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FABRICATION AND MACROSCOPIC PROPERTIES OF FILLER METAL (BCuP-5) ON Cu-PLATE USING LASER CLADDING PROCESS

This study stacked a thin, dense BCuP-5 (Cu-Ag-P based filler metal) on a Cu-plate using the laser cladding (L.C) process to develop a method to manufacture Ag reducing multilayer clad electrical contact material with an Ag-M(O)/Ag/Cu/BCuP-5 structure. Then, the microstructure and macroscopic properties of the manufactured BCuP-5 coating layer were analyzed. The thickness of the manufactured coating layer was approximately 1.7 mm (maximum). Microstructural observation of the coating layer identified Cu, Ag and Cu-Ag-Cu_3P ternary eutectic phases like those in the initial BcuP-5 powder. To evaluate the properties of the manufactured coating layer, hardness and adhesion strength tests were performed. The average hardness of the laser cladded coating layer was 183.2 Hv, which is 2.6 times greater than conventional brazed BcuP-5. The average pull-off strength measured using the stud pull test was 341.6 kg/cm^2. Cross-sectional observation of the pulled-off material confirmed that the coating layer and substrate maintained a firm adhesion after pull-off. Thus, the actual adhesion strength of Cu/BcuP-5 was inferred to be greater than 341.6 kg/cm^2. Based on the above findings, it was confirmed that it is possible to manufacture a sound Ag reducing multilayer clad electrical contact material using the laser cladding process

Keywords: Laser cladding, BCuP-5(Cu-15Ag-5P), Microstructure, Switching device, Multi-layer

1. Introduction

Electrical contact material is used in parts that mechanically open and close circuits such as switching, relays and circuit breakers in the automotive, electronics and other industries [1]. Electrical contact material requires outstanding electrical conductivity, thermal conductivity and durability [2]. Meanwhile, one of the electrical contact materials, Ag(O)/Ag-based contact materials, are used in a wide current range covering low current up to high current.

In order to manufacture electrical contact material it is necessary to form a multilayer Ag-M(O)/Ag/BCuP-5 structure by bonding BCuP-5(Cu-15Ag-5P) filler metal to the bottom of the actual contact part, Ag-M(O)/Ag. In addition, there have been attempts to develop an electrical contact material with an Ag-M(O)/Ag/Cu/BCuP-5 structure to reduce the amount of the precious metal, Ag. At present, roll bonding and fusion bonding processes are commonly used to bond BCuP-5 to the bottom of the above-mentioned electrical contact material [3]. However, these processes have the issues of increased manufacturing costs due to difficult control and reduced usage life due to an easily formed uneven interface between the substrate and BCuP-5 layer. Therefore, it is necessary to develop a new process to bond BCuP-5 to electrical contact material.

Brazing filler metal is widely applied to Cu, Cu alloy and other alloys for the prevention of the formation of intermetallic compounds, the maintenance of clean surfaces and the adaptability to the shape and size of the joints [4]. Among many brazing filler metals, BCuP-5 filler metal is a representative brazing material as a substitute for silver based filler metal. This alloy is used as a brazing material in various fields such as ship, heat exchanger because of its excellent corrosion resistance, flowability, processability and spreadability [5]. Meanwhile, BCuP-5 filler metal is known to be used for brazing of Cu and Cu alloy because it can form a brittle phase on the surface when used in Ni based alloy and stainless steel [6].

Laser cladding is a thermal spray process which sprays powders melted by a laser beam on a substrate to form a coating layer [7]. This process can form an even interface between the substrate and coating layer, and it is also capable of forming a coating layer with high bonding [8]. These advantages allow laser cladding to be used in various fields including automobiles, aerospace and molding.

This study attempted to laminate BCuP-5 filler material on a Cu plate using laser cladding process to resolve the issues in conventional electrical contact materials. Furthermore, this study investigated the microstructure and key physical properties of the laser cladded BCuP-5 coating layer and reviewed possible applications.

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2. Experimental method

This study used BCuP-5 powder from Sun Kwang Brazing Filler Metal. To analyze the BCuP-5 powder, a size analyzer (masterisizer-2000) and XRF (X-ray Fluorescence Spectrometer, XSZ Primus II) were used.

