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# MODERN SURFACE DEPOSITION METHODS FOR IMPROVING THE PROPERTIES OF MATERIALS

BY

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**Abstract.** This study presents the most current research in the field of materials science and engineering aimed at improving the properties of materials through surface deposition. Thermal deposition methods are intended to create superficial layers with high properties to improve the performance of materials. The improvement of the microstructural, mechanical and corrosion resistance properties are the main characteristics pursued for a large range of components so that superficial depositions manage to satisfy these needs, however, according to the specialized literature, these are only part of the material properties that can be improved by submissions. Depending on the needs of the applications, even the thermal protection or electrical conductivity properties can be improved. The plasma jet thermal deposition (APS), high-velocity oxygen fuel (HVOF) or Cold Spray (CS) methods are just one of the deposition techniques that are capable of creating a surface layer with superior properties to the base material, which can contribute both to the increase in the performance of the materials in the

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technological manufacturing process and to the restoration and reconditioning processes of the various components that can be brought back into good working order through thermal deposits.

**Keywords:** Cold Spray, APS, HVOF, Microstructural properties, Mechanical properties.

## 1. Introduction

Surface deposition methods, through the benefits they bring, are gaining more and more attention in various industries such as aerospace, military, petrochemical, automotive and even medical, so that the interest given to the development of these deposition technologies is constantly growing (Davis *et al*. 2004; Singh *et al*., 2012). The principle underlying these thermal deposition techniques, to increase the improvement of material properties, is to create a superficial layer on the base material with the aim of leading to a significant improvement of the properties. In the last decades, through extensive research in the field, it was found that these thermal depositions are not intended to replace, but rather to complement the traditional techniques for improving the properties of materials. Until now, several thermal deposition techniques are known, such as cold methods, electric methods and combustion methods. All these methods have the same goal, namely the increase of material properties (Pawlowski, 2008; Mitchell, 2012). In this revision work, the impact brought on the increase in the performance of the materials using the Cold Spray deposition method, Thermal deposition in plasma jet, High-speed oxygen fuel, and other deposition methods was followed. These methods were the main deposition techniques followed in this study, because they have different deposition temperatures and represent an interesting study on the comparison of the results obtained in the existing research in the specialized literature. The cold deposition method Cold spray (CS) is the only deposition method that succeeds in depositing the particles below their melting point, the usual values being approx. 600-700°C, while the High Speed Oxygen Fuel (HVOF) deposition method is the next deposition method (related to the high values of the deposition temperatures), after Cold spray, but in which the particles are deposited in a molten state, the temperatures being of approx. 2000-3000°C. At the opposite pole, there is the plasma jet thermal deposition method (APS) where the deposition temperatures exceed 10,000-15,000°C so that the comparison of these methods represents an interesting study from the point of view of the deposition temperatures and at the same time, very important, the deposition velocities of the particles In this revision work, the impact brought on the increase in the performance of the materials using the Cold Spray deposition method, Thermal deposition in plasma jet, High-speed oxygen fuel, and other deposition methods was followed. These methods were the main deposition techniques followed in this study, because they have different deposition temperatures and represent an interesting study on the comparison of the results obtained in the existing research in the specialized literature. 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Mainly, the thermal deposition techniques start from the traditional methods of surface improvement of the materials so that the main role assigned is that of giving the surface a superficial improvement of the properties. Approaching the cold deposition technique, which, unlike the other methods, can re-alize stable coatings of the order of tens of millimeters, thermal deposition also gains interest in the restoration and reconditioning processes of various components that show a high degree of wear so that, through the large cover thicknesses, they are brought back to nominal dimensions corresponding to functioning. This is the main reason, in addition to meeting the needs of increasing performance, for which cold depositions are at a higher level than other methods such as the plasma jet thermal deposition method, which achieves stable depositions of a maximum of 50 - 100 µm. Of course, the cold deposition method still remains the only method that deposits particles below their melting point, so that the properties of the material used as raw material are preserved, the connection between the base material and the coating, achieved through a mechanical interlocking phenomenon due to the high deposition speeds, being supersonic speeds (depositions are carried out at speeds of up to 1000 m/s) (https://vrcmetalsystems.com/).

The base material uses, imposes by itself, by its characteristic that it has constraints on the choice of the suitable deposition technique for achieving the coatings in optimal conditions. According to the specialty literature, it could be possible to achieve deposition including on plastic materials, but this could only be achieved by lowering the deposition temperature, so that the base material is not affected, or even destroyed.

