The influence of alumina content in Cu-Al_2O_3 powder on the properties of cold spraying coatings

Feng Li[1, 2,*] , Guan Chang[1], An Guosheng[1, 2], Li Wensheng[1, 2],Chang Jirong[1],Gerog Goransky[3], Viktor Vaganov[3]

1. School of Materials Science and Engineering, Lanzhou University of Technology, Lanzhou 730050, China

2. State Key Laboratory of Advanced Nonferrous Materials Process and Recycles, Lanzhou 730050, China

3. Belarusian National Technological University, Office 117, 67 Nezavisimosty Ave., Minsk, Belarus, 220013

Key words:Cold spraying; Al_2O_3-Cu coating; thickness; bond strength

Abstract:The cold gas dynamic spray was used to prepare the Al_2O_3-Cu alloys coating on Al, Cu and steel substrate in this study with the mixture of pure Al_2O_3 powder and pure copper powder. The influence rule of coating performance for different ratios was analyzed. The results showed that at a relatively high substrate hardness, different ratios is less effective to bond strength and vice versa. Al_2O_3-Cu coating on Al substrate can get largest thickness when the mixed-powder include 10% Al_2O_3. Al_2O_3-Cu coating on Cu substrate can get largest thickness when the mixed-powder include 15% Al_2O_3. Al_2O_3-Cu coating on steel substrate can get largest thickness when the mixed-powder include 25% Al_2O_3. Al_2O_3-Cu coating on Al substrate can get maximum bond strength when the mixed-powder include 10% Al_2O_3. Al_2O_3-Cu coating on Cu substrate can get maximum bond strength when the mixed-powder include 20% Al_2O_3. Al_2O_3-Cu coating on steel substrate can get maximum bond strength when the mixed-powder include 25% Al_2O_3. The thicker the coating thickness, the lower the bond strength.

Introduction

The cold spraying process is done at low temperature. In the process low-temperature heating makes the coating is not easy to produce problems such as oxidation, phase change, decarburization

and organizational change. Cold gas dynamic spray has the following advantages: its work efficiency is high, material can be reused, low environmental polluted, etc. Cold gas dynamic spray is a kind of green technology and it will have wide applications in the future[1].

Cold spraying technology is divided into low pressure cold spraying[2-7] and high pressure cold spraying[8-13]. High pressure cold spraying technology use heated high pressure gas in low temperature to change its kinetic energy into heat energy when the solid particles impact substrate and surface of coating material, thus forming a layer of almost impermeable coating[14].But in the process of application, the cold high pressure spraying has a lot of shortcomings,because the requirements for pressure (minimum to 15 atmospheres) lead to the stopping of large equipment and reducing the security of use. In addition, it increases its operation using cost greatly that some devices have to operate in nitrogen or inert gas. And gas consumption and powder consumption are large, spraying orientation is poor and spraying coating is not smooth which is easy to produce sand holes. Low pressure cold spraying that doesn't contain high temperature、flame、dangerous gases、radiation and chemical waste can hand operation under the condition of high safety and good directional property. Therefore, the technology will be widely used in repairing of aerospace materials and the preparation of anti-corrosion coating on the surface of the metal. Eric Irissou etc studied the size of Al particle and the mass fraction of Al_2O_3 leading to the effect about powder mixture on the preparation and properties of coating,and then got the conclusion that the addition of alumina powder can improve the deposition of coating[15]. Heli Koivuluoto etc did the control research of high pressure cold spraying copper-coating and low pressure cold spraying copper-coating to, and then got the conclusion that adding Al_2O_3 to copper powder improves the structure of the coating density in the process of low pressure cold spraying[16].

In recent years, some domestic research institutions, such as Institute of Metal Research , Chinese Academy of Sciences, University of Science and Technology Beijing, Beijing Institute of Aviation Materials, Xi 'an Jiao Tong University, Northwestern Polytechnical University, Chongqing University, Dalian university of technology, Harbin Welding Institute and so on, have carried out the study of cold spraying technology. In terms of the present domestic research situation of the copper coating, Wen-ya Li[17] studied deformation behavior of Cu and Cu substrate by the finite element numerical method. Rui Ding etc. studied corrosion resistance of copper coating conditions in the ocean[18]. At present, domestic research about the influence of Al_2O_3 on copper coating

preparation is relatively less, therefore, this article mainly further research coating preparation direction.

Experiment content

Coating preparation principle and parameters

The main factors influencing the particle velocity: gas pressure, gas temperature, feeding speed, spraying particle characteristics and spraying distance, etc. Table. 1 displays experimental parameters for this experiment.

