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Influence of Cold Spray Nozzle Displacement Strategy on Microstructure and Mechanical Properties of Cu/SiC Composites Coating

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Abstract. In this work an influence of cold spray nozzle displacement parameters on the properties of copper-silicon carbide cold spray deposits is considered. In particular the influence of nozzle traverse speed and distance between deposited tracks on the coating porosity and behavior during compressive tests was analyzed. It was shown that cold spraying at low nozzle traverse speed leads to formation of thick tracks with quasi-triangular cross-section. As a consequence, the particle impact angle on the sides of spraying track increases that. Thus, the particle deformation at impact on the track periphery becomes insufficient and local porosity value rises. Increase of nozzle traverse speed allows increasing coating density and mechanical properties due to amelioration of particle deformation conditions. Compressive tests revealed significant anisotropy of mechanical properties of copper-silicon carbide cold spray deposits. In particular, compressive strength measured in vertical direction (perpendicular to the substrate) was significantly higher than one measured in horizontal plane (parallel to substrate). This anisotropy could be explained by the orientation of particle deformation pattern during impact.

Introduction

The cold spray (CS) technology is a technique of a solid-state coating deposition using high velocity and preheated gas flow (typically nitrogen or helium) for acceleration of micron-sized particles of powder through converging-diverging supersonic nozzle. This process is operated at relatively low temperatures and high impact velocities, that leads to the powder bonding and formation of deposits on the substrate due to sever plastic deformation of the powder [1-5]. The initial patent of the CS introduced cold spray as coating deposition technology, however further researches demonstrated its potential in the field of additive manufacturing. [6-8]. The advantages of this process is that the temperature of the impact particles is far lower than the melting point contrary to the conventional thermal spray and additive manufacturing methods that offers a formation of low-oxide deposits with low porosity and little or no changes in phase composition in comparison with initial powder [9].

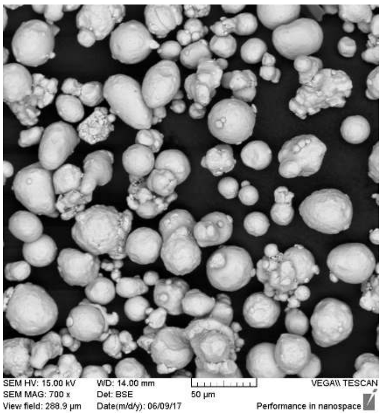
In general cold spray is used for production of metal deposits. However, possibility of deposition of metal-ceramic composite coatings by spraying of different mixtures of metal and ceramic powders was also studied [10-15]. In this case the adhesion of the metal to the substrate as well as primary matrix formation is ensured by the plastic deformation of metal particles, whereas the ceramic particles sticks to the surface by mechanical anchoring mechanism and form hard inclusions in softer metal binder [15-17]. Previous studies showed that addition of ceramic powder to the metal ones increases the coating adhesion and density; ameliorate its mechanical properties and corrosion resistance, mechanical properties and the corrosion resistance in comparison of the cold spray deposits of the same but pure metal without ceramic inclusions [10-17]. Several studies also revealed increased performance in wear resistance behavior. For example in the work of Triantou et al. [16] devoted to comparison of pure copper and copper-alumina cold spray deposits the authors found that wear resistance of composite deposits is higher due to the presence of alumina in copper matrix. In addition, the hardness, the density and the corrosion resistance was also improved.

It is also known that the strategy of nozzle displacement influences the properties of cold spray deposits. In particular spraying at lower nozzle displacement speed leads to formation of thicker single tracks that could lead to decrease of deposition efficiency and coating density. However, previous study of influence of fabrication strategy on the propertied of cold spray deposits was performed for the deposition of metal powders, whereas no experimental tests were done for the metal-ceramic powder mixtures.

The aim of this work is to perform a comparative study of microstructure and mechanical properties of cold sprayed Cu/SiC coating with different nozzle displacement strategies. The work was performed in the frame of "COCONUT" research project supported by ANDRA agency [18].

Experimental Procedure

Annealed low carbon steel plates with the dimensions 50×100×5 mm were as a substrate. Deposits were produced using powder blend containing copper (70 wt. %) and silicon carbide (30 wt. %). The particle size distributions of SiC and Cu powders size was 15±5 and 38±5 µm respectively. SEM images of powders are presented in Fig. 1. Before spraying, the surfaces of the substrates were treated by grit blasting (Mesh 14 grains of alumina at 10 bars as stagnation pressure in the jet). Mean roughness of the surface after grit blasting was equal to S_a = 18 µm. The deposits were produced using CGT Kinetiks 4000 commercial cold spray system equipped with Type 24 supersonic nozzle. Nitrogen was used as working and powder carrier gas. The process parameters are given in table 1. Two different nozzle displacement speeds were used: 5 mm/s (slow spray strategy) and 20 mm/s (fast spray strategy). It should be noted that the height of single track for the "slow" nozzle displacement strategy was 4 mm whereas for "fast" one it was near 1 mm.



