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Effect of Oxidation Changes of Cold-Sprayed Tantalum Coatings

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ABSTRACT:

Variation in the cold-spray parameters can be an interesting study as it determines factors such as bonding between particles. The bonding between particles influences their Nano mechanical properties. Therefore, variation in cold - spray parameters will affect the Nano mechanics of the sprayed region. The current work has theoretically mentioned how bonding energy is altered due to the presence of oxides.

I. 1. Introduction

CS is a recently emerged technology in the field of thermal spray technology and was developed in the mid-1980s by A. Papyrin and his team at the Institute of Theoretical and Applied Mechanics of the Siberian Branch, now called Khristianovich Institute of Theoretical and Applied Mechanics in Novosibirsk city, Russia. While studying aerodynamic systems in a supersonic wind tunnel, these researchers decided to use small particles of steel and aluminum mixture with the supersonic gas system to make a two- phase (gas + solid) fluid. It was observed that particles of different sizes and sprayed at 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" [1]. Figure 1 shows a historic development of the CS process.

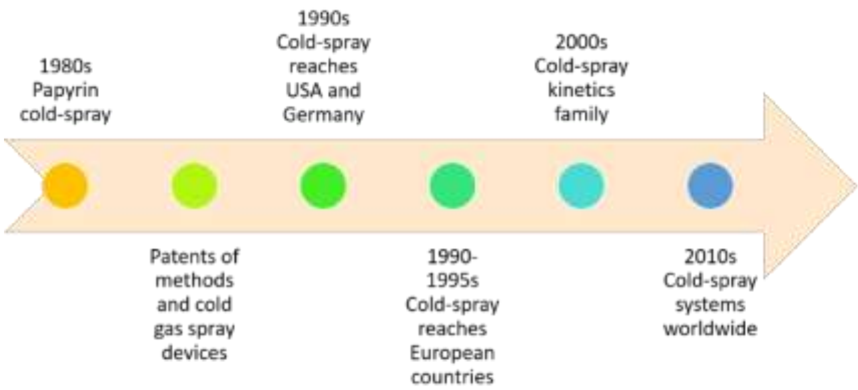

Figure 1: Development of the CS process [1]

1) *1.1 Advantages of CS over thermal spray techniques*

As indicated in Figure 2, CS 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 discussed in later sections.

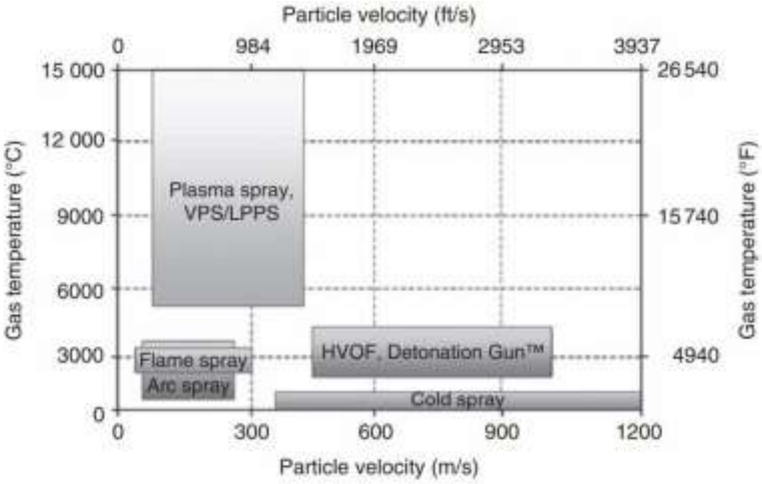

Figure 2: Gas temperature comparison of thermal spray techniques and CS [2]

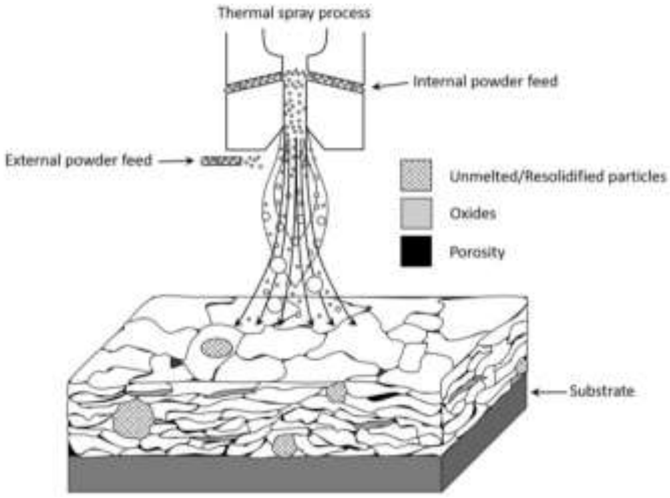

Figure 3: Schematic representation of oxide and porosity formation in thermally sprayed coatings [3]

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. Figures 2 and 3 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.