Table 1 experimental parameters

Gas pressure	0.5-0.8MPa
Gas temperature	300-400°C
Spray particle size	30-40μm
Send the powder gas	compressed air

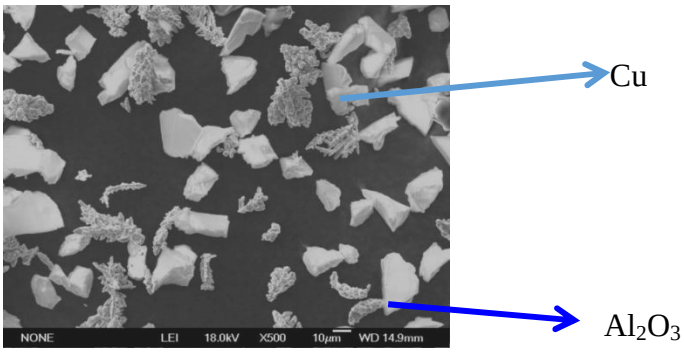

Figure 1 micro morphology of Al_2O_3 and copper powder

Figure. 1 copper powder and Al_2O_3 powder mixing according to certain proportion, this experiment preparation quality of Al_2O_3 content is respectively 5%, 10%, 15%, 20% and 25%, five different ratio, spray in cold spraying equipment to the substrate surface.

This experiment selects the copper, aluminum and iron base material, and sandblasting processing. Table. 2 for the parameters of the base material. Table. 2 lists the copper, aluminum and iron respectively the three different substrate hardness and copper coating and ceramic coating hardness. The table shows that the iron substrate hardness second highest copper substrate aluminum substrate minimum hardness, ceramic coating hardness is significantly higher than

copper coating hardness.

Table 2 substrate model and hardness

	copper	aluminum	steel
model	T2	LY12	45#
hardness（HV）	92.4	84.3	135.5

Coating performance testing

The thickness of the coating

Thickness is an important index of the preparation of the coating, coating in the field of industrial role is a big repair function, if the thickness to reach a certain degree, will lose its anticipated effect even greater loss. The experiment this paper sums up the ceramic phase content on the influence of the thickness of coating deposition.

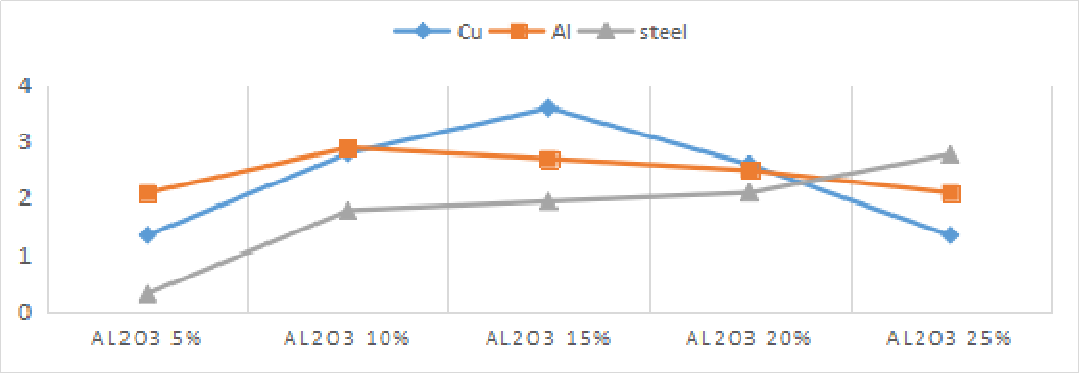

Figure 2 copper coating on the different substrate coating thickness and the accumulation

The Figure 2 shows that all kinds of powder, are available on copper iron aluminum substrate to achieve a good deposit. Spraying thickness gradient is bigger, so its application scope will be more broad.

Bonding strength

Many experiments found fracture occurs in the interface between coating and basal body. These tests eventually rupture occurred at the interface between coating and substrate, rather than the internal coating, shows that the bonding strength of coating internal itself is greater than the coating and interface bonding strength, to join the ceramic phase can affect the bonding strength between coating and substrate.