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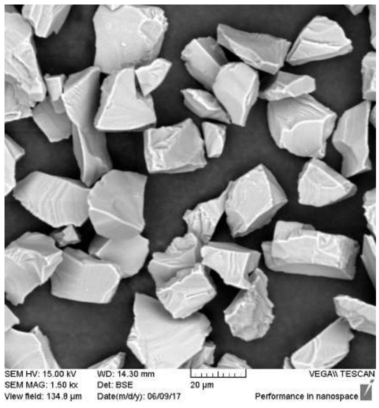


b

Fig. 1. SEM images of copper (a) and silicon carbide (b) powders used in experiments

Table 1. Spraying parameters used for copper-silicon carbide deposition

Strategy	Nozzle traverse speed (mm/s)	Number of layers	Hatch distance (mm)	Gas pressure (bar)	Gas temperature (°C)	Spray distance (mm)
Slow	5	2	2	35	500	30
Fast	20	8				

The resulting thickness of deposits was 16 mm that corresponds to 8 mm per layer for slow strategy and 2 mm per layer for fast strategy.

The obtained specimens were cut, polished and etched and then, observed by scanning electron microscope (SEM). Also, the mechanical properties (micro-hardness, compressive strength and tensile strength) were examined. Fig. 2 shows the dimension of the samples for the tensile and compression tests and their orientation relatively nozzle displacement.

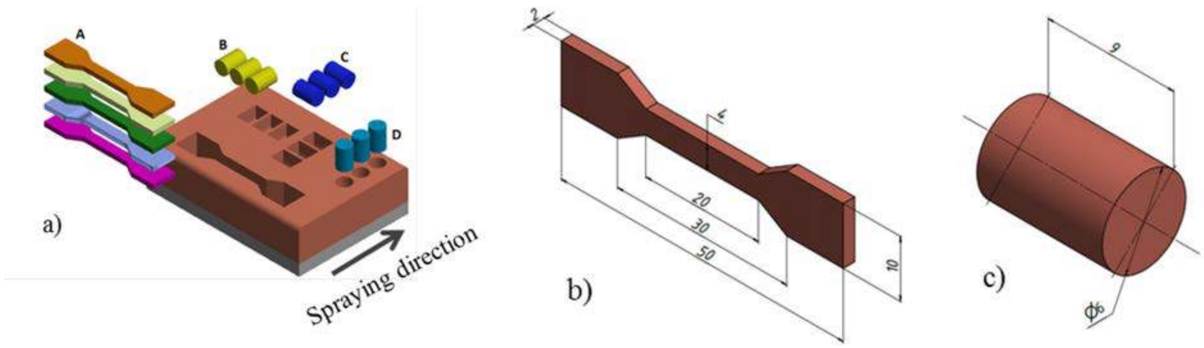


Fig. 2. Samples for mechanical tests: a – general overview of sample orientation relatively nozzle displacement, b – dimension of samples for tensile tests, c – dimension of samples for compression

Results and Discussion

Microstructure analysis. The SEM images etched specimens deposited at slow and fast strategies are presented in Figs. 3 and 4. The coating/substrate interface was hardly deformed during grit blasting. No signs of coating delamination or cracking at the interface were found for both samples.

At the same time the sample produced at "slow" deposition strategy has significant defects. In particular some zones in the deposit cross-section have a columnar structure with clearly visible voids between the columns. These zones correspond to the areas of connection between superposed tracks. Due to extremely high height of single tracks, the impact of particles on the track size occurred at very sharp angles that leaded to poor cohesion between them in horizontal plane.

In case of spraying at "fast" strategy, no column structure was detected. Reasonable height of single track allowed keeping all time the particle impact angle higher than 60° that resulted in formation of dense deposits with some small defects only at the periphery.

Micro-hardness measurements. The micro-hardness level of the composite deposits was measured in direction from the coating surface to the substrate with a load of 250 g. The average result curves were obtained for 5 lines of measurements and the standard deviation and confidence interval were calculated. The results of the measurements of the "slow" and "fast" strategy deposits are shown in Fig. 5. The micro-hardness level of the Cu-SiC coatings varies in a range from 60 to 130 HV with no particular difference between two spraying strategies. Some hardness increase induces by grit blasting was detected in the substrate at the near surface area.