To observe the microstructure and cross-section of the BCuP-5 coating layer laminated using laser cladding (laser cladded BCuP-5), the material was ground with SiC grinding paper (#400~#2000) and then mirror polished at 1 mm. Initial microstructure and phase analysis was performed using SEM-EDS (scanning electron microscope, VEGA II LMU), XRD (x-ray diffraction, Rigaku KRD Ultima IV) and TG-DTA (thermal analysis system, Rigaku TG-DTA 8122). To measure the internal porosity of the laser cladded BCuP-5 coating layer, 20 measurements were made using an image analyzer, and their average was taken.

To measure the hardness of the laser cladded BCuP-5 layer, a Vicker's hardness tester (AVK-C100) was used. Hardness measurement was performed at the cross-section of the coating layer, and the applied load was set to 0.5 kgf. Twelve hardness measurements were made and the average was calculated. To assess the bond strength between the laser cladded BCuP-5 coating layer and the substrate Cu-plate, a stud pull test was performed. First, the coating layer surface was ground evenly, and then stud pins were fixated to the surface, and heat treatment of 150°C was performed for 70 minutes to bond the stud pins. A stud-pull tester (Sebastian 4) was used to take five bond strength measurements, and their average was calculated. In addition, the surface and cross-section of the pulled-out sample were observed using FE-SEM (field emission scanning electron microscope, MYRA 3 XMH).

3. Results and discussion

Fig. 1 shows the analysis result of BCuP-5 (Cu-Ag-P-based filler metal) powder used in this study. BCuP-5 powder morphology and grain size distribution observation results (Fig. 1a, b) confirmed that the powder had a clean-surfaced spherical shape, and its average grain size (D_{50}) was 18.8 mm. XRD analysis results for BCuP-5 powder (Fig. 1c) show that the powder consists of Cu, Ag and Cu_3P phases.

Microstructural observation of cross-sectional BCuP-5 powder is shown in Fig. 2. Fig. 2a confirms that the initial powder consisted of a two-phase structure with a bright area and a relatively darker area. High magnification observation of powder microstructure results (Fig. 2b) confirmed that the relatively darker area had white particles with a few hundred nm size. Based on the EDS analysis of local areas (Fig. 2) and existing references, it was assumed that the relatively darker area is Cu phase, the relatively brighter area is Cu-Ag-Cu_3P ternary eutectic phase, and the white particles are Ag phase [9].

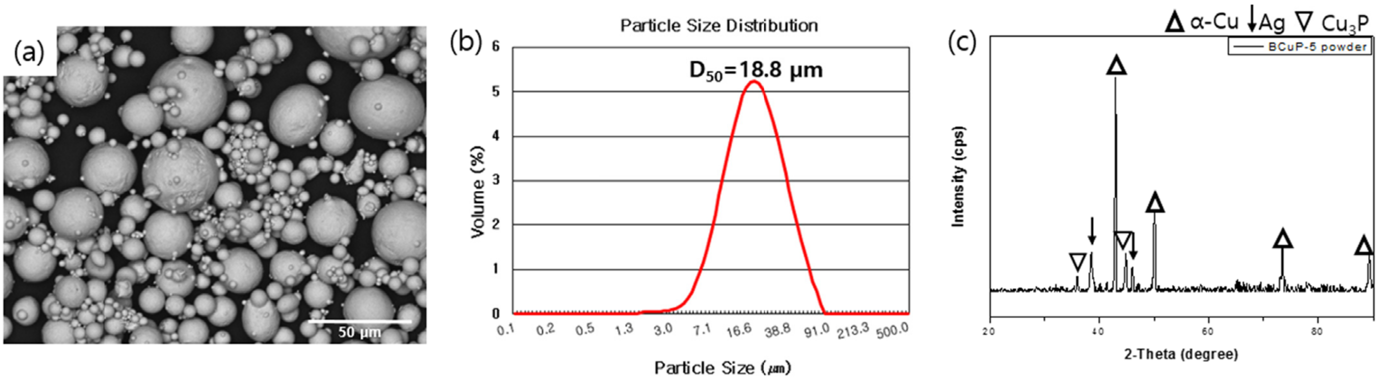
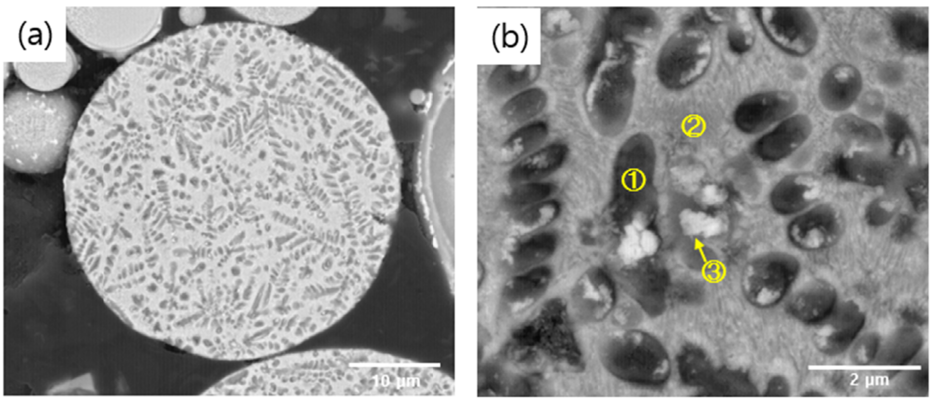