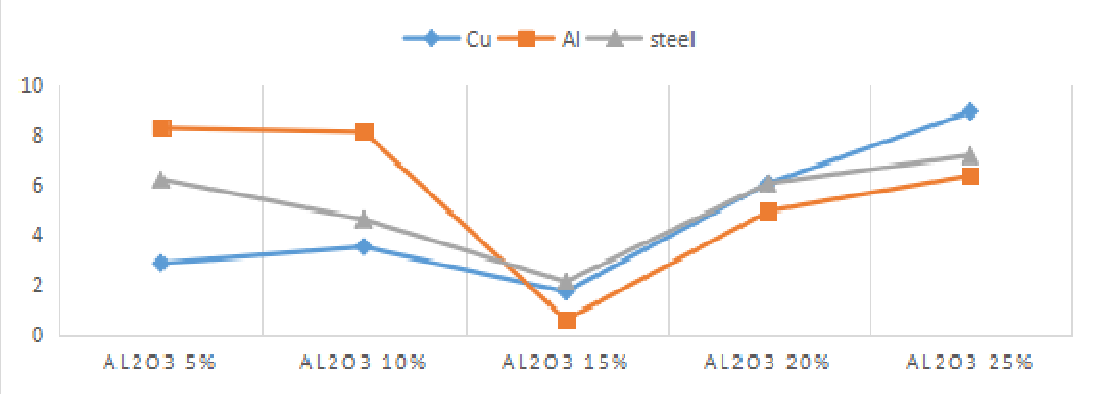

Figure 3 bonding strength of copper coating on the different substrate

Ceramic phase in the coating deposition rate

Table 3 loss of Al_2O_3

Cu in the powder	75%	80%	85%	90%	95%
Cu substrate	0.21	4.94	10.69	9.73	15.58
Al substrate	2.96	7.45	12.02	15.88	21.15
Fe substrate	1.95	6.11	10.36	17.13	14.61

According to the coating interface microstructure pictures, by ImageJ software can accurately calculate the ceramic phase in the coating deposition rate. The table. 3shows that the sedimentary rate instead of increased along with the increase in ceramic is matched, but after reaching a maximum value began to decrease.

Relationship of coating thickness and bonding strength

Through the test of bonding strength and coating thickness measurement, founded that between the bond strength and thickness of the coating has a close contact. Using “Origin” software, make different substrate coating-bonding strength

curve respectively as figure 4. By combining data curve, found that there are the laws of the thicker the coating bond strength is lower.

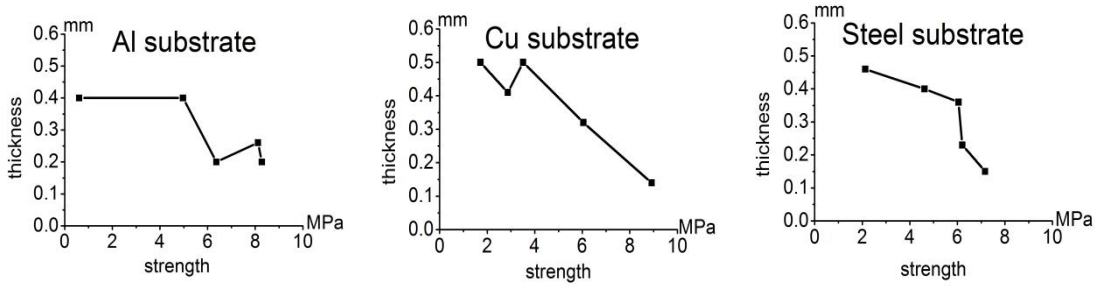

Figure 4 bonding strength-coating thickness

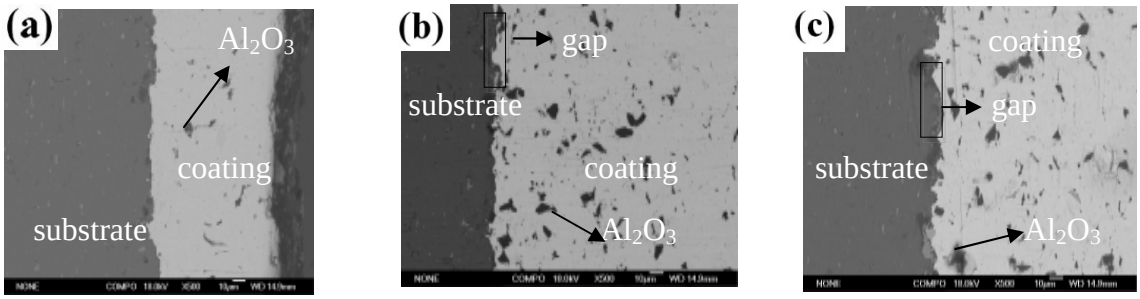

Figure 5 cross section structure of aluminum substrate copper coating

In order to explore the deep reasons , used SEM metallographic analysis of different thickness of the coating technology, figure 5 are the photos of the thickness of 0.20mm(a), 0.26mm(b) and 0.40mm(c). When the coating thickness for 0.20mm, almost no gap between coating and substrate, the coating more thickness, the gap between coating and substrate and a increasing trend.