The research in the field does not focus only on the materials used in the construction industry of mechanical components, but also expresses an interest in the medical sector, as studies have been carried out aimed at the realization of thermal coatings to improve the properties of various medical, orthopedic utensils and even on implants or different rods that come into direct contact with the human body. In addition to improving these components, specialists in the field are paying more attention to Mg-based biodegradable materials, which are intended to reduce the recovery time of patients following surgical interventions. In other words, instead of having a second surgical intervention to extract the respective elements that support the bone structure, through the properties of biodegradable materials, they decompose and are assimilated by the body, after they have lasted for a sufficient time, necessary for healing (Barbinta *et al*., 2014).

In the military industry, a series of studies were carried out aimed at obtaining and improving the properties of the lining materials, by creating superficial layers with properties of resistance to mechanical demands and impact in the case of projectile impacts, these deposits being made using the technique cold deposition Cold Spray. Following the research, it was found that this method has a high potential for obtaining armor materials, making deposits with hardness values double that of the base material, values up to 45 - 47 HRC (Lupu *et al*., 2024). These studies have contributed significantly to the concretization of future research with the aim of exposing the extent to which superficial depositions solve major challenges on the reconditioning of various components in the military sector that consume significant financial resources (Lupu *et al*., 2024).

The space industry also places a distinct interest in the use of surface deposits for the creation of components with properties at least equal to those of the materials currently used, in order to produce components that meet the requirements in terms of performance, but which can be made at lower specific weights. Also, studies can be found in the specialized literature that also aim to solve problems on the performance of existing materials, such as increasing the resistance from the point of view of thermal influences on the black boxes of aircraft that are subject to extreme operating regimes in the event of accidents, and which requires sufficient resistance in case of extreme temperatures in order not to affect the electronic components inside them (Lutcanu *et al*., 2023; Lupu *et al*., 2023).

A major disadvantage of the deposition methods is constituted by the high costs of manufacturing these installations and at the same time, the cost of the raw materials used which can reach significant costs in the case of the need for some properties that can only be achieved by using some deficient materials that bring, high costs. However, thermal depositions manage to cover needs that are much more difficult to achieve through other traditional techniques for improving material properties (https://www.oerlikon.com/metco/en/; https://www.solvusglobal.com/).

## 2. Materials and methods used for thermal deposition

The Cold Spray (CS) cold deposition method is a method that has developed the most in recent years due to its unique characteristics. This deposition method, unlike the other existing techniques, is the only method that allows the deposition of particles below their melting point. Depositing below the melting point has the advantage that raw material powders retain their properties, unlike methods in which the powders are deposited in a melted/semi-melted state. In Fig. 1, you can see a Cold Spray deposition installation, manufactured by the American manufacturer VRC Meta Systems (https://vrcmetalsystems.com/).

Fig. 1 – Cold Spray installation, VRC Raptor model (https://vrcmetalsystems.com/).

This version of the cold deposition installation has the great advantage that it is mobile so that work can be carried out exactly at the beneficiary, thus performing depositions on equipment that is impossible to move, such as Maritime Ships, Oil Installations, etc. In Fig. 2, the working principle of the cold deposition technique is presented (https://vrcmetalsystems.com/what-is-cold-spray/).

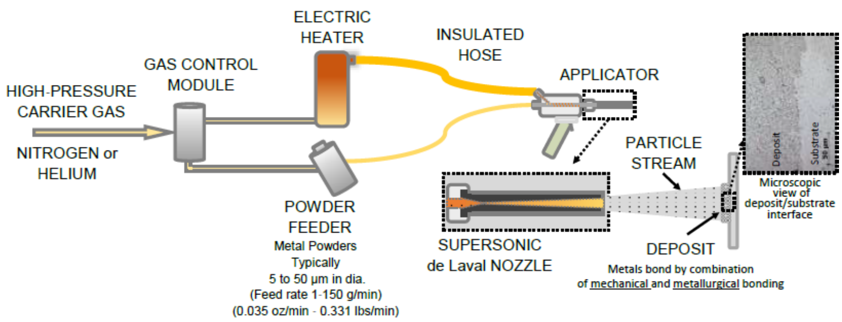


Fig. 2 – Operating principle of the cold deposition method (https://vrcmetalsystems.com/what-is-cold-spray/).

The cold deposition method, due to the high deposition speeds (supersonic speeds) that reach up to 1000 m/s, propels the particles onto the base material, strengthening them through a mechanical interlocking phenomenon. Due to the deep penetration of the particles into the base material, a strong bond is formed resulting in a stable layer with low porosity. The working pressures of the carrier gas, which can be either N or He, are between 3-7 MPa and the deposition temperatures are below 1000°C, using the usual way, optimal values of approx. 600-700°C.

