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Study on Porosity of WC-12Co Coating on 40Cr Steel Base by Explosive Method

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***Abstract*— Detonation spray is one of the thermal spray methods that is used to coat the surface of the part or restore the shape and size of the worn shaft part very effectively. The basic criteria of the coating to be achieved are the adhesion strength between the coating and the base metal layer and porosity. In this paper, the author focuses on studying the influence of spray speed, spray distance on coating porosity. The results show that with spray speed v = 1000mm and distance L = 300mm, the coating has the best porosity. This is an important criterion to determine the parameters of injection technology, so that the surface coating of the shaft-shaped part has both lubricating properties during working and has high durability**

***Index Terms*— Detonation spray , porosity, coating, adhesion, surface**

I. INTRODUCTION

In the mechanical technology industry, many advanced and modern new technologies were born. These new technologies are all aimed at creating mechanical products with better quality, higher productivity, saving materials and cheaper prices. However, those criteria must be based on meeting working requirements such as load-bearing capacity, abrasion resistance, heat resistance, corrosion resistance... Previously, due to technological limitations, people did not Fabrication of materials with different properties such as materials with high hardness, wear resistant but flexible at the core, anti-rust materials, anticorrosion materials ... Metal spraying technology was born. Having met those requirements, By metal coating, one can create heat-resistant layer, conductive layer, anti-corrosion layer for steel structures working in oxidizing or corrosive environments. Process, increasing the service life without changing the previous manufacturing technology, restoring the shape and size without having to make a completely new part. To evaluate the strong development of metallurgical spray technology, it can be based on the development of equipment and the scope of application in the field of industry and life. The development history of spray coating technology is shown in the diagram in Figure 1.1.

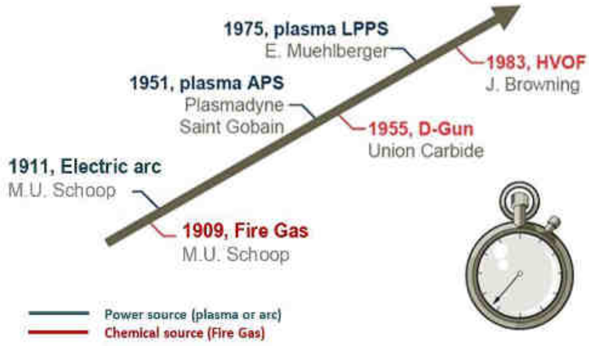

Figure 1.1. Diagram of the development history of spray coating technology

Metal spraying technology is increasingly interested in because it is important and determines the properties of coating materials. It is to create a surface layer capable of meeting working conditions such as wear-resistant, corrosion-resistant, heat-resistant.... Metallic spray technology is also used in many fields with many purposes. Various purposes such as:

- Protects against rust and corrosion in atmospheric, soil and water environments.
- Create a conductive layer on the surface of nonconductive objects, used for decoration of technical works.
- Restore worn machine parts.
- Repair defects for castings or defects that appear when mechanical processing, saving precious metals.

Currently, metal spraying technology in general and thermal spraying method in particular is still very new compared to other technologies, but has been widely applied in many industries, especially in mechanical engineering. transportation, oil and gas.... and has become an indispensable technology in the process of restoring worn parts.

Detonation spray is a high-tech coating spray, a coating with low porosity, high adhesion, can spray heat-resistant, wear-resistant and corrosion-resistant powder materials that can be used to restore detailed surfaces worn out. Detonation spray methods are widely used in all industries such as: machine building, aviation, rocketry, shipbuilding, petroleum, metallurgy [1]... Table 1 summarizes the thermal spray processes and lists some of the specific important process attributes and the resulting coating characteristics

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Table 1 Thermal spray process comparisons

