International Journal of Research Publication and Reviews, Vol 5, no 1, pp 730-735 January 2024

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

# Mechanical Behavior of Nanomechanical Variations of Cold-Sprayed Tantalum Coatings

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**ABSTRACT:**

This work however uses a non-contact method of calibration which saves the cantilever tip from potential damages, saving the results from the detrimental effects of tip topography. The work also discusses the effects of local sample deformation and volume of tip-surface contact on local changes in Young's modulus at the interface of coating and substrate. This work uses Electron micro-probe analysis (EPMA) to show the presence of oxides at the interface. The presence of oxides changes the bond energy as compared to a pure tantalum bond; ultimately affecting the local modulus mapped using AFM. The effect of oxides on the local modulus at the coating-substrate interface is theoretically discussed.

## 1. Introduction

AFM is highly dependent on topographical features as the cantilever tip-sample interaction can vary, causing variations in the property mapped. This work however uses a non-contact method of calibration which saves the cantilever tip from potential damages, saving the results from the detrimental effects of tip topography. The work also discusses the effects of local sample deformation and volume of tip-surface contact on local changes in Young's modulus at the interface of coating and substrate. This work uses Electron micro-probe analysis (EPMA) to show the presence of oxides at the interface. The presence of oxides changes the bond energy as compared to a pure tantalum bond, ultimately affecting the local modulus mapped using AFM. The effect of oxides on the local modulus at the coating-substrate interface is theoretically discussed. different velocities and angles were deposited onto the material surface when the fluid velocity had reached a certain critical value. This new process is termed as "cold spray (CS)" [1]. Figure 1 shows a historic development of the Cold spray process.

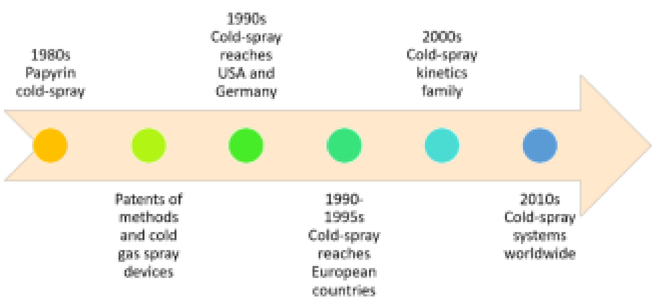


**Figure 1:** Development of the CS process [1]

## 2. Advantages of CS over thermal spray techniques

As indicated in Figure 2, Cold Spray techniques have a lower operating temperature as compared to thermal spray techniques. Due to this reason porosity and oxide formation. can be reduced in CS techniques. However, there can be traces of oxides in CS coatings, which are:

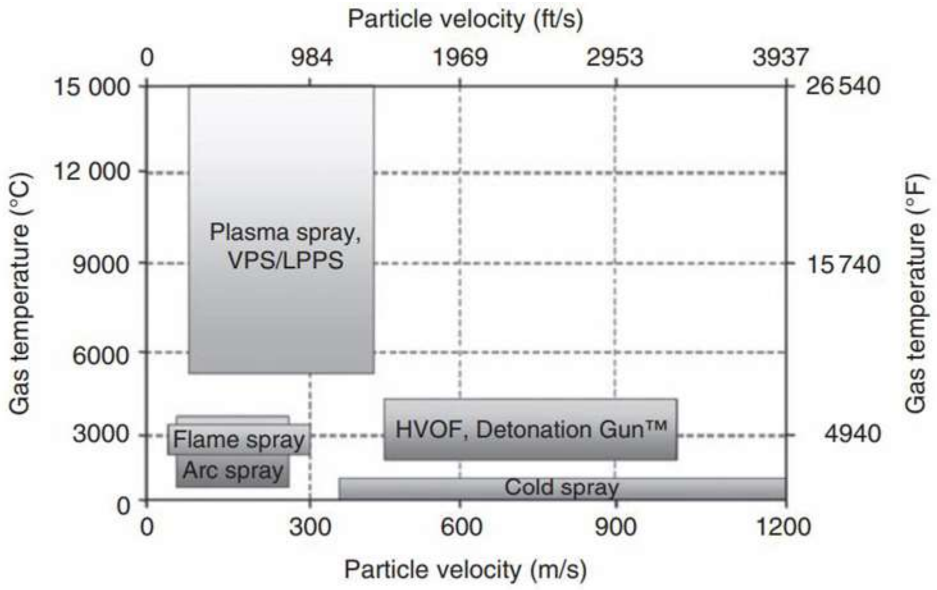


**Figure 2:** Gas temperature comparison of thermal spray techniques and CS [2]

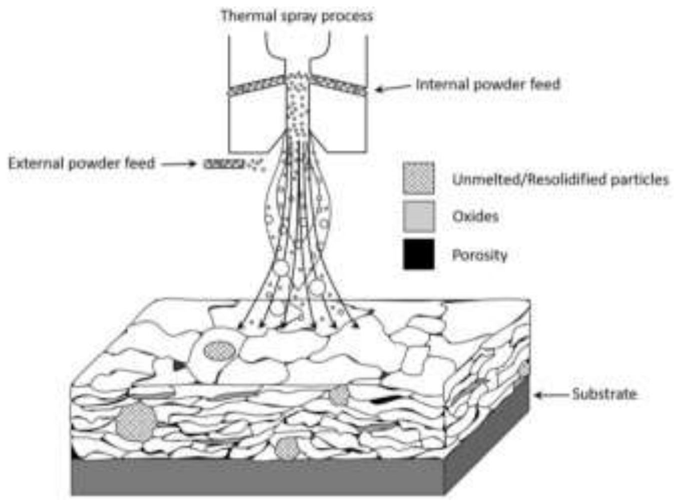


**Figure 3:** Schematic representation of oxide and porosity formation in thermally sprayed coatings [3]

The significantly reduced porosity results from the absence of splashing and its solid-state impacting nature supports its ability to have lower levels of porosity. As the metals are deposited on a molten or semi-molten state on the substrate, there is an increased chance of oxide formation on the coating unlike in CS where the metals are not molten and is impinged in the solid state. Figure 4 supports a demonstration of these phenomena. Due to the solid – state attachment nature of CS, it mostly maintains the initial phases, unlike thermal spray techniques. Also, CS does not experience much grain growth, unlike thermal spray techniques.

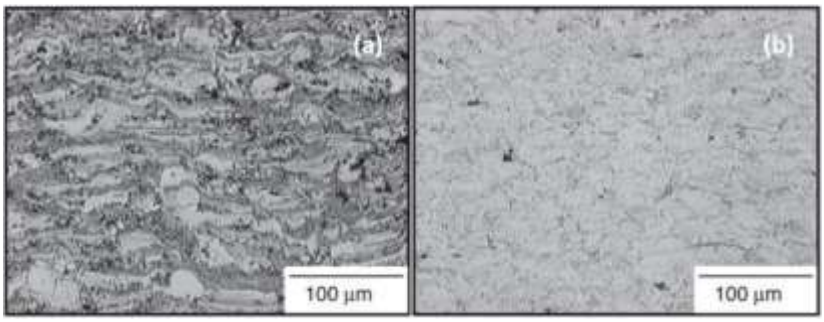


**Figure 4:** Comparison of two copper coatings produced from the same feedstock powder **(a)** copper plasma-sprayed in ambient air with ~5% porosity and 1.7% wt. oxide **(b)** copper cold sprayed in ambient air with <1% porosity and only 0.3% wt. oxide [4]

## 3. Factors affecting CS coatings

### *3.1 Spray powder deformation behavior*

The most accepted mechanism of bonding in CS processes is adiabatic shear instability. "Adiabatic" refers to the absence of heat transfer, and in this case, the heat generated due to impact remains on the surface. It requires high strain deformation of the sprayed particles, and thus high ductility is a requirement for the spray particles.

