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EFFECT OF STAGNATION TEMPERATURE ON MECHANICAL PROPERTIES OF CU+AL_2O_3+ZN COATINGS PRODUCED BY LOW PRESSURE COLD SPRAY PROCESS

1. Introduction

The cold spraying technique was developed in the Soviet Union in the 80's. Mainly, the process is characterized from other Thermal Spraying coating techniques from the use of much more lower operative pressures and significantly lower process temperatures. The coatings are formed when powder materials are accelerated to supersonic velocities by the use of a convergent-divergent nozzle to consequently be impacted on a substrate; the bonding phenomena has been a controversial point of discussion, but there is an agreement on that bonding is due a high degree of plastic deformation on non melted particles during their impact [1].

The Low Pressure Cold Spraying Technology (LPCS) is characterized for using air as the accelerated fluid with inlet pressures from 5 to 9 atm and a top temperature that reaches the 630 Celsius. The acceleration of the particles through the diverging gas-stream is due the resultant drag force applied to their surfaces; this approach converge in the idea that not only the gas velocity is the responsible for particles acceleration, but the density of the gas as well which is dependent on the Mach number of the accelerated stream [2]. In LPCS a wide range of powder materials (i.e. Cu, Al, Ni, Zn) can be co-sprayed with ceramic particles as Al_2O_3 [3]. The main reasons for using ceramic particles are: to propagate the surface activation while spraying and to clean the nozzle while metallic particles are hammered and better deformed in the process in comparison of spraying them without ceramics; different studies [3-5] have shown that the addition of ceramic particles give results on better coatings adhesion and better density; for this reason it is acceptable to say, that the ceramics addition to the metallic matrix in the LPCS process acts as a reinforcement for the MMC (Metal Matrix Composite) [6].

The aim of this study was to characterize the micro-structure and mechanical properties of Cu+Al_2O_3+Zn coatings in order to get more information about their adhesion strength and micro-hardness dependent on their spraying temperature.

2. Experimental Procedures

In this investigation a C-01-11 (65% wt. %Cu+10 wt.%Al2O3+25 wt.%Zn) commercial powder (Fig. 1) from Obnisk Center for Powder Spraying (OCPS) was sprayed with a DYMET 405 Cold Spraying equipment available at the National Aerospace University of Ukraine. Aluminum 2024 substrates with a diameter of 24.7 mm for Adhesions tests and 50 x 30 mm substrates for metallographic studies were prepared for spraying with sanding paper P360. The SK-20 Nozzle with an Exit Diameter of 4.9 mm was used to accelerate the powder within three different stagnation temperatures - 424 C, 526 C and 632 C. Five different specimens sets were prepared in order to spray them at different stagnation temperatures.

The Coatings were characterized using a SELMI REM-106 Scanning Electron Microscope (SEM). The ASTM E3-01 for Preparation of Metallographic Specimens was followed for the substrates of this study; the specimens were etched using dilute hydrochloric acid (HCl) in order to better distinguish the borders of the deformed particles. The Deposition Efficiency was measured for each Stagnation Temperature under the standard ISO 17836-2004.

Mechanical testing was performed on the coatings in order to determine their adhesive-cohesive strength and micro-harnesses. A tensile strength machine was used in order to determine the Adhesive-Cohesive strength of the coatings according to the ASTM 633 Standard; four tests per coating were performed to determine the average adhesive-cohesive strength at every stagnation temperature. Micro-Hardness tests were also performed under the ASTM E92 Standard (Standard Test Method for Vickers Hardness of Metallic Materials).