Attribute	Flame spray	High-velocity oxyfuel	Detonation gun	Wire arc	Air plasma	Vacuum plasma	Radiofrequency plasma
Jet							
Jet temperature, K	3500	5500	5500	>25,000	15,000	12,000	10,000
Jet velocities, m/s (ft/s)	50–100 (160–300)	500–1200 (1600–4000)	>1000 (>3300)	50–100 (160–300)	300–1000 (1000–3300)	200–600 (700–2000)	20–80 (70–300)
Gas flow, sLm	100–200	400–1100	N/A	500–3000	100–200	150–250	75–150
Gas types	O_2, acetylene	CH_4, C_3H_6, H_2, O_2	O_2, acetylene	Air, N_2, Ar	Ar, He, H_2, N_2	Ar, He, H_2	Ar, He, H_2
Power input, kW equiv.	20	150–300	N/A	2–5	40–200	40–120	40–200 (plate)
Particle feed							
Particle temperature (max), °C (°F)	2500 (4500)	3300 (6000)	N/A	>3800 (>6900)	>3800 (>6900)	>3800 (>6900)	>3800 (>6900)
Particle velocities, m/s (ft/s)	50–100 (160–300)	200–1000 (700–3300)	N/A	50–100 (160–300)	200–800 (700–2600)	200–600 (700–2000)	20–50 (70–160)
Material feed rate, g/min	30–50	15–50	N/A	150–2000	50–150	25–150	20–50
Deposit/coating							
Density range (%)	85–90	>95	>95	80–95	90–95	90–99	95–99
Bond strength, MPa (ksi:)	7–18 (1–3)	68 (10)	82 (12)	10–40 (1.5–6)	<68 (<10)	>68 (>10)	>68 (>10)
Oxides	High	Moderate to dispersed	Small	Moderate to high	Moderate to coarse	None	None

One of the quality requirements of spray coating technology is that the coating must be adhered to the substrate metal surface. To achieve that, the pressure of the spray particles at the time of contact with the surface of the sprayed substrate must be large enough, thanks to the impact energy, to melt the contact surface and thereby create a bond between the spray material and the base material.

Explosion nozzle (Figure 1.2) consists of the following main components: A combustion chamber, which is led with oxygen and combustible gases as a source of energy, spark plugs, spray powder tanks, control valve system, and containers gas, electrical and hydraulic control systems. The blast nozzle is placed on a 3-way adjustable bracket, suitable for the injection position of the part to be sprayed.

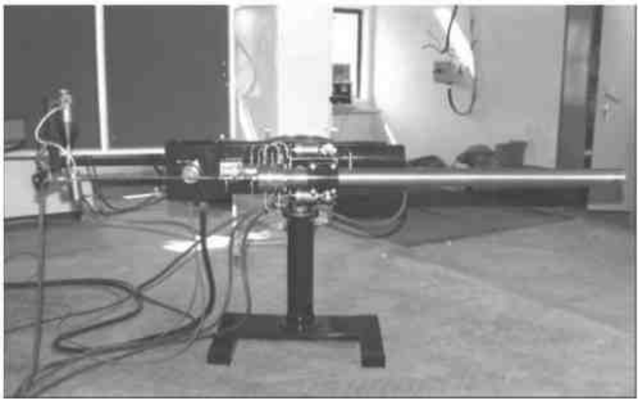


Figure 1.2. Structure diagram of explosive nozzle and spraying process

2. RESEARCH CONTENTS

2.1. Spray principle

Principle of gas thermal injection process - explosive spray. Oxygen and acetylene gas are mixed in the combustion chamber with a determined ratio, then the spray powder is supplied with nitrogen gas, using spark plugs to activate sparks into the combustion chamber containing a mixture of gas and powder explosive reaction. After the explosion, the combustible gas forms high pressure and high temperature, heats the powder particles and is moved to the barrel, the gas flow rate increases gradually from the point of explosion to the tip of gun barrel [2], when coming out of the nozzle, the powder particles accumulate very large kinetic energy, the speed can reach 820 m/s [3], they fly to adhere to the substrate surface. Due to the structure of the spray gun, after explosion and sudden thermal expansion, they create a negative pressure area in the combustion chamber and suck the mixture of spray powder and nitrogen gas into the combustion chamber, preparing for the next explosion. Just like that repeat the process of explosion - thermal expansion. As a result, the high-pressure and high temperature combustion gas carrying the spray powder is ejected from gun barrel [2].

