Improvement of the mechanical and microstructural properties of the materials used for armour by surface deposition using the Cold Spray method

Fabian Cezar LUPU[1], Corneliu MUNTEANU*,[1], Bogdan ISTRATE[1]

*Corresponding author
[1]Gheorghe Asachi" Technical University of Iasi, Faculty of Mechanical Engineering, Bulevardul Profesor Dimitrie Mangeron 67, 700050 Iasi, Romania,
fabian-cezar.lupu@academic.tuiasi.ro, cornelmun@gmail.com,
bogdan.istrate@academic.tuiasi.ro

DOI: 10.13111/2066-8201.2024.16.4.7

Received: 04 September 2024/ Accepted: 26 November 2024/ Published: December 2024

Abstract: *Superficial depositions gain interest in various industries due to the significant improvement of the properties of the base material that is subjected to superficial depositions. The deposits can be made both in the technological process of manufacturing the various components and in the reconditioning processes of the components with high levels of wear. Superficial coatings are applied with the aim of creating a protective surface layer, that is hard and resistant to both external factors and various demands. Depending on the nature of the application of the component, to be coated the mechanical, microstructural, thermal, corrosion resistance, etc. properties can be improved. The objective of this work is to demonstrate the ability of thermal deposition to improve the mechanical and microstructural properties of materials used in the construction of armour for military equipment using the Cold Spray (CS) thermal deposition method. Among all the deposition methods, this method is the only one that manages to deposit the particles below their melting point, having the lowest deposition temperatures, thus preserving the properties of the deposited material. This paper presents experimental results for armor elements that are subjected to severe exploitation regimes and contributes to the scientific progress in the field of deposits applicable to most industries such as petrochemical, military, aerospace, automotive, and medical.*

Key Words: *Cold Spray, Mechanical properties, Microstructural properties, Powders, Coatings*

1. INTRODUCTION

The present work consists of research into improving the properties of armour elements through thermal deposition. Thermal depositions have the role of creating a superficial layer with high properties and depending on the desired performance, deposition materials with appropriate properties are chosen. Until now, several deposition techniques are known, such as cold deposition (Cold Spray), thermal plasma jet deposition (APS), high-speed oxygen fuel (HVOF), etc. [1-3]. In the specialized literature, there are numerous studies in the field of superficial depositions that confirm the fact that the superficial layers manage to satisfy the needs of different industries, both in terms of improving the material properties and the technological manufacturing process, as well as in the reconditioning processes of the various components that present mechanical wear.

Wenquan et al [4] carried out research on the evaluation of tribological and microstructural properties for cold coatings using Ti-diamond composite powders. These powders were ball milled. Through the XRD results, it was confirmed that after the cold deposition process (Cold Spray), no phase change occurred for any of the coatings. The results of the wear tests showed that for Ti-10MD, the lowest friction percentage was obtained with a low wear rate. During the research, it was observed that both wear coefficients and wear rates first decreased and then increased. It was found that the best wear resistance was obtained for the 10% diamond content.

Jingjie et al [5] conducted research using cold deposition based on CuNi, CuSn and CuNiSiCr. After deposition, the layers were found to be heterogeneous, fine-grained and highly deformed. Due to the lack of deformation on the inside of the particle, the hardness is higher on the outside because this is where a large deformation occurs. The average hardness of the coatings is 134.5 HV for CuNi, 129.6 for CuSn and 161.85 for CuNiSiCr. The results showed that the cold deposited layers have a high density with a good deposition efficiency and a high hardness. The average value of the porosities obtained is approx. 0.4% By means of nanoindentation mapping, it was found that the hardness of the particle is lower on the inside than on the outside. The deformation of the particle is predominantly on the outside, which leads to obtaining the variance of hardness from lower on the inside to higher on the outside.

Rocio et al [6] carried out research on the effect of temperature and pressure in the spraying process on the wear properties using stainless steel-based coatings on carbon steel base material. The samples were tested using micro scratch tests. After testing, it was found that the material greatly improved and increased scratch resistance, obtaining a lower wear rate than the carbon steel base material. At a pressure of 60 bar with temperatures between 800°C and 1100°C, the width of the micro scratch site is approx. 5 μm and the COF values are in agreement with other studies in the field [7-8].

