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# Number of Passes and Thickness Effect on Mechanical Characteristics of Cold Spray Coating

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**Abstract**

Nowadays, with severe competitive business environment, limited material sources and high cost of manufacturing, the importance of maintenance and repair is self-evident. In this field, cold spray technology is gaining more and more attention especially in light alloy components. One of the potential applications of cold spray coating is dimensional recovery of damaged structural parts. In most cases, thick coatings are necessary to fill the damages such as cavities, worn or corroded parts. Thick coatings can be deposited in a single or multiple passes giving different thermal input and stress distribution to the substrate and coating itself. The thermal input, the amount and type of residual stress (compressive or tensile) confer appreciable or depreciable characteristics to the coating mechanical properties. In this study, single and multi-pass deposition of a 0.5 mm thick Al 6082 coating on the same substrate is studied to explore the number of passes effect on mechanical characteristics. In addition, one pass deposition of 0.65 and 0.8 mm thick coating is investigated to examine the thickness effect. Micro-structural observation, micro-hardness measurements and X-Ray diffraction (XRD) measurement of residual stress were performed on all groups. Adhesion test and tubular coating tensile test were also carried out to characterize the coating in different cases. Observation of fractured surface was used to investigate the failure mechanism of the cold-sprayed coating. A critical discussion on the effects of pass number and thickness on mechanical properties of coated specimens is presented.

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## 1. Introduction

One rather recent developed coating treatment that is gaining increasing attention in several industrial applications is cold gas dynamic spray. The cold gas dynamic spraying or simply cold spraying is a progressive step in the development of high kinetic energy coating processes. Similar to the other thermal spray methods in principle, it follows the trend of increasing particle spray velocity and reducing particle temperature as in the high velocity oxygen fuel (HVOF) process, but to a more extreme level. During the process, solid powders (1 to 100 micrometers in diameter) are accelerated in supersonic gas jets toward a substrate. The basic principle of cold spraying has been described elsewhere [1]-[4]. One of the most important processing parameters in cold spray is critical velocity, which particles should exceed to be able to adhere to the substrate. There has been a large effort to investigate cold spray critical velocity. Numerical and experimental studies have been performed to assess the impact process of single particles. Particle temperature, size distribution, oxygen content, nozzle shape and carrier gas type have been shown to affect the critical velocity [5]-[8].

The degree of bonding between particles within cold-spray deposit is also of great importance as it affects the mechanical and physical properties. Adiabatic shear instability and the resulting plastic flow localization are the phenomena that are believed to play a major role in the particle/substrate bonding during the cold spray process.[9],[10].Van Steenkiste et al. [11] described deposition of large aluminum particles (> 50 μm) onto a brass substrate by cold spray. They argued that particle melting does not occur and bonding results from severe deformation and subsequent disruption of oxide film on metallic particles allowing nascent metal surfaces to come into contact. Tokarev et al. [12] suggested that particles impacting a substrate in cold spraying first activate the substrate by roughening it. Only once the roughening occurs, the coating is able to initiate and grow. It has also been reported that, with a greater roughening of the substrate surface (going from polished to grit-blasted), deposition efficiency of metallic powders slightly increases [13]. J.G. Legoux et al. [14] measured the coating deposition efficiency as a function of the surface temperature of the substrate during deposition, the gun transverse speed, and the particle velocity. Both single particle impact samples and thick coatings were produced and characterized. Results show that the higher substrate temperature brought about a higher deposition rate of Cu particles, even under the condition where particles were kept at room temperature. Rech et al. [15], [16] showed that the influence of process conditions (gas pressure and temperature, substrate pre-heating, etc.) and the deposition strategy (single pass deposited coatings, multi pass deposited coatings, thickness/pass ratio) is fundamental in the determination of mechanical and microstructural properties of cold spray coating. The presence of tensile stress peaks at interfaces between sequential passes of a multi-pass coating was identified.

One of the potential applications of cold spray coating is repairing damaged parts. Nowadays, with severe competitive business environment, limited material sources and high cost of manufacturing, the importance of maintenance and repair is self-evident. This is even more vital in the case of aeronautical engine, components, frames and large parts where both the production cost and the manufacturing time could be too demanding. Moreover, repaired part must retain bulk material properties to withstand service loads. Conventional repair methods are carried out by thermal techniques on light alloys used in aeronautic (eg. Aluminum and Magnesium). These are very sensitive to high temperature and fast cooling rates. Due to high cooling rates, tensile residual stresses are developed in the material [17], which is detrimental for fatigue behavior. Moreover, tensile residual stress often limits the maximum coating thickness that can be achieved with traditional thermal spray processes. All the above mentioned aspects affirm the necessity of a low temperature-high velocity repairing technique.

It is well established that compressive residual stress and surface hardness are beneficial in terms of fatigue behavior [18]-[21]. The peening effect of incoming high-velocity solid particles in the cold spray process deforms underlying, previously deposited material. This tends to close any small pores or gaps in the underlying material. In addition, the cold spray particles are deposited at relatively low temperature. The net result is that cold-sprayed coatings, unlike most traditional thermal spray coatings, are typically in the compressive residual stress state [22], [23]. Since cold-sprayed coatings generally have no tensile residual stress to drive the opening or extension of cracks in the coating material, most ductile metals can be deposited to almost any desired thickness.

The main concern in the present study, is obtaining thick coatings which are necessary to repair damaged parts. Thick coatings can be deposited in a single or multi-pass, giving different thermal input and stress distribution of the component [16]. The thermal input, the amount and the type of residual stresses (compressive or tensile), vicinity

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