Fig. 1. (a) Morphology of the BCuP-5 powder particle, (b) particle size distribution and (c) XRD result of BCuP-5 powder



① Cu

Element	Wt%
P	1.0
Cu	86.5
Ag	12.2
Total	100

② Cu-Ag-Cu_3P

Element	Wt%
P	7.8
Cu	63.5
Ag	28.7
Total	100.0

③ Ag

Element	Wt%
P	2.0
Cu	31.5
Ag	66.5
Total	100

Fig. 2. SEM/EDS microstructures of BCuP-5 powder (a) low magnification and (b) high magnification

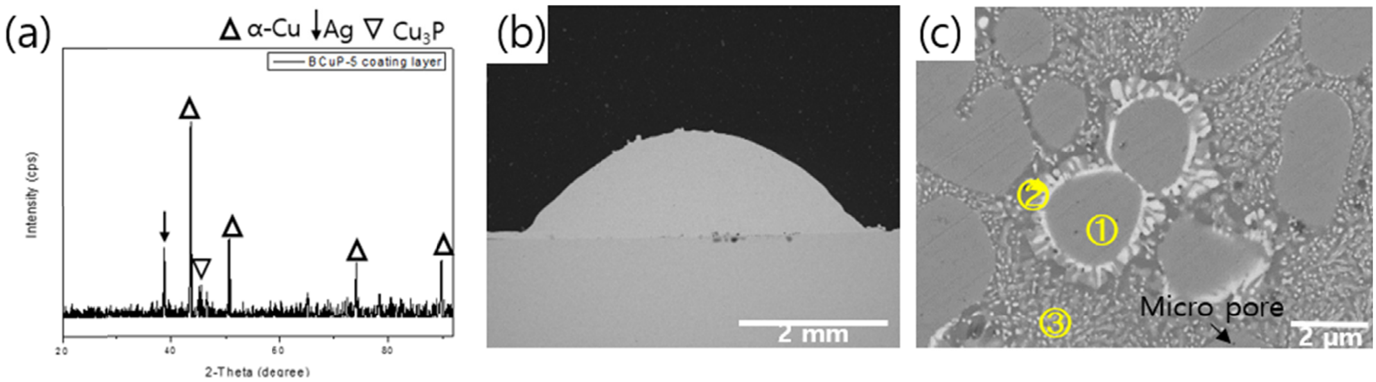
Multiple preliminary experiments were performed to form a BCuP-5 coating layer on Cu plate using laser cladding, and suitable conditions were defined. With the defined conditions (power source: 4 Kw, scan speed: 2 mm/s, powder RPM: 0.8, gas: Ar), BCuP-5 was laminated on a Cu plate with W×D×H of 11.5 cm×2.5 cm×1.5 cm. Fig. 3 is an image of the BCuP-5/Cu of 9 cm×0.5 cm (W×D) manufactured using laser cladding.