2. MATERIALS AND METHODS

The research consists of both the determination of the hardness of coated and uncoated samples as well as of the microstructural evaluation of the submitted samples.

The tests were carried out using existing equipment at the Mechanics Faculty of the Gheorghe Asachi Technical University in Iasi. Hardness determination tests, both for the base material and for the deposited layers, were performed on the CETR UMT-2 tribometer [9], and the microstructural analyzes were performed on the Quanta 200 3D Dual Beam scanning electron microscope [10, 11].

The realization of the superficial depositions was carried out within the research program: "Program in materials, Additive and Secure Manufacturing, and Multiscale Materials Engineering (3ME)", Grant number: W911NF2020024. The project was carried out within the US Army Research Laboratory, Northeastern University from Boston in collaboration with several universities and research institutes: MIT, MMT, CTC, UCONN, VRC Metal Systems and TUIASI. As part of this project, it was possible to carry out cold thermal deposition on the Cold Spray-VRC Gen III deposition installation, provided by the Research

Laboratory of the American Army, in collaboration with Northeastern University from Boston.

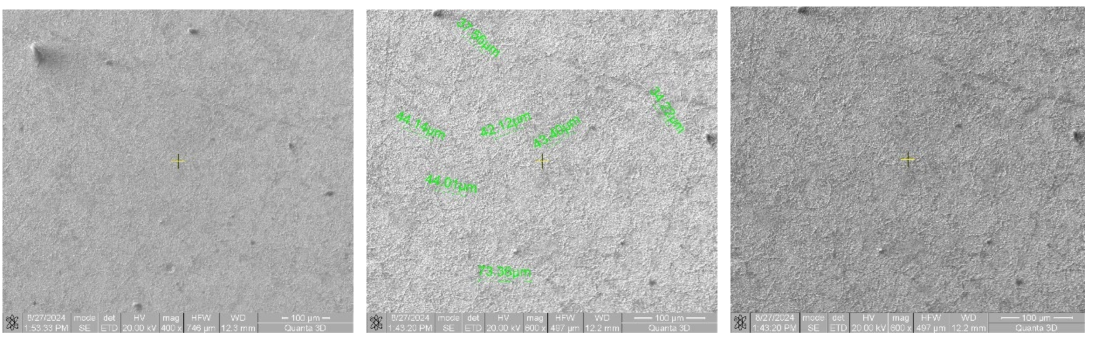
The basic material used to make the deposits is AISI 52100 alloy steel [12], which is a steel with high properties and is used for a series of applications in the military sector, and the research in this paper shows the extent to which this type of material, together with the deposits superficial, manages to present properties corresponding to armor elements. The powders used for deposition are powders based on NI Cr/C, which has the commercial name of WIP-C1.

Beforehand, a layer of across with WIP-BC1 powders was made to achieve a much tighter bond between the additive and the base material [13].
It was chosen to use the cold deposition method because, among the existing methods up to now, the Cold Spray method [14-15], is the only method that succeeds in depositing the particles below their melting point, having the lowest deposition temperatures. The deposition temperatures are up to 1000°C, as a rule, the average value of the usual temperatures being approx. 600-700°C. The cleaning gas can be both Helium and Nitrogen, with working pressures of up to approx. 3.5 MPa. Figure 1. shows the convergent-divergent spray nozzle of the Cold Spray installation, attached to the robotic arm for deposition.

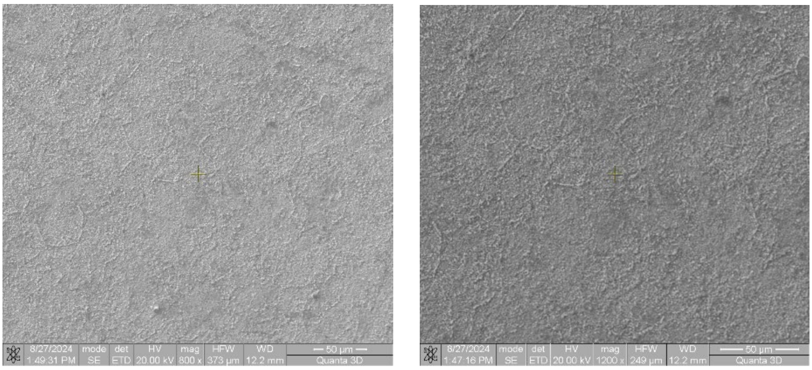
Figure 1. The spray nozzle of the Cold Spray installation mounted on the robotic arm