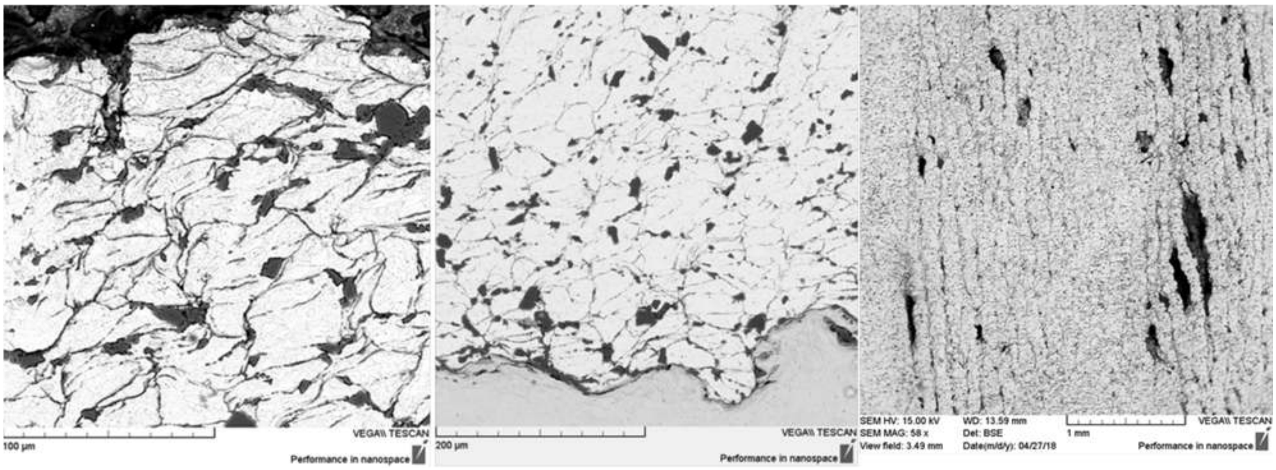


Fig. 3. SEM images of deposit produced at “slow” strategy (5 mm/s, 2 layers): upper layer (left), bottom layer (middle) and defects in side of upper layer (right).

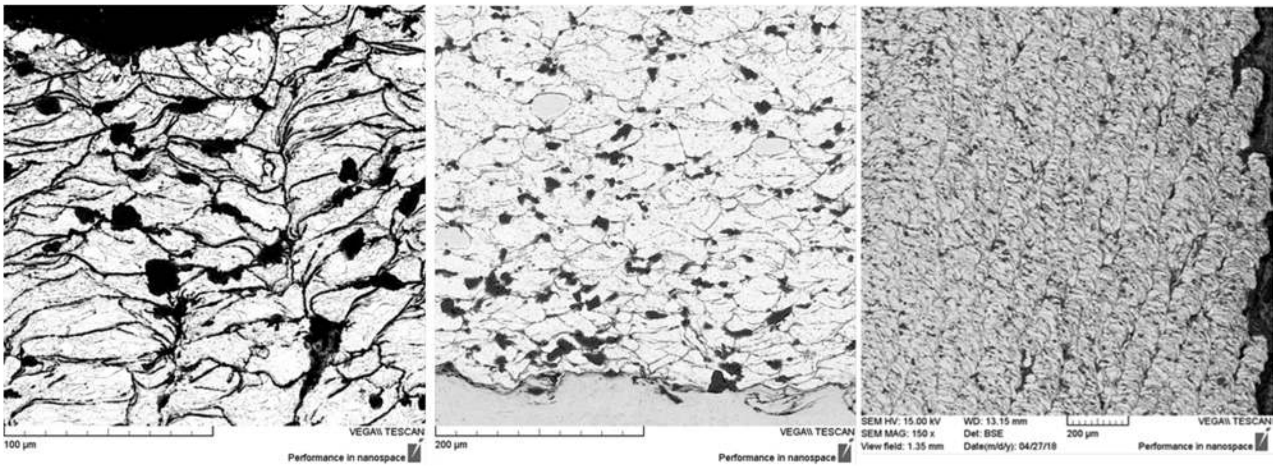


Fig. 4. SEM images of the deposit produced at “fast” strategy (20 mm/s, 8 layers): upper layer (left), bottom layer (middle) and side of upper layer (right).