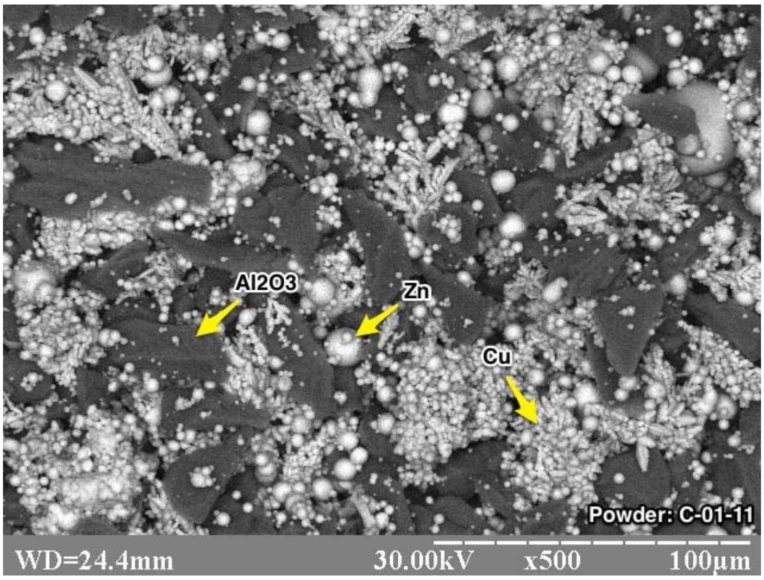

Figure 1 - Morphology of powder C-01-11 Powder in a blend of 65%wt.%Cu+10wt.%Al_2O_3+25wt.%Zn provided by OCPS

3. Metallographic analysis of Coatings

The LPCS coatings were prepared for metallographic analysis under the ASTM E3-01 standard [7] to consequently be observed in a SEM Microscope. Fig. 2 Shows the SEM images at the 200x Amplification for specimens sprayed at 424 C (a), 526 C (b) and 632 C (c). In the microstructure the black particles are non-deformed Alumina particles that were impregnated into the coating. The thickness of the C-01-11 coatings was 200 microns. From visual inspection the coatings to be dense without any noticeable porosity. It is not possible to recognize the powder particle boundaries in the microstructure, for this reason it is etched with dilute hydrochloric acid (HCl). The flattened shaped particles, indicates a high degree of deformation. Despite the high density of the coatings, some open boundaries can be detected near the coating surface and some oxidized boundaries can be spotted within the coating structure. The oxidation layers can be attributed to the electrolytic feedstock powder production method; this is common for dendritic powders which because their morphology, have larger surface area than spherical particles produced by the atomized method. The Air used as operating gas can cause another oxidation source. Black particles within the coatings structure are the Al_2O_3 part of the powder blend.

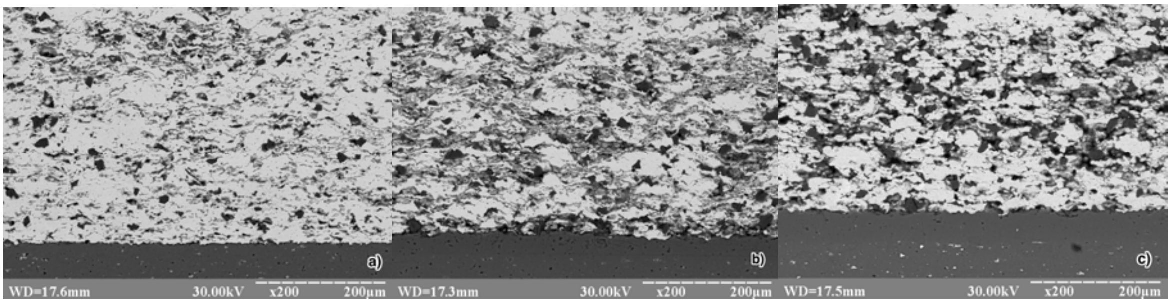

Figure 2 - SEM images at the 200x Amplification for specimens sprayed at 424 C (a), 526 C (b) and 632 C (c). In the microstructure the black particles are non-deformed Alumina particles that were impregnated into the coating

4. Mechanical Properties of Coatings

Mechanical testing was performed on the coatings in order to determine their adhesive-cohesive strength and micro-harnesses. A tensile strength machine was used in order to determine the Adhesive-Cohesive strength of the coatings according to the ASTM 633 Standard; four tests per coating were performed to determine the average adhesive-cohesive strength at every stagnation temperature. Micro-Hardness tests were also performed under the ASTM E92 Standard (Standard Test Method for Vickers Hardness of Metallic Materials).