Deposition method High-velocity oxygen fuel (HVOF), also deposits the particles at higher speeds, but the temperatures are above the cold deposition values, these being between approx. 2500-3000°C

At the opposite pole, there is the plasma jet deposition method (APS), where the melting temperatures are between approx. 10,000-15,000°C. Plasma jet deposition allows the creation of coatings with a thickness of up to approx. 100 μm, with very stable coatings at a thickness value of approx. 50 μm. This method is versatile, being able to deposit a wide range of raw materials, covering a wide range of deposition temperature values.

In Fig. 3 the principle of thermal deposition in the plasma jet and the main elements that make up the installation can be observed (https://www.researchgate.net/figure/Schematic-of-atmospheric-plasma-spraying-process-showing-in-flight-oxidation-of-particles_fig1_333016910).

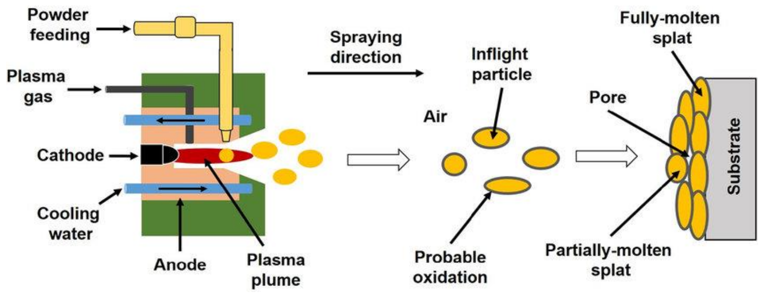


Fig. 3 – Plasma jet thermal deposition installation (https://www.researchgate.net/figure/Schematic-of-atmospheric-plasma-spraying-process-showing-in-flight-oxidation-of-particles_fig1_333016910).

The preparation of the samples for all deposition methods presupposes compliance with specific preparation steps so that the surface to be deposited is sandblasted and degreased. Any contamination of the deposition surface can lead to exfoliation or a weak connection between the substrate and the additive material.

Currently, there is a large range of materials intended for use as raw material for deposition facilities, and for the most part, these materials are in the form of powders, metallic or ceramic, Manufacturers established in the manufacture of these types of powders, in the main ones are Oerlikon Metco and Solvus Global (https://www.oerlikon.com/metco/en/; https://www.solvusglobal.com/).

The choice of these powders is made according to the necessary characteristics of the material subjected to deposition, as it is possible to improve both the microstructural and mechanical properties, as well as the corrosion behavior. For special applications, one can even opt for powders designed to improve thermal properties or electrical conductivity and not only.

## 3. Current experimental results from specialized literature

Ashokkumar and collaborators (Ashokkumar *et al*., 2024), carried out research in the automotive and aerospace fields regarding the applicability of the Cold Spray method using magnesium-based alloys. Magnesium-based alloys are used due to their good casting properties, low density, and high strength-to-weight ratio. Due to the low corrosion resistance of magnesium, cold depositions were made using a metal matrix coating (MMC). It was found that the MMC coatings with porosity greater than 13% led to the lowest adhesive strength with values of approximately 41 MPa. Coatings with porosity up to 2% led to adhesive strength values of approx. 70 MPa. In Figs. 4a and b you can see in the section both the deposited layer and the base material. Figure 4c shows an X-ray diffractogram (XRD) from where it can be seen that the main highlighted energies are for Aluminum and Alumina.

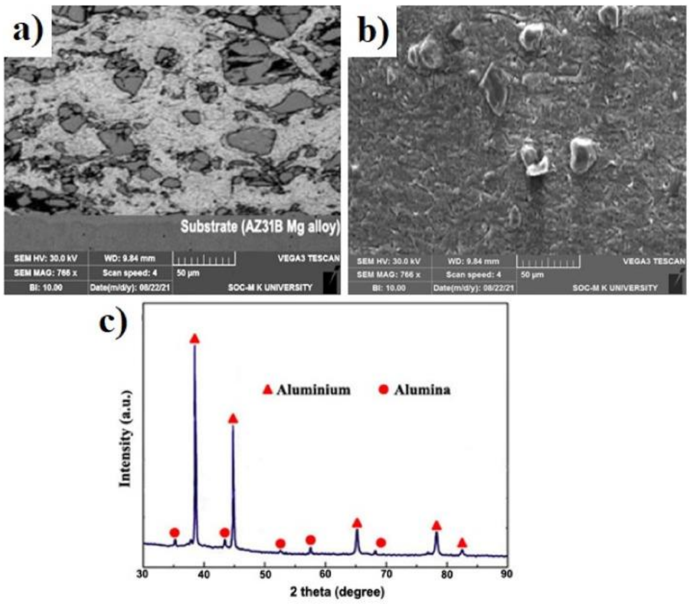


Fig. 4 – SEM images (a and b) and XRD graph (c) (Ashokkumar *et al*., 2024).