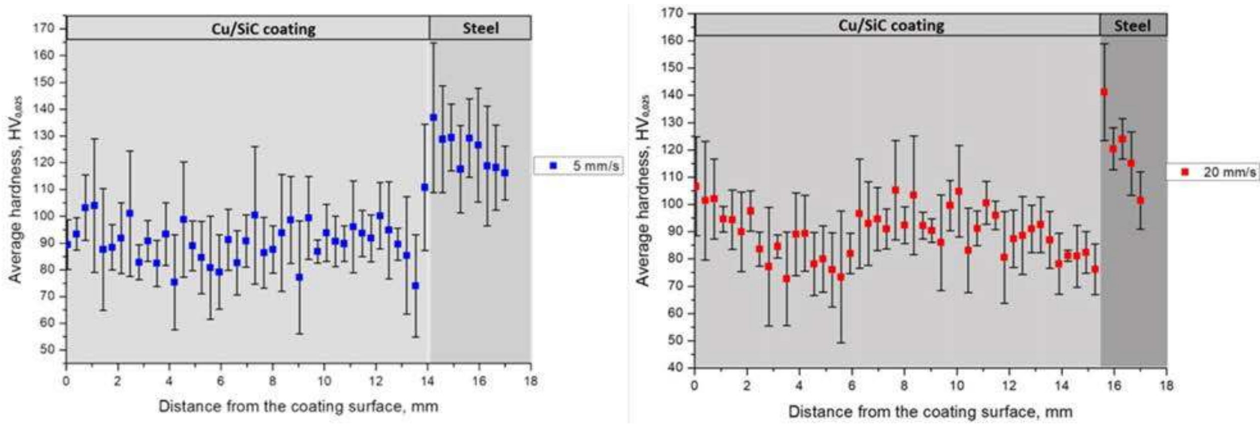
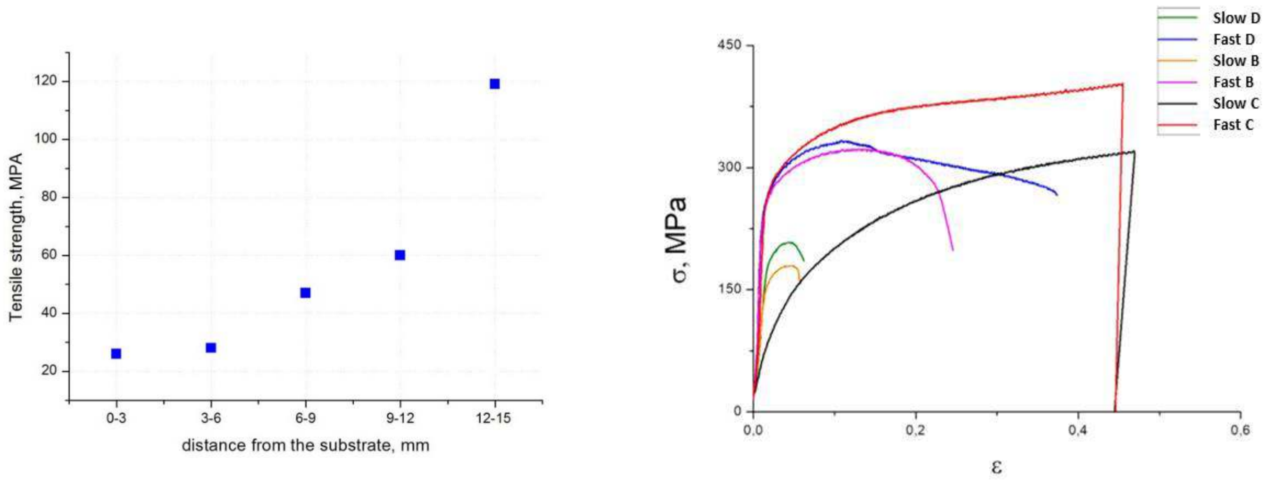


Fig. 5. Micro-hardness distribution in the 2 composite coatings: deposited at “slow” strategy (left) and “fast” strategy (right).

Tensile tests. Unfortunately the tensile strength of deposit produced at “slow” spraying strategy was not measurable due to very high frigality of the material: the samples were broken during fixation in tensule test machine. However, the fast strategy specimens were successfully tested. The obtained results are shown in Fig. 5. The samples have gradient distribution of ultimate tensile strength which is increased in direction from the surface of the coating to the substrate. It is supposed that this effect can be explained by densification of the bottom layers of the coating during deposition of upper layers.



a b

Fig. 6. Mechanical tests of the samples: a – tensile tests of the sample deposited at "fast" strategy, b – compressive tests of the samples deposited at fast and slow strategies

Compressive tests. Mechanical behavior of the composite coatings was also studied under a compressive load. Orientation of samples relatively build direction is mentioned in Fig. 2. Fig. 6 represents the stress-strain curves (σ-ε). In order to compare the slow and fast strategy samples the average curves were built. It is clearly seen the fast strategy allows formation coatings with higher compressive strength in all tested direction. At the same time anisotropy of compressive strength for both cases was detected. Furthermore, in similar spray conditions, a study has shown that, the ultimate strength of cold sprayed pure copper varies from 26 up to 87 MPa depending on its distance to the interface and its orientation according to the spraying direction [19].

Conclusion

The cold spray deposition strategy influence strongly on the quality of the coatings such as their microstucture and mechanical properties. As the main conclusion of the performed work, it is suggested optimization of the cold spray parameters such as nozzle traverse speed. The highest mechanical properties and coating quality was observed for the coating sprayed at 20 mm/s nozzle traverse speed.

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