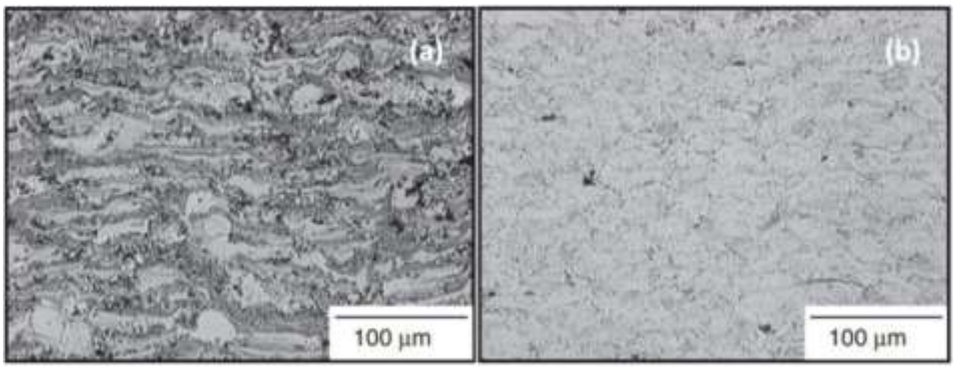

Figure 4: Comparison of two copper coatings produced from the same feedstock powder **(a)** copper plasma-sprayed in ambient air with ~5% porosity and 1.7% wt. oxide **(b)** copper cold sprayed in ambient air with <1% porosity and only 0.3% wt. oxide[4]

2) ***1.3 Disadvantages of CS over thermal spray techniques***

Unlike thermally sprayed techniques, which can deposit a wide-range of materials such as metals, polymers, and ceramics, CS can only deposit ductile materials and hence mostly ductile metals. The most accepted mechanism for CS is adiabatic shear instability plastically deforms sprayed metal powders onto the substrate, which are eventually attached to them. This demands high ductility for the powders.

Also, CS processes generally require more quantities of process gas and in many cases must rely on hydrogen as the process gas. This makes this process expensive in most cases compared to thermal spray technologies [4].

3) ***1.4 Applications of CS***

CS is a recently developed technique with the potential of additively manufactured components and also to repair damaged components [5]. They have their uses in thermal power plants where the sprayed coatings provide protection against failures such as erosion, corrosion, and high-temperature oxidation. High adhesion strength and hardness along with retention of most of the original powder properties, gives this technique an advantage in nuclear power plant sectors as well [6].

- It is used CS to deposit chromium powders as fuel cladding which had enhanced properties compared to the traditional Zr-based alloys. The chromium coating exhibited good bond strength and corrosion resistance even with the absence of post- fabrication surface treatments. According to the authors, the CS technique has its advantage in terms of high deposition efficiency and advantage for the industries. It, however, resulted in a non-uniform and heterogeneous structure.
- Discussed the economic aspects of repair using CS technology. As the technology has the ability to repair a part using spraying instead of replacing it, there is cost and environmental benefit. The authors have described the process as "green technology" and have also mentioned its use in long-term sustainability of high-value assets.
- It is used cold sprayed refractory metals in gun barrel liners for chrome reduction. As per the investigation, successful cladding makes CS process as an alternative to extrusion for refractory donor tubes (the extrusion process for refractory metals can be difficult and expensive).
- It provides a comprehensive review of the application of CS techniques in the field of aerospace engineering. According to the authors, the process can deposit aluminum and its alloys to protect of magnesium components against corrosion. The method can also be used for wear protection around fastener holes and protecting hydraulic tubes against chafing. Apart from aerospace applications, the authors have also investigated that CS can be used to join dissimilar metals such as ZE41A-T5 Mg and 6061Al with bond strength equal or superior to the substrate.

