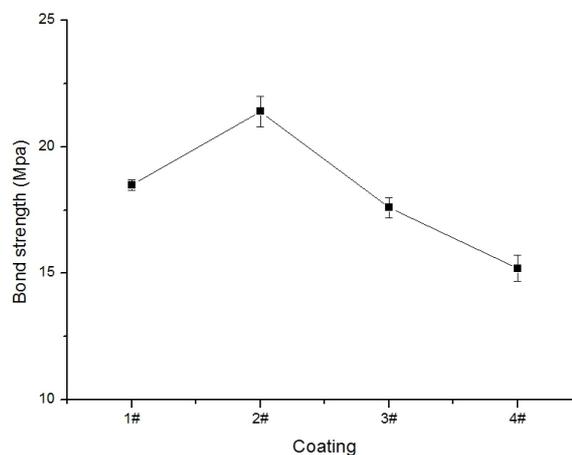


Fig. 4 Bonding strength of cold-sprayed copper coatings

It can be seen from Fig. 4 that the particle size of the copper powder in the original powder is in the range of 10-40  $\mu$ m. When the content of Al<sub>2</sub>O<sub>3</sub> is 20%, the bonding strength of the coating reaches the highest, and the value is 21.4 Mpa. With the increase of the content of Al<sub>2</sub>O<sub>3</sub> in the original powder, the bonding strength of the coating first increased and then decreased. Compared with the bonding strength of the copper coating mentioned in [8], a larger particle size range in the copper powder can give a coating with higher bonding strength. From 2.1 we can see that in the four kinds of coatings, Al<sub>2</sub>O<sub>3</sub> particles are present at the joint between the substrate and the coating. During the deposition of the coating, the ceramic phase does not combine with the copper particles, but only promotes the deformation of the copper particles. With the increase of the content of Al<sub>2</sub>O<sub>3</sub> in the original powder, the higher the degree of work hardening of the coating, the better the coating binding, and the trend of

the increase of the bond strength. When the content of  $\text{Al}_2\text{O}_3$  is increased to 40%, too much ceramic phase reduces the "sticking" effect between the copper particles, resulting in a decrease in the performance of the bond between the particles and the substrate. Therefore, the bonding strength of the coating tends to decrease.

## Conclusion

- (1) The copper-based composite coating prepared by cold spraying has uniform and dense coating structure, and the porosity of the coating can reach 0.52%.
- (2) The performance of coatings prepared from copper powders in the particle size range of 10-40  $\mu\text{m}$  is improved over that of the 30-40  $\mu\text{m}$  copper powders. With the change of alumina content in the original powder, the mechanical properties of the coating also changed. When the content of  $\text{Al}_2\text{O}_3$  was 20%, the coating had the highest microhardness (173.1HV) and bonding strength (21.4MP).

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