4.1 Bond Strength

The ASTM C 633 standard for Adhesion or Cohesion Strength of Thermal Spray coatings [8] studies the adhesion strength for coatings sprayed at different stagnation temperatures. The C-01-11 powder blend was sprayed at different spraying stagnation temperatures - 424 C, 526 C and

632 C - with a constant stagnation pressure of 0.8 MPa with the DYMET 405 Low Pressure Cold Spraying equipment.

Under the ASTM C 633 specifications 5 testing samples for each stagnation temperature were studied. Epoxy ED-20 was selected for this study and tested for its maximum adhesive strength presenting 22 MPa (SD 3) of adhesive bonding strength. Test samples were prepared for the spraying operation with sanding paper P360. Coatings of ≈350μm were evenly applied on the test sample. Tensile specimens were assembled as specified in ASTM C 633 using the Epoxy ED-20, which was curated in 12 hours at ambient temperature. Fig. 4.1 shows an image of a tensile specimen allocated into a self-aligning device before the tensile strength test operation.

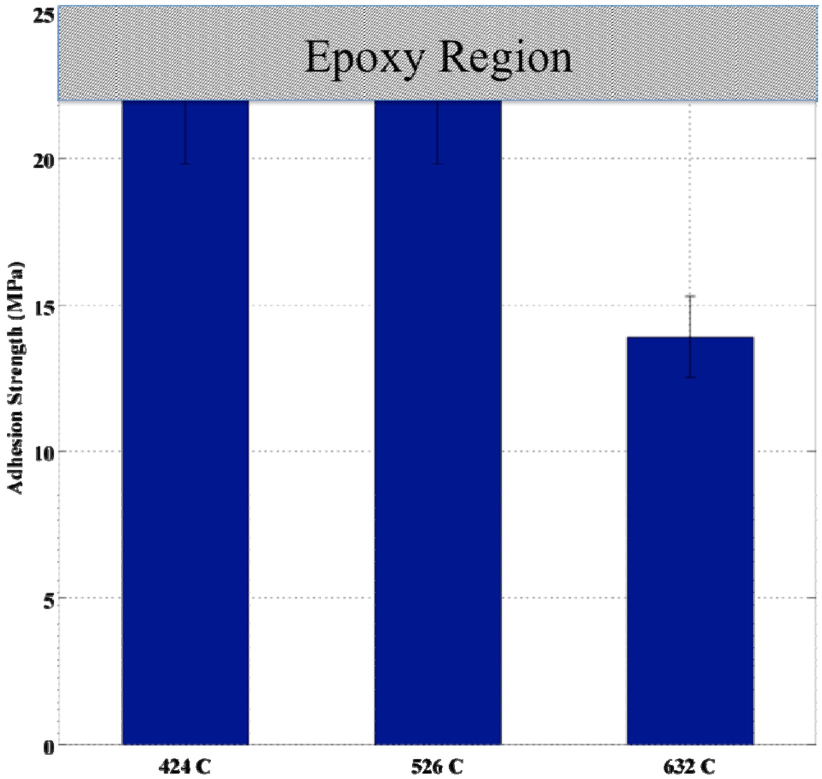

Figure 3 – Adhesion test results for C-01-11 coatings sprayed at different stagnation temperatures

Tensile strength was applied for each of the specimens with five runs for each stagnation temperature and material configuration. Fig. 3 shows the results of the adhesion strength study. C-01-11 coatings present better adhesive strength at stagnation temperatures of 424 C and 526 C with failure in the epoxy; at the stagnation temperature of 632 C the coating presents adhesive failure at ≈14 MPa.

4.2 Micro-Hardness

The micro-hardness for coatings sprayed at different stagnation temperatures is studied under the ASTM E92 Standard (Standard Test Method for Vickers Hardness of Metallic Materials) [9]. The C-01-11 powder blend was sprayed at different spraying stagnation temperatures - 424 C, 526 C and 632 C - with a constant stagnation pressure of 0.8 MPa with the DYMET 405 Low Pressure Cold Spraying equipment. The Vickers hardness was determined using a load of 50gr. for all the samples. Fig. 4 shows the results for micro-hardness readings.