II. 2 Oxidation changes

It has been discussed in section 1, that minute traces of oxygen can be present in CS coatings. Furthermore, the oxide inclusions can result in a reduction in ductility, which can often not be removed by post – processing heat treatments. It has been reported that tantalum can be cold – worked till 500°C, beyond which results in excessive oxidation. It has used finite element modeling to understand the widely accepted phenomenon of deformation of powder particles during particle deposition. [7[

An oxide film both at the substrate and particle can be disrupted during particle impact, thus permitting metallic bonding. However, some oxide debris remains. It has also been reported elsewhere that oxide inclusions at the interfaces inhibit bonding and lower the bond strength of the sprayed particles [8].

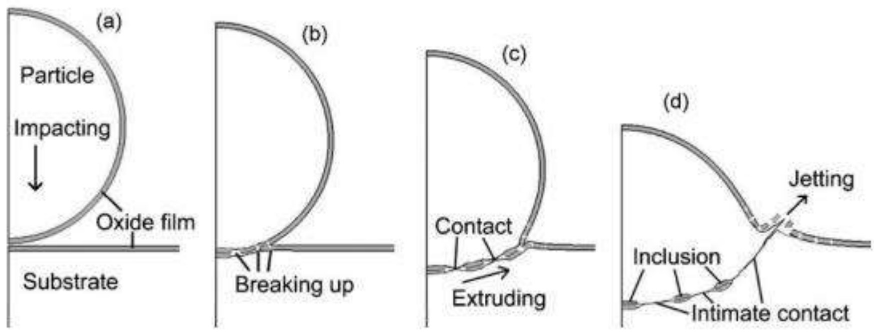

Figure 5: Schematic diagram of particle impact and bonding at the interface of sprayed particle and substrate interface [9]

The interface is the place where the first bond between CS particle and substrate takes place. It is where oxide can be present, and a study of the influence of oxide inclusions will give an idea of its effects on bonding. There is also a difference in the bond energy between Ta-Ta atoms and Ta-O atoms, as one is a metal-metal and the other is a metal-nonmetal bond [10].

III. 3. Microstructure of the coatings

It is evident from the microstructure that the coating-substrate interface is clean and free from cracks or pull outs. However, the high magnification SEM microstructure of the etched coating shows unbounded/partially bonded inter-splat boundaries as evident.

Cold spraying is a thermal spray process which enables production of metallic and metallic-ceramic coatings with dense (very low porosity level) and pure (low oxygen content) structures. Several coating properties such as corrosion resistance and electrical conductivity rely on these properties. Cold spraying consists of two processes: high-pressure cold spraying (HPCS) and low-pressure cold spraying (LPCS) divided by the pressure level used in the processes (40 bar versus 10 bar).

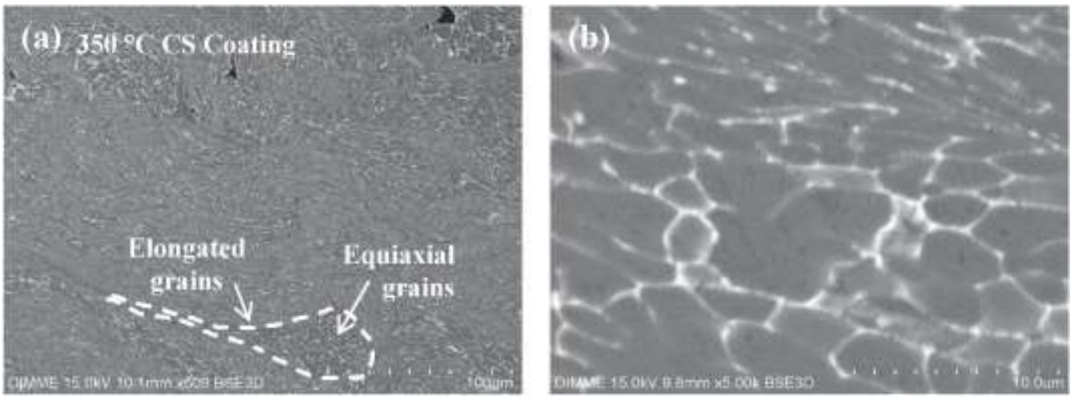

Fig.6 Microstructure of the coatings

IV. 4. Conclusions

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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