3. RESULTS AND DISSCUSIONS

By means of electron microscopy, the microstructures of both the base material and the deposited layers could be analyzed. Chromium carbide and Ni agglomerated particles were deposited on AISI 52100 steel. Figure 2 (a, c) shows the surface of the base material at different magnifications, and Figure 3 (a, e) shows the deposition morphology in cross section. In Figure 3. it can be seen that the particles penetrate into the base substrate, simultaneously deforming after the collision both the particles and the substrate which has a high hardness that increases the degree of deformation of the particles and which, at the same time, allows the deposition of the particles resulting in the obtaining of dense coatings and associated with the surface of the substrate. In Figure 3 (a) it can be seen that the deposited surface is flat, without cracks in the coating material or in the particles in the coating material. As can be seen, the structure is predominantly pearlitic, characteristic of a steel with a high carbon content, belonging to the category of hypereutectoid steels.

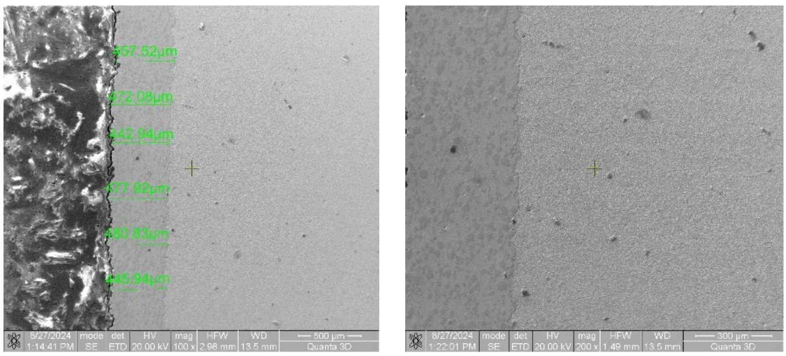


(a) (b) (c)

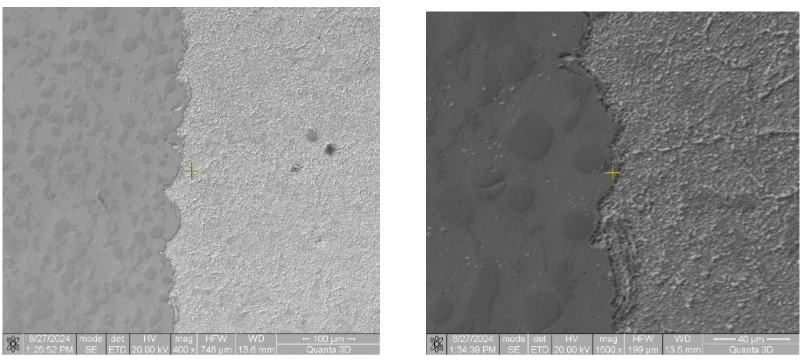


(d) (e)

Figure 2. Base material micrograph (a) 400X; (b–c) 600X; (d) 800X; (e) 1200X



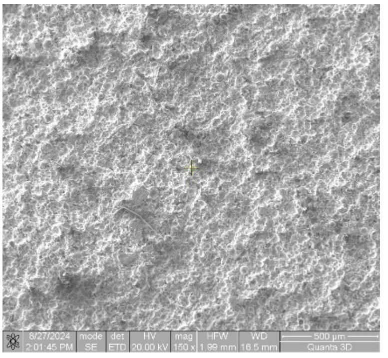
(a) (b)



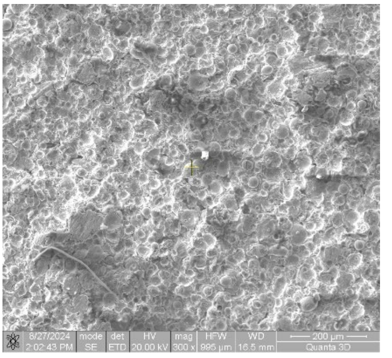
(c) (d)

Figure 3. Cross-sectional micrograph of coated material (a) 100X; (b) 200X; (c) 400X; (d) 1500X.