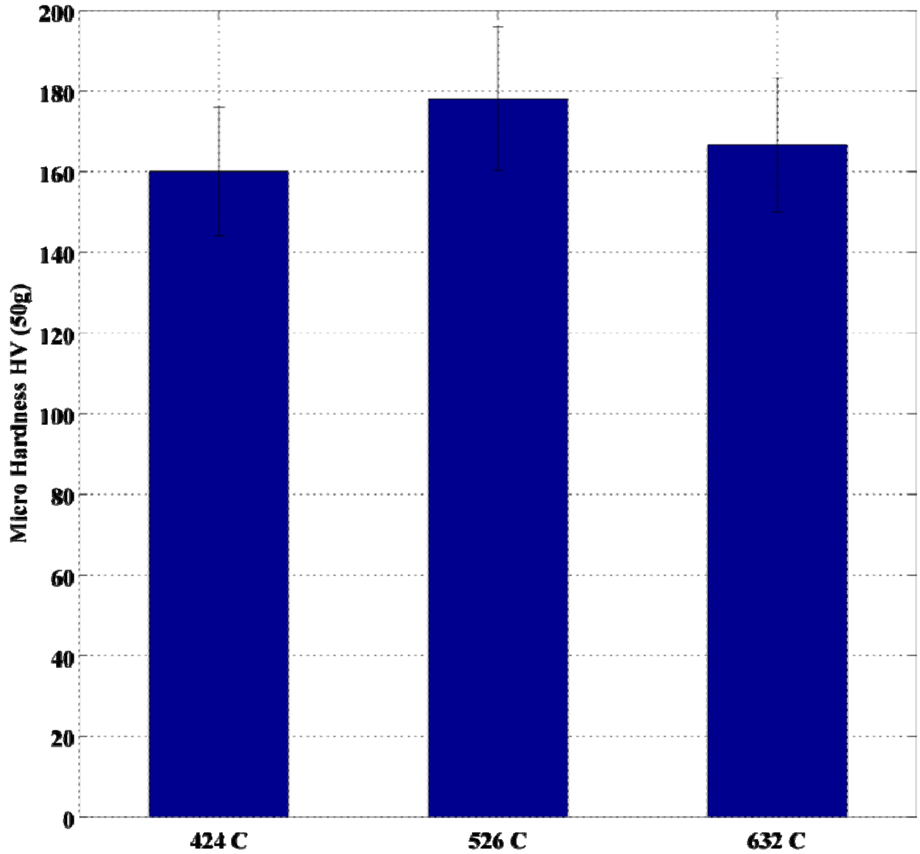

Figure 4 – Results of micro-hardness readings

Conclusion

In this work, the characterization of Low Pressure Cold Sprayed coatings at several stagnation temperatures was presented. The C-01-11copper based material powder MMC blend was sprayed at different stagnation temperatures - 424 C, 526 C and 632 C - and a constant stagnation pressure of 0.8 MPa using the Dymet 405 Cold Spraying system. The coatings were applied onto Aluminum 2024 substrate specimens. The ASTM E3-01 standard was applied in order to prepare the specimens for metallographic study; the study reveled an increase on strain when the powder material was sprayed at higher stagnation temperatures. The standard ASTM C 633 was used in order to determine the bond strength of coatings sprayed at the different stagnation temperatures; the adhesion strength of the coatings was higher than the adhesion strength of the epoxy while presenting adhesive failure at the epoxy zone at stagnation temperatures of 424^0C and 526^0C; at the stagnation temperature of 632^0C there was a decrease in adhesive bond strength presenting adhesive failure at ≈14 MPa. The ASTM E92 Standard was applied in order to determine the micro hardness of coatings; C-01-11 coatings presented an increase in micro hardness when spraying it at higher stagnation temperatures. Further research is recommended in order to determine the yield adhesion strength of C-01-11 coatings.

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