Fig. 3. Macro image of BCuP-5 coated on Ag plate using laser cladding process

Fig. 4 shows the cross-sectional analysis result of a laser cladded BCuP-5 coating layer. The XRD analysis results of the coating layer (Fig. 4a) confirmed that the BCuP-5 coating layer consists of Cu, Ag and Cu-Ag-Cu_3P ternary eutectic phase. Macro observation of the coating layer (Fig. 4b) confirmed that the maximum height is approximately 1.7 mm. Microstructural observations of the laser cladded BCuP-5 coating layer (Fig. 4c) identified a spherical dark gray area (① area), striped white area (② area) and a light gray area with white particles of a few nm (③ area). EDS analysis of each area confirmed that the dark gray area is Cu phase, white area is Ag phase, and light gray area is Cu-Ag-Cu_3P ternary eutectic phase. In addition, inside the laser cladded BCuP-5 coating layer, super-fine pores were observed, and their ratio measured 0.08%.

An EPMA analysis of the interface between the coating layer and substrate is shown in Fig. 5. With this analysis, it was confirmed that intermixing did not occur on the interface between the coating layer and substrate despite the fact that the coating layer was cladded at high temperatures.

To identify the microstructural difference between the BCuP-5 powder and laser cladded BCuP-5 coating layer, thermal analysis was performed on the initial powder and laser cladded BCuP-5 coating layer, and the results are shown in Fig. 6. Thermal analysis confirmed that the initial powder (Fig. 6a) began phase change at approximately 642.3°C, and the laser cladded



