A Study on the Tensile Strength of Coatings Prepared by Cold Spray

○H. Fukanuma, R.Z Huang (Plasma Giken Co. Ltd)

Abstract: In this study, Nickel, Aluminum and Copper coatings were deposited by Cold Spray process on three kinds of substrates, Al, Cu and Stainless Steel. The tensile strength of the coatings was tested and the hardness of the substrates was also measured. The influences of substrate hardness on the tensile strength were discussed. The influences of working gas temperature on the tensile strength were also discussed.

Key Word: Cold Spray, Tensile Strength

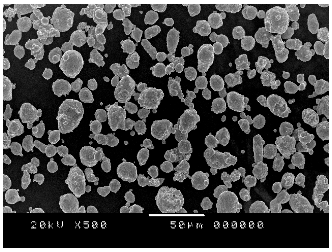
Introduction

Cold spray is a relatively emerging spray coating technology that was first developed in the mid 1980's at the Institute of Theoretical and Applied Mechanics in Russia [1]. In Cold spraying process, spray particles are injected into a supersonic jet of compressed gas and accelerated to a high velocity (300-1200m/s). The deposition of particles takes place through the intensive plastic deformation upon impact in solid state at a temperature well below the melting point of spray materials [2]. In the recent years, many studies have been republished contributing to enhancing the understanding of the fundamental mechanisms of cold spray, such as coating deposition, bonding and coating characteristics. But so far, the underlying mechanism of bonding has not been well clarified [3].

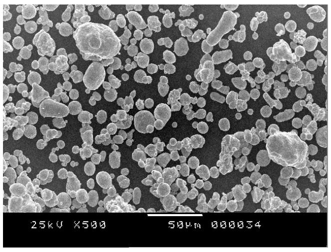
In the present study, through the test of cold spray coating tensile strength, the effects of the working gas temperature and the type of substrate on the strength of coatings were discussed in order to advance the understanding of bonding mechanism.

Experimental procedures

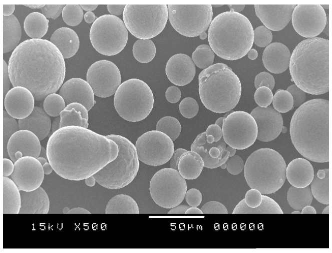
Three kinds of commercially available powders, Ni (SFR-15,15 μm), Cu (SFR-15, 15 μm) manufactured by Nippon atomized metal powders corporation and Al (Al-99.7, -45 μm) manufactured by Hikari sozai kougyou Co., Ltd were used to prepare coatings. The morphologies of the three powders are shown in Fig.1.



(a) Ni



(b) Cu



(c) Al

Figure 1: The morphologies of feedstock powder

Three kinds of materials, Cu (pure copper), Al (A5052) and Stainless Steel (SUS304) were used as substrates. Prior to spraying, the substrate surfaces were sandblasted using 36 mesh alumina grits. The micro-Vickers Hardness of substrates was measured with the FM-700 micro-hardness tester (Future-Tech. Crop), as shown in Table 1.

Table 1: The hardness of three substrates

Substrate	Stainless Steel	Cu	Al
HV	185.29±6.97	94.66±2.65	86.43±3.74

A cold spray system developed by Plasma Giken Co. Ltd was employed in the experiments. The system is a typical cold spray system with a converging- diverging (De-Laval) nozzle. Nitrogen gas was used as the driving gas and the powder feed gas. The spray conditions for cold spraying were shown in Table 2. The velocity of in-flight Al particles under the condations of preparing coatings was measured with DPV-2000.

Table 2: The spray conditions

Working gas pressure (MPa)	3	
Working gas temperature (^oC)	For Cu and Al	For Ni
	200, 300, 400	400,500,600
Spray distance (mm)	20	

The tensile strength of coatings was tested with tensile testing equipment, STM-F-2000BP, manufactured by Toyo Baldwin Co., Ltd. The samples have a 16 mm diameter and 40 mm length. The top portion of the coating was glued to an uncoated specimen before the measurement.

Results and Discussions

1. The tensile strength of Ni coating

Figure 2 shows that the relationship between the average tensile strength as well as their respective standard deviations of Ni coatings and the gas working temperature. The figure shows for three type of substrates, the tensile strength increases with the increasing of gas working temperature. The tensile strength of Ni coatings on stainless steel substrate is the lowest and the rupture occurred at the substrate-coating interfaces. To the coating on the Cu substrate, the rupture occurred partly inside the coating and partly at the substrate-coating interfaces at the gas temperature of 400^oC, at the substrate-coating interfaces at the gas temperature of 500^oC, partly at the substrate-coating interfaces and partly in the adhesive when the gas temperature up to 600^oC. The coating on the

Al substrate, the rupture occurred at the substrate-coating interfaces at the gas temperature of 400°C, in the adhesive while the gas temperature up to 500°C and 600°C.