Conclusions

This paper mainly talked about The influence of Al_2O_3 content in Cu-Al_2O_3 powder on the properties of cold spraying coatings. The results showed that at a relatively high substrate hardness, different ratios is less effective on the properties of coatings and vice versa. Al_2O_3-Cu coating on Al substrate can get largest thickness when the mixed-powder include 10% Al_2O_3. Al_2O_3-Cu coating on Cu substrate can get largest thickness when the mixed-powder include 15% Al_2O_3. Al_2O_3-Cu coating on steel substrate can get largest thickness when the mixed-powder include 25% Al_2O_3. Al_2O_3-Cu coating on Al substrate can get maximum bond strength when the mixed-powder include 10% Al_2O_3. Al_2O_3-Cu coating on Cu substrate can get maximum bond strength when the mixed-powder include 20% Al_2O_3. Al_2O_3-Cu coating on steel substrate can get maximum bond strength when the mixed-powder include 25% Al_2O_3. The thicker the coating thickness, the lower

the bond strength.

ACKNOWLEDGEMENTS

The authors are grateful to the International science and technology cooperation program of China (Grant No. 2015DFR51090) and The national high-end foreign experts program of China (Grant No. GDT20156200088) for financial support.

Reference

[1] Zhou Xianglin, several cold spraying copper coating on metal substrate test and simulation [J] journal of heat treatment, 2009, 30（6）:158-163（in Chinese）
[2] Li Geng, zhou yong, Xue Feng, etc. The cold spraying technology [J] Heat treatment technology and equipment, 2009, 30 (4) : 11-14.21.（in Chinese）
[3] Wang Feng, Qi Bo, Chen, et al. Supersonic cold spraying Cu - A1203 composite coating characteristics [J]. Materials review, 2009, 23 (12) : 47-51.（in Chinese）
[4] Lee Changjiu. China's cold spraying[J]. China surface engineering, 2009, 22 (4) : 5 -14.（in Chinese）
[5] Shen L,Kong L, Preparation of TiAl3 一 Al corn—posite coating by cold spraying[J]. Transactions of Nonferrous Metals Society of China. 2009. 19(4):879—882.
[6] Zhang Huabing, Shan Aidang, Wei Lun, etc. The cooling power spraying coating combination mechanism and technology progress [J]. Materials review, 2007, 21 (4) : 80-83（in Chinese）
[7] BaoZeBin. Cold spraying pure copper coating process optimization design and performance study [D]. Liaoning engineering technology university, 2004（in Chinese）
[8] Stoltenhoff T, Borchers C, Gärtner F, et al. Microstructures and key properties of cold-sprayed and thermally sprayed copper coatings [J].Surface and Coatings Technology, 2006, 200(16): 4947-4960.
[9] Fukumoto M, Wada H, Tanabe K, et al. Effect of substrate temperature on deposition behavior of copper particles on substrate surfaces in the cold spray process [J]. Journal of Thermal Spray Technology, 2007, 16(5-6): 643-650.
[10] Sudharshan Phani P, Vishnukanthan V, Sundararajan G.Effect of heat treatment on properties of cold sprayed nanocrystalline copper alumina coatings [J]. Acta materialia, 2007, 55(14): 4741-4751
[11] Champagne V K. The repair of magnesium rotorcraft components by cold spray [J]. Journal of Failure Analysis and Prevention, 2008, 8(2): 164-175.
[12] Assadi H, Schmidt T, Richter H,et al. On parameter selection in cold spraying [J] Journal of thermal spray technology,2011,20(6): 1161-1176.
[13] Han T, Gillispie B A, Zhao Z B. An Investigation on Powder Injection in the High-Pressure Cold Spray Process [J]. Journal of thermal spray technology,2009,18(3): 320-330.
[14] Thomas Müller, High pressure gas cold spraying [J]Advanced Materials& Processes, 2007, 165(9):24
[15] E Irissou, JG Legoux, Anvestigation of Al-Al_2O_3 Cold Spray Coating Formation and Properties

[J]Journal of thermal spray technology, 2007,16(5):661-668
[16] H Koivuluoto, M Hononkanen, Cold-sprayed copper and tantalum coatings-Detailed FESEM and TEM analysis[J]Surface and coatings technology, 2010,204(15):2353-2361
[17] Wenya Li, Changjiu Li, cold spraying Cu particle parameters on its collision deformation behavior [J]journal of metals, 2005,41（3）:282-268（in Chinese）
[18] Rui Ding, Study on preparation technology of cold sprayed copper composite coating and its anti corrosion and anti fouling property [D] Ocean University of China, 2014（in Chinese）