① Cu

Element	Wt%
P	2.3
Cu	85.0
Ag	12.7
Total	100

② Cu-Ag-Cu_3P

Element	Wt%
P	6.2
Cu	64.7
Ag	29.1
Total	100.0

③ Ag

Element	Wt%
P	1.7
Cu	40.2
Ag	58.1
Total	100

Fig. 4. Results of coating layer observation (a) XRD and (b, c) SEM/EDS

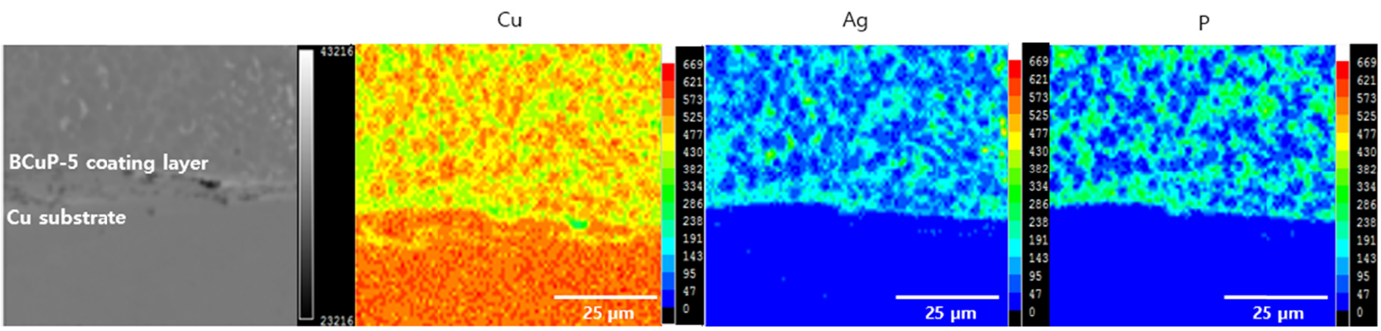


Fig. 5. EPMA analysis results of BCuP-5/Cu substrate

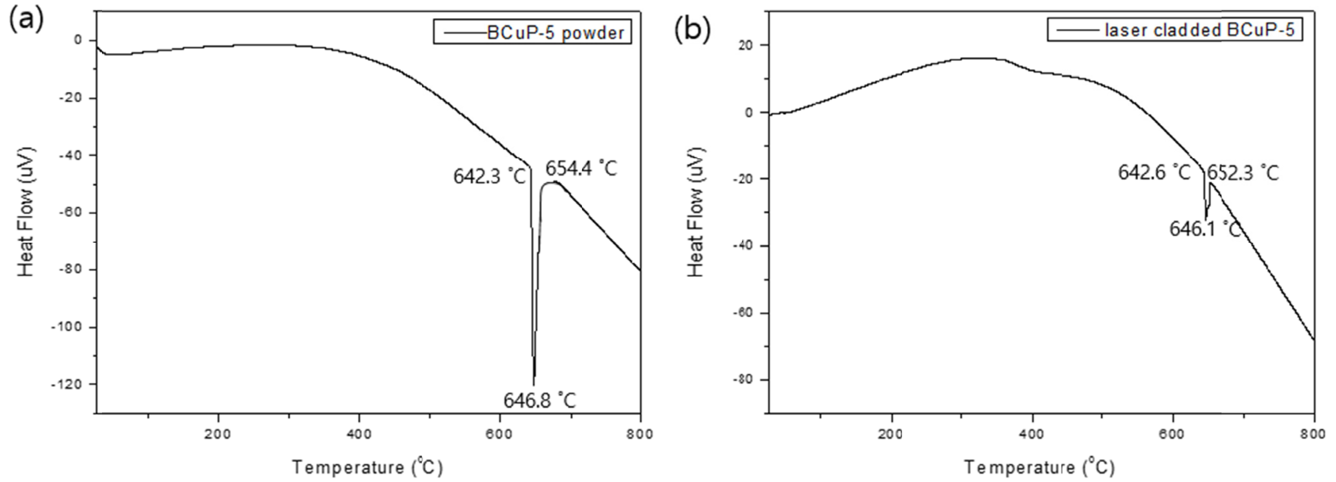


Fig. 6. TG/DTA results (a) BCuP-5 powder and (b) laser cladded BCuP-5 coating layer

BCuP-5 coating layer (Fig. 6b) began phase change at approximately 642.6°C. In general, BCuP-5 alloy is known to consist of Cu phase, Ag phase and Cu_3P phase from room temperature up to approximately 640°C, and at higher temperatures, it is known to have phase change due to the melting point of Cu_3P [5]. In other words, the two materials (powder and coating layer) began melting at nearly the same temperature. Based on this finding, it was confirmed that the laser cladded BCuP-5 coating layer can be used as filler metal material.

The size and morphology of the powder and process parameters are known to have an influence on the porosity, hardness and bond properties of the coating layers manufactured using laser cladding. The hardness of the powder feedstock and laser cladded BCuP-5 coating layer were measured, and their averages were calculated as 102.1 Hv (powder feedstock) and 183.2 Hv (coating layer). In other words, the hardness of the laser cladded BCuP-5 coating layer is greater than the hardness of BCuP-5 powder and conventional BCuP-5 alloys manufactured with brazing (71.0 Hv). This result is suspected to be due to the suitable condition control and greater cooling rate of laser cladding that resulted in the formation of a denser coating layer [10].

The bond strength of the laser cladded BCuP-5/Cu material was measured as 34.2 MPa. The SEM-EDS observation of the sample surface pulled out after the stud pull test (Fig. 7a) measured high concentrations of BCuP-5 composition elements, Cu, Ag and P. In other words, even after the stud pin fixated to the coating layer was pulled out, the BCuP-5 coating layer remained bonded to the Ag plate. This finding suggests that the interface area which was initially considered to be the weak area is actually bonded more strongly than the coating layer interior. Cross-sectional observation after stud pull (Fig. 7b) also confirmed that the BCuP-5 coating layer and Ag plate are still bonded. With these findings, it is suspected that the actual bond strength of Ag/BCuP-5 will be greater than the measured 34.2 MPa. Considering that the bond strength of commercial electrical contact materials are reported to be around 20~30 MPa [11], the laser cladded BCuP-5 coating layer achieved greater bond strength.

