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The Basic Principles of DYMET Technology

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Abstract

Dynamic Metallization (DYMET) process is developed to produce thick aluminum, copper, zinc, nickel, cobalt, lead, and tin coatings on any metal or ceramic substrates. It consists of a surface treatment process in which a mixture of solid metal and ceramic powders are accelerated by compressed air at pressures between 0.5 and 0.8 MPa.

Introduction

The method of thin metal coating of surfaces by a supersonic jet of fine metal powders is known since almost 50 years [1]. This supersonic blasting method includes the mixing of a metal powder with compressed air at a stagnation pressure of 1.0 MPa and acceleration of this mixed jet in the supersonic nozzle. The method did not attract the attention and was not carefully investigated at the time of invention.

Last decade, the process of thick metal coating of surfaces by the supersonic jet of fine solid metal particles, called Cold Spray [2, 3], was extensively investigated. The main process parameters revealed are the necessity of a critical particle velocity and the development of an adiabatic shear instability at the interface followed by a particle intensive plastic deformation [4].

Both processes consist of the acceleration of solid metal particles by a compressed gas jet. The main difference between these two processes is the particle velocities. To produce a thick coating instead of a thin one, the accelerated particles have to overcome the critical velocity [3, 4]. While both processes use supersonic nozzles to accelerate the particles, the practical difference is related to the stagnation pressure of the accelerating gas. The declared stagnation jet pressure is 1 – 3 MPa for Cold Spray [3] and 1 MPa for supersonic blasting [1].

Supersonic Blasting Process Analysis

The accelerating gas stagnation pressure determines the velocity of the particle jet. Calculated values for the velocity of spherical copper particles accelerated in the supersonic nozzle by compressed air with stagnation pressures of 0.5, 1.0, 2.0 and 2.5 MPa are presented in Fig. 1. Reducing the air stagnation pressure causes a decrease of the particle velocity.

The critical velocity value for copper particles is about 540 m/s [4]. Particles with the size above 10 µm can not be accelerated to the critical velocity with air at stagnation pressures below 1.0 MPa. For this reason, thick coatings can not be produced by the Cold Spray process using these conditions and only thin coating layer may be produced by supersonic blasting.

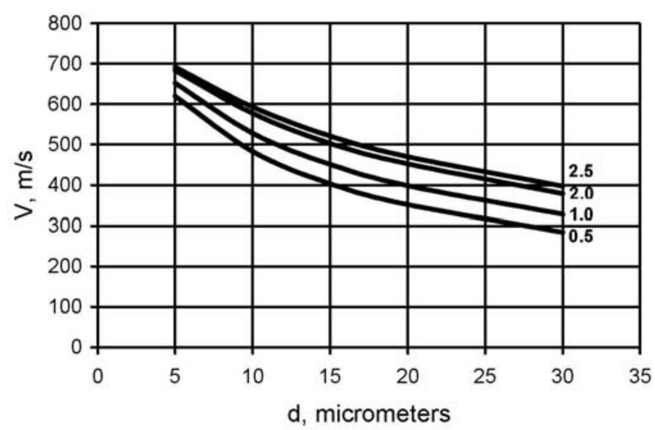

Figure.1: Calculated values for the velocity of spherical copper particles accelerated in the supersonic nozzle by compressed air with stagnation pressures of 0.5, 1.0, 2.0 and 2.5 MPa.

Careful considerations of the supersonic blasting process [1] shows, that the substrate surface roughness may be the main reason of the thin coating creation. To reduce the rebounding force caused by the high velocity particles onto the substrate during the impact, the kinetic energy dissipation is necessary. This energy dissipation may be caused only by the viscous flow of the particle or substrate materials. And the possibility of the viscous flow initiation differs drastically for rough and smooth substrate surfaces.

It is obvious that the contact pressure at the surface roughness peaks may substantially exceed the contact pressure on the flat surface. Thus the same contact impact force, controlled by the particle velocity, may be insufficient to deform particles on the flat surface and may cause viscous flow at the peaks of the rough substrate surface. Metal particles may be deposited at the peaks and cavities of the rough surface, creating then a thin coating layer. After the entire rough substrate surface is filled with the striking metal particles, it will become smooth and further deposition will cease.

The heat transfer process at the particle and substrate interface is not adiabatic at low particle velocity. Heat sink reduces the solid particle thermal softening developing at the impact interface. The deposition of thin aluminum coating may be observed on glass and ceramic surfaces at jet velocity below the critical value, but under the same conditions, aluminum particles do not deposit on aluminum substrate surface.

The coating formation by supersonic metal blasting is limited both by the rough surface smoothing while depositing soft metal particles and by improving the heat conductivity of the substrate surface. Under this process, the sprayed powder material does not built up upon itself. The surface smoothing and the surface heat conductivity rise during thin coating formation prevent further particles deposition.

Thick Metal Coating Creation

Based on the results of the supersonic blasting process investigations the method of a thick coating creation instead of the thin one using the same process parameters was developed [5]. This thick coating formation method relies on the surface roughness enhancement performed by impinging of ceramic particles. Thus, the erosion of the smooth deposited layer by the ceramic particles jet produces a new surface roughness and creates the condition for the further particles deposition.

If the surface of the sand blasted steel substrate is treated by a pure aluminum powder jet at the supersonic blasting conditions, only a thin aluminum coating is produced. Under the same conditions, a pure alumina particles jet causes only erosion on the surface. But alternated runs of metal particles and ceramic particles jet cause the coating thickness to grow.

The variation of the time delays between successive jet runs did not reveal any time dependent activation processes. Only the impact statistics influence the thick coating formation rate for jet velocities below the critical value.