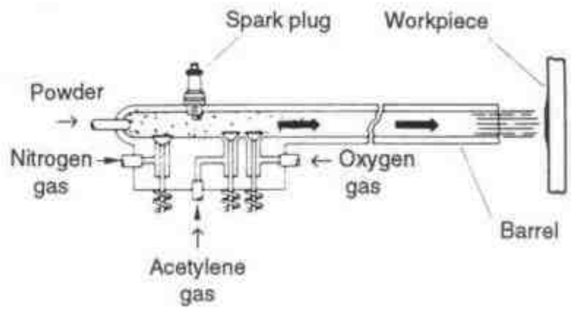


Figure 1.3. Diagram of the principle of gas thermal nozzle - Detonation spray

The spray powder mass is heated and imparts energy, having initial kinetic energy, forming spray particle beam pulses. When coming out of gun barrel, the spray particle beam was melted and the pressure inside the spray dropped suddenly, the large particles were broken up to form many small fog-like particles. At this time the mixture of air mass and spray powder with high pressure and speed flies to the surface of the object to be coated and forms a coating.

2.2. Heat spray coating

In thermal spray coatings exist oxides and porosity. During their flight from the gun to the substrate surface, the particles have chemical and physical interactions with their surroundings. Thermal spray coating is composed of thin layers with borders parallel to the substrate surface. Each spray usually has from 5 to 15 thin layers, depending on the spray parameters (powder feed flow, spray distance, spray powder size, nozzle travel speed)

The conditions for forming the boundary between layers and between particles are determined by the length of time they remain in the atmosphere [4].

During spraying, the interaction time between particles with the surrounding environment is very short, and then solidifies and cools rapidly, losing the ability to interact. Due to such a short time, the diffusion process is not deep and has little effect on particle adhesion. The attachment of the particle to the substrate, mainly depends on the degree of physical bonding, which manifests itself as the appearance of adhesion spaces on the contact surface. The formation of spray layer is the process of placing countless and consecutively deformed spray particles on the substrate surface, when the spray particles contact each other or contact the surface without filling the space, it will cause porosity in the coating. The process of physical contact does not limit the interaction because under the impact of the impulse, the molten particles will qquickly spread out and pressed against the surface of the substrate. Below is an image of the morphology of the thin metal layer impacting on the surface of the base metal shown in Figures 2.1 and 2.2, thereby showing the cross-sectional diagram of the microstructure of the thermal spray coating.

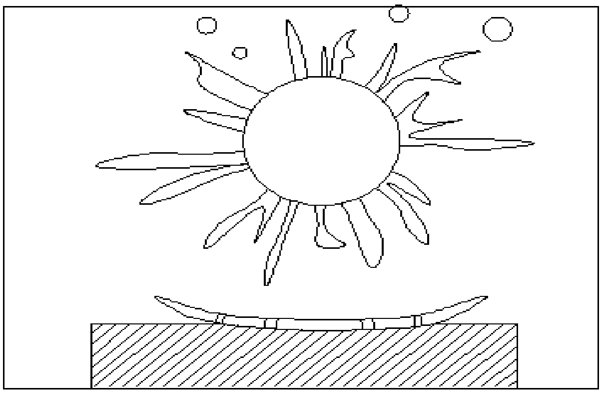


Figure 2.1. State diagram of the thin metal layer falling on the surface

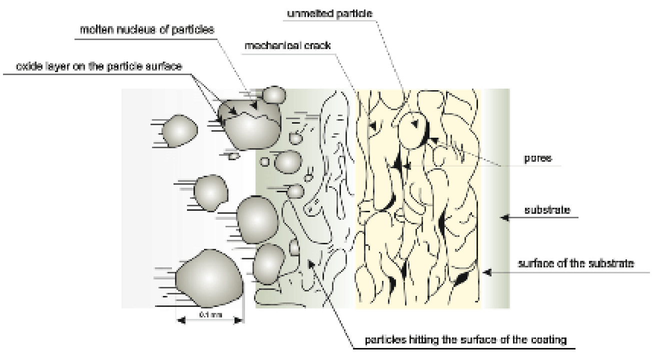


Figure 2.2. Structural cross-sectional diagram of thermal spray coating

2.3. Porosity

Porosity is one of the important properties of thermal spray coatings. During the spraying process, when the particles have not melted, they will solidify and shrink in volume to form micro-porosity. In addition because the following spray particles do not fill all the space, they also create porosity the porosity of the coating is shown in Figure 2.3.