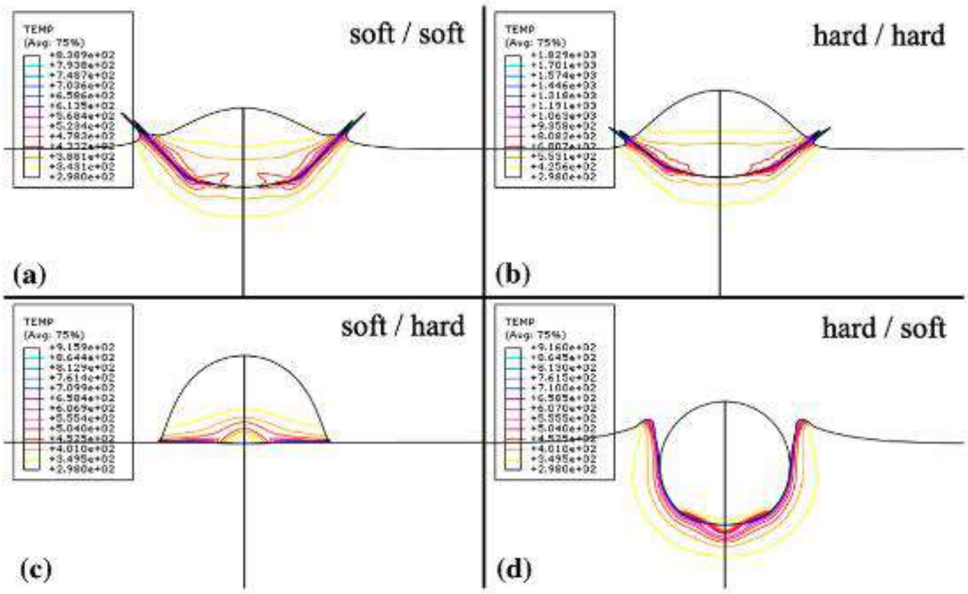


**Figure 5:** Simulation of impact **(a)** Al on Al at 775m/s (soft on soft) **(b)** Ti on Ti at 865 m/s (hard on hard) **(c)** Al on mid steel at 365 m/s (soft on hard) **(d)** Ti on Al at 655m/s (hard on soft) [5]

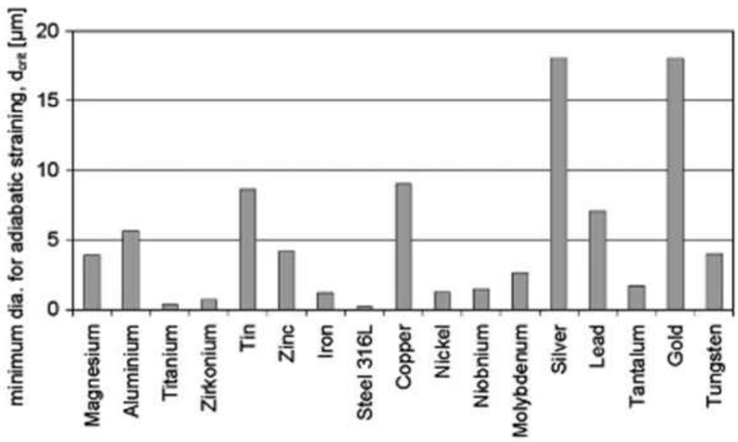


**Figure 6:** Minimum diameter required for adiabatic shear instability [6]

The high kinetic energy generated during this process creates high pressure that promotes. It also studied the bonding mechanism of CS coatings and classified four categories on the basis of hardness of both the powder and the substrate (Figure 5) and (Figure 6) shows the minimum powder diameter required for adiabatic shear instability to occur for different metals.

### *3.2 Spray gun parameters*

#### *3.2.1 Spray angle*

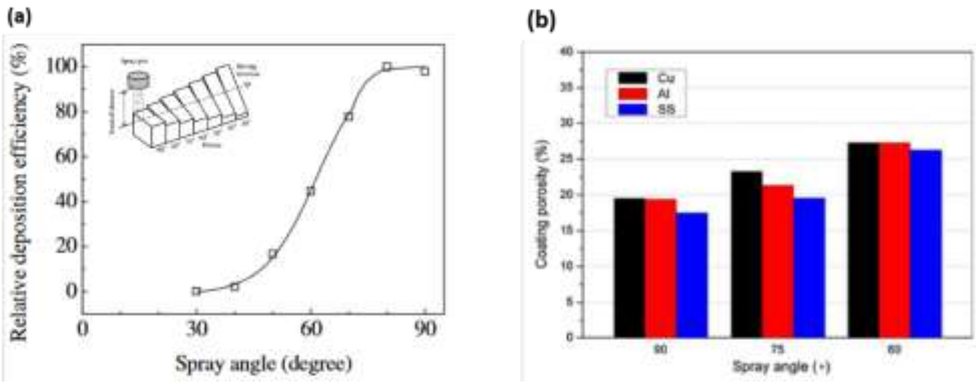


**Figure 7: (a)** Effect of spray angle on the relative deposition efficiency of copper (inset) spray gun arrangement with respect to the substrate and its change in angle along horizontal direction [7], **(b)** effect of spray angle on coating porosity [7]

Pointed out that the normal component of particle impact velocity changes with spray angle. They have studied the effect of the change in spray angle for copper and titanium particles while the spray angle was continuously changed during the spray process. They have found that relative deposition efficiency for both copper and titanium particles change with change in spray angle and is highest for 90° (Figure 7).

[11] Studied the effects of spray angle in CS titanium particles on aluminum, copper, and stainless steel substrates. They have found that porosity of the coating changes with spray angle and the least porosity is observed in the case of 90° spray angle (Figure 7(a), (b)).