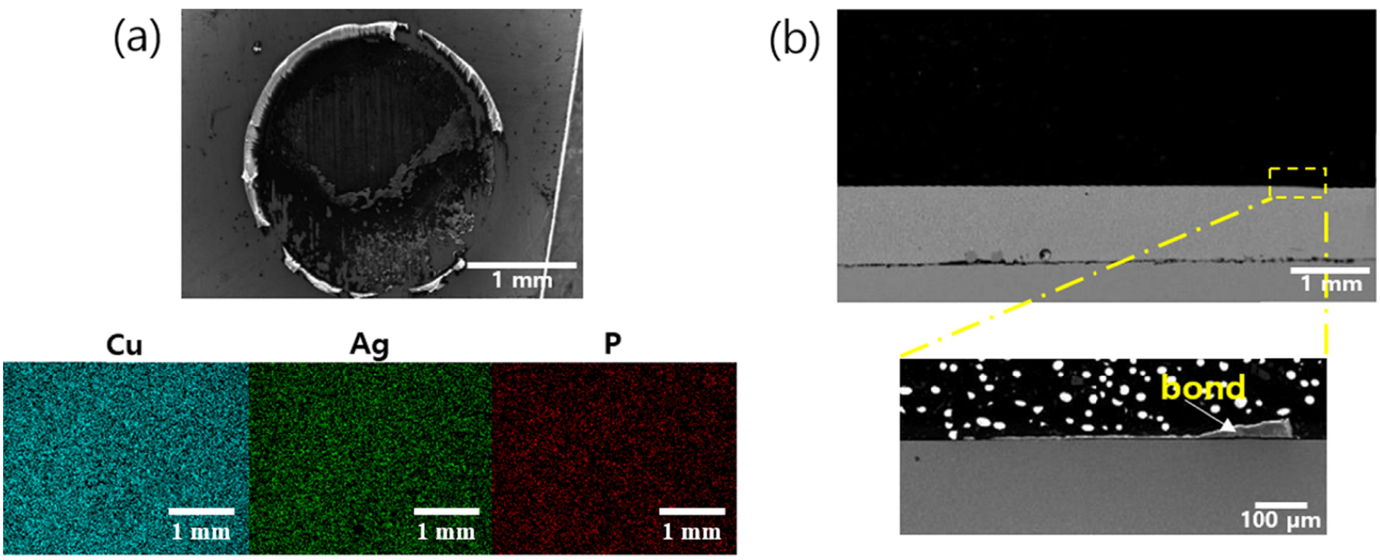


Fig. 7. SEM observation results of pull outed specimen (a) surface image and (b) cross-sectional images

Based on the above manufacturing results and physical properties, it is confirmed that laser cladding can be applied successfully in manufacturing a multilayer clad electrical contact material filler metal coating layer.

4. Conclusion

This study laminated a BCuP-5 coating layer on a Cu-plate using laser cladding, and after analyzing the microstructure and properties of the manufactured material, the following conclusions were drawn:

1. Microstructural observation confirmed that the BCuP-5 powder and laser cladded BCuP-5 coating layer are both composed of Cu, Ag and Cu-Ag-Cu_3P ternary eutectic phases. Cross-sectional observation of the manufactured coating layer measured a maximum coating layer thickness of 1.7 mm, and the internal porosity of the coating layer measured approximately 0.08%.
2. The hardness of BCuP-5 and the laser cladded coating layer measured 102.1 Hv and 183.2 Hv, respectively. The high hardness of the laser cladded BCuP-5 coating layer is suspected to be due to suitable condition control and a high cooling rate. In addition, the melting point of the coating layers is confirmed to be nearly identical to that of the initial powder. In other words, the laser cladded BCuP-5 coating layer can be used as an electrical contact material filler metal.
3. The interface bond strength between the Cu layer and BCuP-5 coating layer measured 34.1 MPa. The bond between the Cu layer and BCuP-5 coating layer remained after the bond strength test, and it is suspected that the actual bond strength of Cu/BCuP-5 will be greater than 34.1 MPa.

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