Studies carried out by Tommi and collaborators (Tommi *et al.*, 2023), highlighted the tensile-deformation behavior of coatings made by different techniques, such as APS HVAF and HVOF. The coatings were made using powders based on NiCr and NiCrBSi. After the tensile tests, no significant microstructural changes were observed. The average value of the stresses was approximately 400 MPa. At the same time, hardness determination tests were carried out, obtaining values of approx. 390 HV for coatings based on NiCr by HVOF and HVAF and approx. 260 HV through APS. For coatings based on NiCrBSi, the obtained values were approx. 650-700 HV through HVOF and HVAF and approx. 570 HV through APS. In Fig. 5, SEM images of NiCr-based coatings are presented for the 3 methods and in Fig. 6. SEM images for NiCrBSi based coatings are presented.

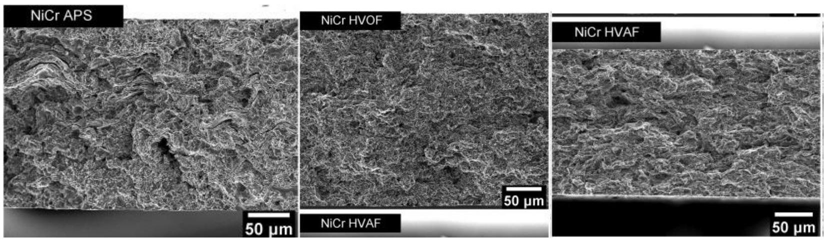


Fig. 5 – SEM images of NiCr-based coatings (Tommi *et al.*, 2023).

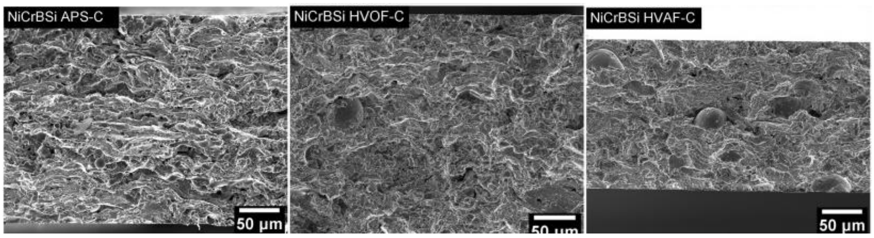


Fig. 6 – SEM images of the coatings based on NiCrBSi (Tommi *et al.*, 2023).

## 4. Conclusions

1. According to the studies carried out, the superficial deposits manage to significantly improve the properties of the materials. They can be used both for the improvement of components in the manufacturing process and for the restoration of worn components.

2. It was found that of all the deposition methods, the cold spray deposition method is the only one that succeeds in depositing the particles below the melting point so that the properties of the raw material used for deposition are preserved. Since the deposition temperatures are high in the case

of the HVOF and APS methods, there are a series of limitations regarding the materials that can support these depositions.

3. By making the surface coatings, it leads to an improvement of the microstructural and corrosion resistance properties and at the same time, the mechanical characteristics are also improved, obtaining hardnesses of approx. 400 HV for the deposited layers.

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## METODE MODERNE DE DEPUNERE SUPERFICIALĂ PENTRU ÎMBUNĂTĂȚIREA PROPRIETĂȚILOR MATERIALELOR

(Rezumat)

Această lucrare prezintă cercetări actuale din domeniul științei și ingineriei materialelor care vizează îmbunătățirea proprietăților materialelor prin depuneri superficiale. Metodele de depunere termică au scopul de a crea straturi superficiale cu proprietăți ridicate pentru a îmbunătăți performanța materialelor. Îmbunătățirea proprietăților microstructurale, mecanice și de rezistență la coroziune sunt principalele caracteristici urmărite pentru o gamă largă de componente astfel încât depunerile superficiale reușesc să satisfacă aceste nevoi, totuși, conform literaturii de specialitate, acestea sunt doar o parte din proprietățile materialelor care pot să fie îmbunătățite prin depuneri. În funcție de nevoile aplicațiilor, chiar și protecția termică sau proprietățile de conductivitate electrică pot fi îmbunătățite prin intermediul acestor depuneri.

Metodele de depunere termică cu jet de plasmă (APS), de combustibil cu oxigen de mare viteză (HVOF) sau de pulverizare la rece (CS) sunt doar unele dintre tehnicile de depunere care sunt capabile să creeze un strat superficial cu proprietăți superioare materialului de bază, care poate contribui atât la creșterea performanței materialelor atât în procesului tehnologic de fabricație cât și la procesele de restaurare și recondiționare a diferitelor componente care pot fi readuse în stare de bună funcționare prin depuneri superficiale.