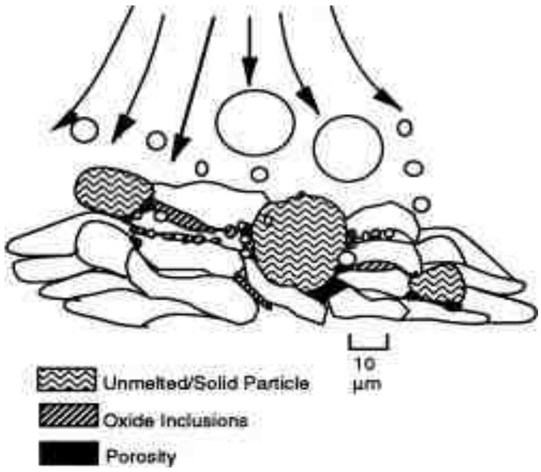


Figure 2.3. Structure representation of the porosity of the thermal spray coating

Depending on the spraying process, the spray method, the coating can receive different porosity, normally the coating porosity reaches values in the range of 0.1 to 15%. The porosity also depends on the optimal selection of spray parameters such as: spray metal particle size, spray speed, spray flow and spray distance... Therefore, the research to reduce porosity is expensive. The lowest value to meet the needs of use in industries has always been of interest to scientists around the world. Currently, a number of thermal spray methods have been researched for lower porosity than other spray methods, in which the explosive spray method has the lowest porosity, due to the gas velocity acting on the spray particles high, pushing most of the accumulated air pockets out of the structure of the mantle [5]. Table 2 shows, the difference of the coating porosity when spraying by blasting method, using different coating materials gives different porosity quality of the coating

Table 2. Difference of coating porosity by detonation spray method

Coating material	Porosity (%)
Diamalloy 1005 niken/crôm molypden background bazơ	1
Diamalloy 2003 tungten cacbit - coban	< 0,5
Diamalloy 3001 coban alloy background	1,5
Diamalloy 3006 crôm cacbit / niken crôm	1

3. US EXPERIMENTAL METHODS

3.1. Spray material:

3.1.1. Base material: For the purpose of spraying to restore the camshaft, the sample composition is equivalent to 40Cr steel. To facilitate the experiment, the spray sample is designed as shown in Figure 3.1 with the outer diameter D = 60 mm, the inner diameter d = 30 mm and the length of the sample L = 20 mm

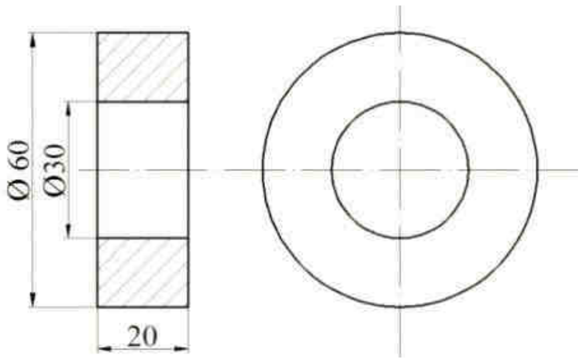
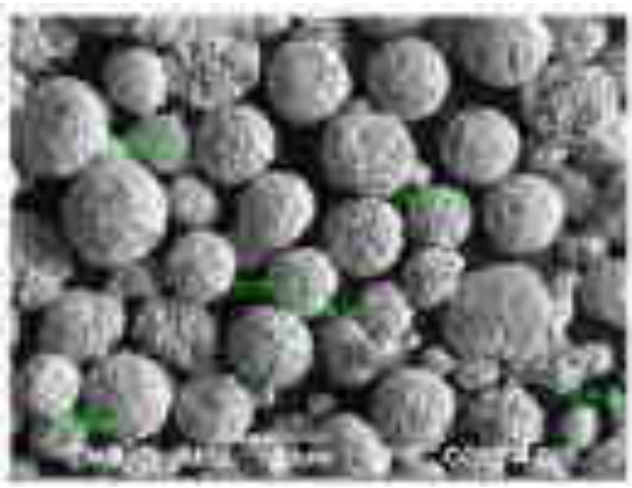
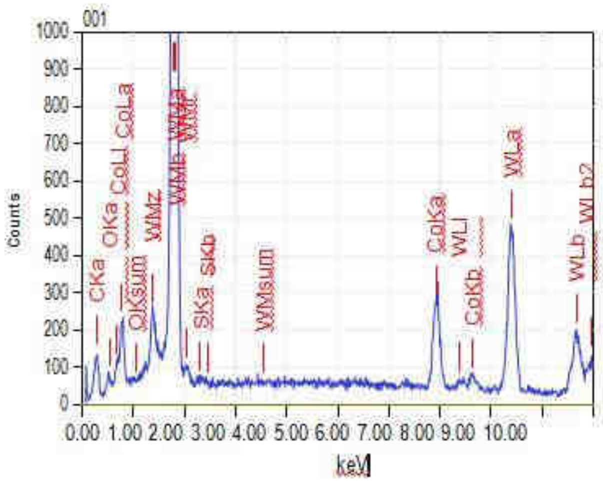