In order to obtain a continuous and uniform surface treatment, a method was developed, which uses a mixture of metal and ceramic particles instead of performing separate alternated runs. The use of a mixed jet will also shorten the time intervals between the ceramic and metal particles impacts and can lead to a local increase of the surface temperature at the impact point.

The deformation of metal particles deposited at a relatively low jet velocity is improved by a compacting effect due to the ceramic particle impacts. Only a small portion of the ceramic particles embeds the coating. The majority of the ceramic particles presses the coating and leaves the surface. The high hardness and low heat conductivity of the ceramic particles induce an important impact energy dissipation, which occurs in the top layer of the coating.

The cross section of a copper coating on a steel substrate is presented in Fig. 2. The amount of ceramic inclusions in the coating does not exceed 5 % of the total amount of ceramic powder used during the spray process.

The proportion of metal to ceramic in the powder mixture determines the coating properties and deposition efficiency. Figure 3 shows the dependency of the deposition efficiency on the ceramic content (wt.%) in the aluminum – alumina powder mixture sprayed using compressed air at a stagnation pressure of 0.5 MPa and a stagnation temperature of 700 K. The upper curve presents the deposition efficiency of pure aluminum, calculated as the ratio of the weight of the pure aluminum in the mixed aluminum – alumina coating and the weight of the

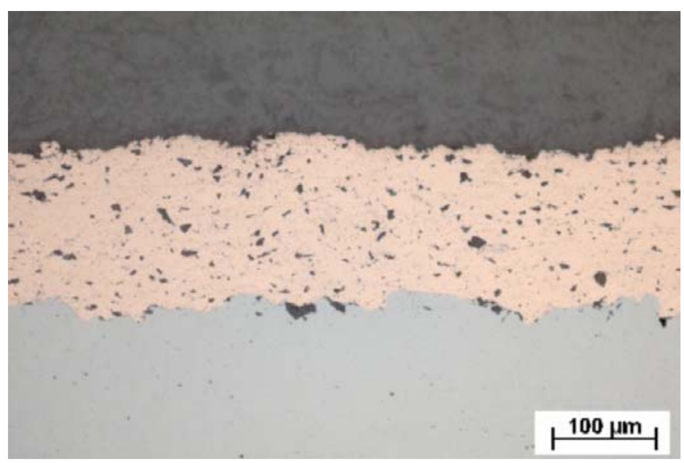

Figure 2: The cross section of a copper coating on a steel substrate

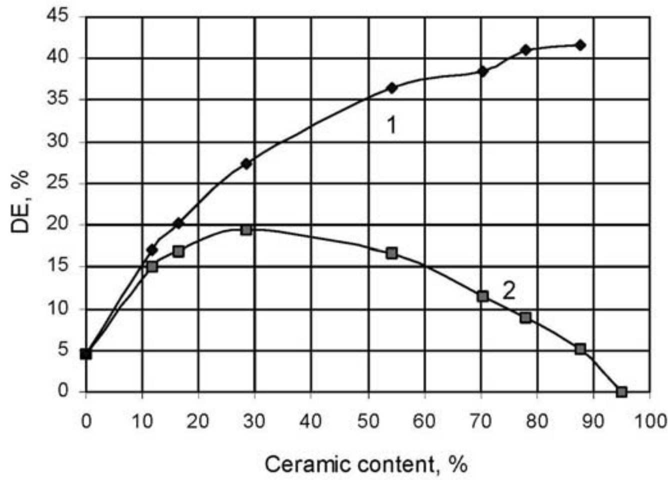

Figure 3: Deposition efficiency of pure aluminum (1) and aluminum – alumina mixture (2) as a function of the ceramic mass content in the aluminum – alumina powder mixture.

pure aluminum in the initial mixed powder used. The lower curve presents the total mixture deposition efficiency. Most of the ceramic particles produce erosion and leave the coating restraining the rise of the deposition efficiency.

DYMET Equipment and Technology Features

The use of a mixed metal – ceramic powder has some specific requirements regarding the nozzle design. The ceramic particles erode greatly the nozzle. To prevent the change of the nozzle throat geometry, a special type of supersonic nozzle has been designed and constructed.

The powder mixture is injected into the accelerated air flow at the divergent part of the supersonic nozzle, and the nozzle's critical section does not erode. The erosion process influences only the divergent part of the nozzle that follows the powder injection point. A simple diverging cone has been designed as a replaceable nozzle insert for the quick and easy replacement of this part.

The presented supersonic thick coating formation process at a low air stagnation pressure using a metal – ceramic powders mixture combined with a specially designed nozzle was called Dynamic Metallization (DYMET) technology.

To produce high quality coatings, the DYMET technology utilizes optimized powder mixtures. The optimization process is based on the choice of the powder mixture to improve the deposition efficiency, coating bond strength and coating density. Usually, the adhesion strength and coating density increase as the ceramic powder content increase. However, depending on the requirements for the coating quality and spray efficiency, the optimal mixture ratio may vary for different jet temperatures.

The use of optimal powder mixtures can produce thick aluminum, zinc, copper, nickel, cobalt, lead and tin coatings with an average deposition efficiency of 20 – 30 %, typical porosity of 1 – 7 % and typical bond strength of 40 – 80 MPa.

Summary and Conclusions

The investigation of the supersonic blasting process revealed the possibility to produce thick metal coatings instead of thin ones by using a mixed metal – ceramic powder mixture with jet velocity lower than the critical velocity in Cold Spray. The coating deposition efficiency by DYMET technology depends on the metal powder – ceramic powder mixture ratio and is less than that of Cold Spray. But because of the low requirements to the accelerating gas (compressed air at pressures of 0.5 – 0.8 MPa), it is used in various applications, particularly in repair, service and production of high cost manufacturing products.

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