2. The tensile strength of Cu coating

Figure 3 shows that the tensile strength of Cu coatings on any of the two types of substrate also increases with the increasing of gas working temperature. Cu coating on stainless steel cracked during depositing. The failure of Cu coatings on the rest of two substrates occurred at the substrate-coating interfaces with the gas temperature of 200°C and 300°C. While the temperature up to 400°C, the failure occurred partly at the substrate-coating interfaces and partly in the adhesive.

3. The tensile strength of Al coating

Figure 4 shows that the tensile strength of the Al coatings on the three kinds of substrates increases with the increasing of gas working temperature. The highest tensile strength of Al coatings was obtained on the stainless steel substrates although the strength of Cu and Ni powder was the lowest on the stainless steel substrates. The rupture of Al coatings on the three substrates almost occurred at the substrate-coating interfaces except for the stainless steel substrate at the gas temperature of 400°C (partly in the coatings and partly in the adhesive.) and 500°C (in the coatings).

4. Discussions

Although the bonding mechanism is not well understood, the hypothesis that bonding happens as the result of extensive plastic deformation and related phenomena at the interface is well accepted [3, 4]. The spray process can be considered consisted of two stages: spraying of the first layer of particles on a substrate (particle-substrate) and buildup of the coating (particle-particle). Therefore, the plastics deformations of the particles and substrates are both important for the coating forming. The results above show that the hardness of substrate has a significant influence on the bonding strength of particle-substrate. For the Ni powder, the bonding strength of interface between coatings and substrates increases with the decrease of substrates' hardness due to the deformation of the substrates easily, as shown in figure 2. Therefore, the rupture of deposits with Al substrate at 400°C occurred inside the coatings owing to the relatively strong coating-substrate strength, while rupture of the deposits for the other two substrates occurred at the coating-substrate interface. For the Cu powder, similarly to the Ni powder, soft substrate is better for the bonding strength of coating-substrate interface as shown in figure 3. However, for the relatively soft Al powder, the hardest substrate, stainless steel, acquired the highest bonding strength of coating-substrate as shown in figure 4. Maybe it is caused by the short impact time for the hard substrate, consequently a higher impact force.

The impact velocity and temperature of particles onto the substrate are the governing spraying factor for particle adhesion [3, 5]. Figure 5 shows that the measured velocity of in-flight particles increases with the increasing of gas working temperature. Therefore, the increasing of gas temperature not only raises the impact temperature, but also accelerates the impact velocity. As a result, the bonding strength of particle-substrate and particle-particle increased as shown in the figure 2 to 4.

Conclusion

The bonding strength of coating-substrate interface is significantly influenced by the hardness of substrate. On the other hand, the higher gas temperature is beneficial to the impact velocity and temperature of particles, consequently improving the bonding strength of particle-substrate and particle-particle.

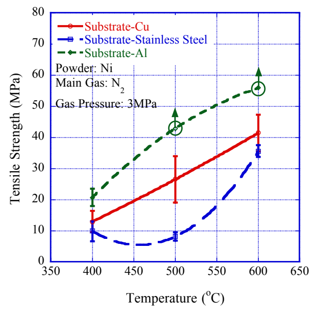


Figure 2: Tensile strength of Ni

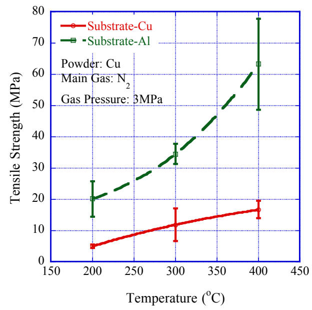


Figure 3: Tensile strength of Cu

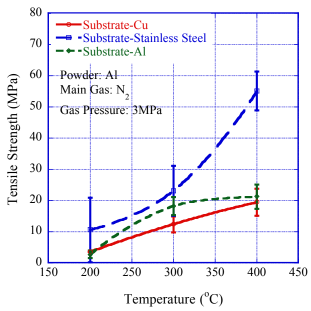


Figure 4: Tensile strength of Al

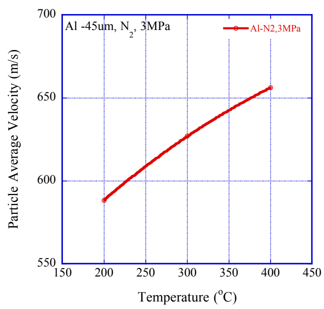


Figure 5: The In-flight particle velocity of Al

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