#### *3.2.2 Standoff distance*

It studied the effects of distance between spray gun tip and the substrate, which is commonly known as standoff distance. They have studied aluminium, copper and titanium powders and have found the effect of standoff distance on relative deposition efficiency (Figure 8).

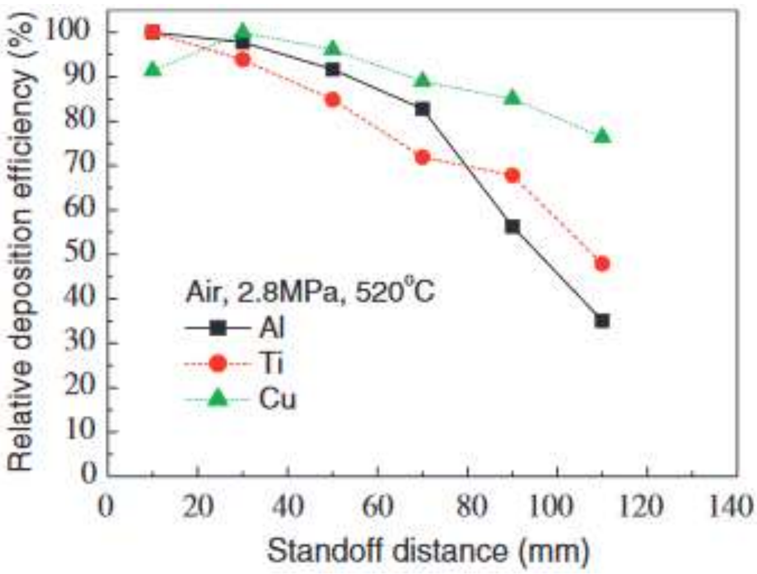


**Figure 8:** Effect of standoff distance on relative deposition efficiency of aluminum, titanium and copper powders [8]

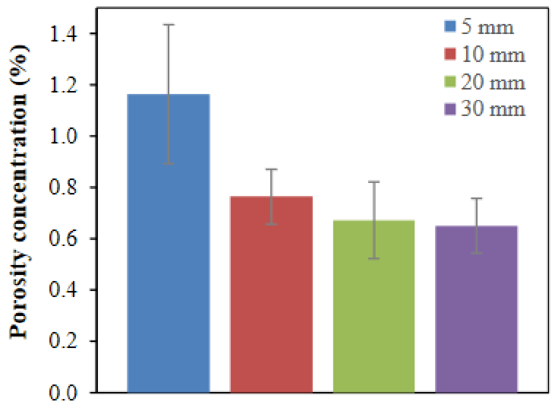


**Figure 9:** Change in the level of porosity with respect to standoff distance [9]

It also studied the effects of copper cold sprayed powders and studied the effects of porosity with respect to standoff distance. Porosity decreased with increase in standoff distance (Figure 9).

#### *3.2.3 Spray particle velocity*

The spray particles are released from the spray gun nozzle with a certain velocity. It has been found that it should attain a certain value for effective bonding. This value of velocity is termed as "critical velocity". In case the velocity is less than the "critical velocity", a Phenomenon similar to grit blasting can cause surface abrasion. As shown in Figure 10, particle velocity is dependent on spray conditions and particles diameter and has its influence on deposition efficiency [6].

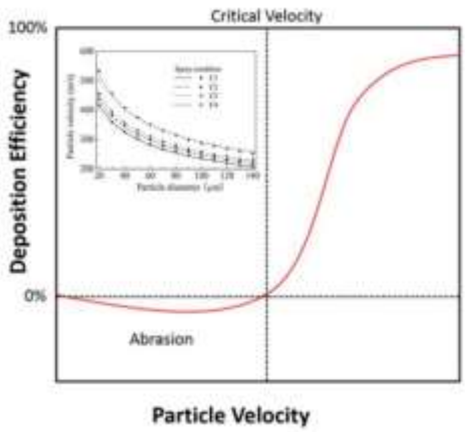


**Figure 10:** Influence of particle velocity on deposition efficiency (inset) influence of spray conditions and particle diameter on particle velocity [10]

## 4. Conclusion

The Cold Spray process has a lower operating temperature than conventional thermal spray techniques. This lowers the chances of high oxide and porosity content of cold-sprayed coatings. Evidence shows that oxide content in CS coatings cannot be completely eliminated. Oxide content disrupts the bonding between CS particles and hence causes changes in the mechanical properties. The interface between the CS coating and the substrate is the first place where the bonding process takes place.

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