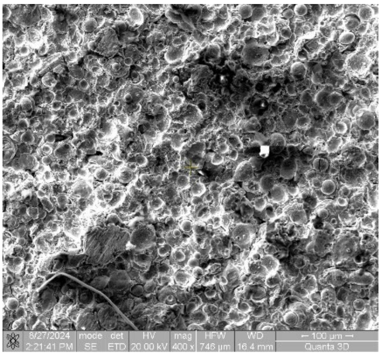
As can be seen from the morphological appearance of the particles in Figure 4, the particles are of different sizes, thus allowing the particles to penetrate and deform the substrate where the small-sized particles are propelled at a higher speed, thus leading to deeper penetration into the surface the substrate. The size of the particles range from approximately 17 and 66 µm (Figure 4 b).



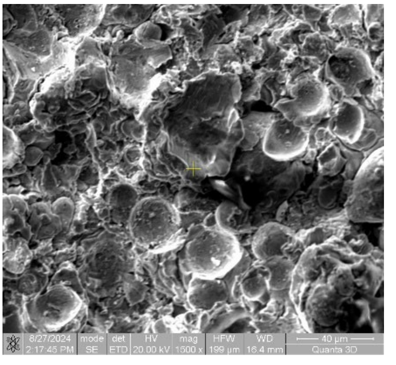
(a)



(b)



(c)



(d)

Figure 4. Surface morphology of superficial deposits (a) 150X; (b) 300X; (c) 400X; (d) 1500X.

Both for the base material and for the deposited layer, X-ray diffractions were made to evaluate the structural analysis.

From Figure 5, can be seen that for the coated material, the predominant phase is NiCr, and for the base material, it is Fe. For boated material, the predominant NiCr phase (cubic structure) was obtained at a 2 Theta angle of ca. 44° and Secondary Cr3C2 phase (cubic structure) obtained at an angle of 2 Theta of ca. 53°-77°. For base material, Fe predominant phase (cubic structure) obtained at an angle of 2 Theta of ca. 45°, Secondary phases, consisting of Fe and Cr3C2, were obtained at 2 Theta angles of 65° and 83°.

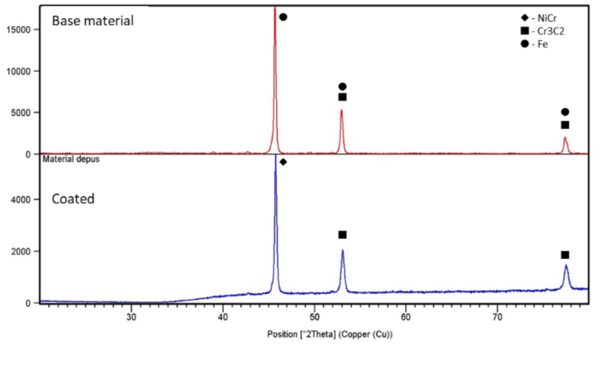
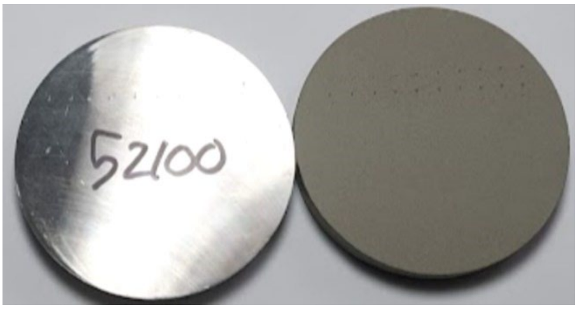


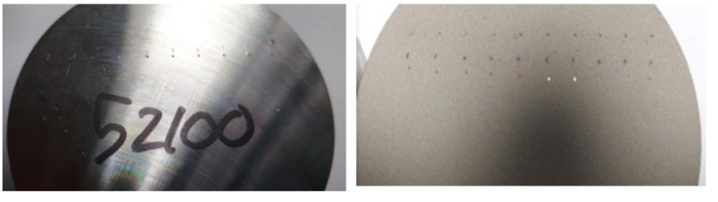
Figure 5. The resulting X-ray diffractograms for the base and coating material

Rockwell hardness tests were made up of the following specifications as follows:
- determination of Rockwell hardness with an applied force of 30 kgf (approx. 294N);
- testing of 1 uncoated sample (base material: AISI 52100 alloy steel);
- testing of 1 coated sample (deposits with Ni-Cr/C-based powders).

In Figure 6, both samples with the base material and samples with superficial deposits are shown after performing the hardness determination tests.



(a) (b)



(c) (d)

Figure 6. Images of the samples used in the hardness tests: (a, c) base material and (b, d) material with surface deposits.

After carrying out the determinations, it was found that the deposited layer leads to an increase in hardness from approx. 28 HRC30 for the base material at approx. 45 HRC30 for the deposited layer. Figure 7. shows the graph with the values obtained after determining the hardness, both for the base material and for the coating material.

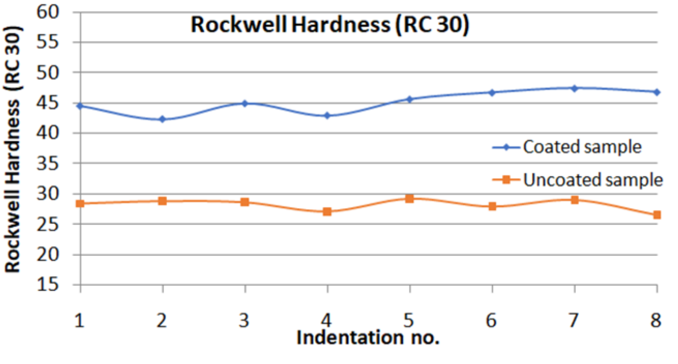
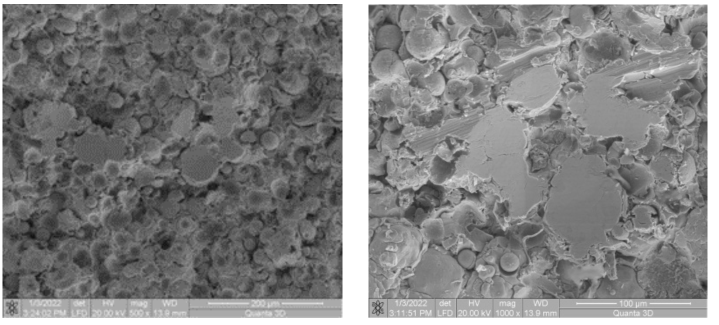


Figure 7. Results obtained from the determination of Rockwell hardness for the base material (blue line) and the coated material (orange line)

In figure 8, from the SEM images, you can see the typical micro indentation marks for the samples subjected to hardness determination tests.



(a) (b)

Figure 8. Indentation marks resulting from hardness determinations

4. CONCLUSIONS

1. Research shows that Ni/CrC forms a stable coating on 52100 alloy steel when deposited by the cold spray technique. Microstructural analysis shows that the coatings are dense and closely connected to the surface of the substrate, and through the simultaneous collision and deformation between the particles and the underlying substrate, the particles are deeply embedded, achieving this strong connection through a mechanical interlocking phenomenon.
2. The hardness of the material increased from 28 HRC for the base material to 45 HRC for the deposited layer.
3. Microstructural analysis shows that the deposited layers are dense and closely connected to the surface of the substrate, and through the simultaneous collision and deformation between the particles and the underlying substrate, the particles are deeply embedded, realizing this strong connection through a mechanical interlocking phenomenon.

ACKNOWLEDGMENT

This paper is an improved version of the presentation at *The 11th International Conference of Aerospace Sciences, **"AEROSPATIAL 2024"***, 17 – 18 October 2024, Bucharest, Romania, within the associated event: The "Gheorghe VASILCA" Prize Award Ceremony.

Within this event, the first author (Fabian Cezar LUPU) obtained the *"Gheorghe VASILCA" Prize* and also gave a public lecture in front of the audience with remarkable experimental results in the field.

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