Figure 3.1. 40Cr steel spray pattern

3.1.2. Spray powder material: Experimentally using WC12Co alloy powder material, with particle size from 15÷45µm for experimental spraying. The main chemical composition of the powder is provided by the manufacturer including WC and 12% Co for the purpose of creating an anti-wear coating due to the good anti-wear properties of the carbide component.



a. SEM image of WC - 12Co spray powder



b. EDX analysis of spray powder composition Figure 3.2. Morphological analysis and composition of WC-12Co powder

3.2. Test method:
To determine the structure and organization of the coating, and the coating thickness, optical microscopy was used to image the coating with different magnifications. In addition, the porosity of the coating is measured based on ASTM B276-05 (2015) [7] which is used to evaluate the porosity of ceramic coatings and bits. The porosity of the coating was determined as the percentage of the pore area over the total area of the micrograph with 200x magnification (Figure 3.3b). The porosity value of the spray sample is calculated as the average of four porosity measurements on four 200x magnification micrographs at four different locations. The process was carried out on an Axioplan 2 – Carl Zeiss optical microscope (Figure 3.15a) (originated from Germany).

a. Axioplan 2 optical microscope

b. Porosity measurement results
Figure 3.3. Equipment and results of porosity measurement

4 RESULTS AND DISCUSSION

Effect of spray speed, spray distance on coating porosity According to the principle of spray flow, the flight speed of the sprayed matter particles will be gradually reduced with the distance from the nozzle to the surface of the substrate. The injection flow rate is decisive to the technological process. Spraying was carried out on the determined test sample, WC-12Co spray material with a particle size of 15-45µm, On the test samples conducted with 3 different spray speeds: V1 = 800m/s, V2 = 1000m/s , V3 = 1,200m/s. After the experiment, the porosity determination was carried out on an Axioplan 2 optical microscope. The porosity of the coating was determined as the percentage of the pore area over the total area of the micrograph. The diagram and 3D porosity graph in the relationship between spray speed and spray distance are as follows:

From Figure 4.2, it can be seen that the best porosity is located in the region with high injection speed and large enough distance. When the spray speed is 1000m/s, the distance must be over 300mm.

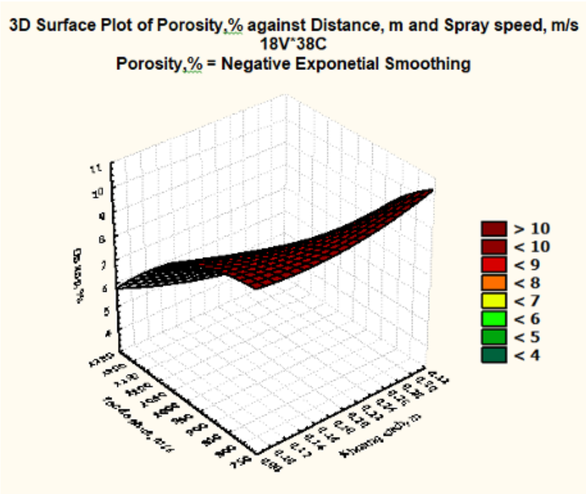


Figure 4.1. 3D graph of porosity relationship with spray speed and spray distance

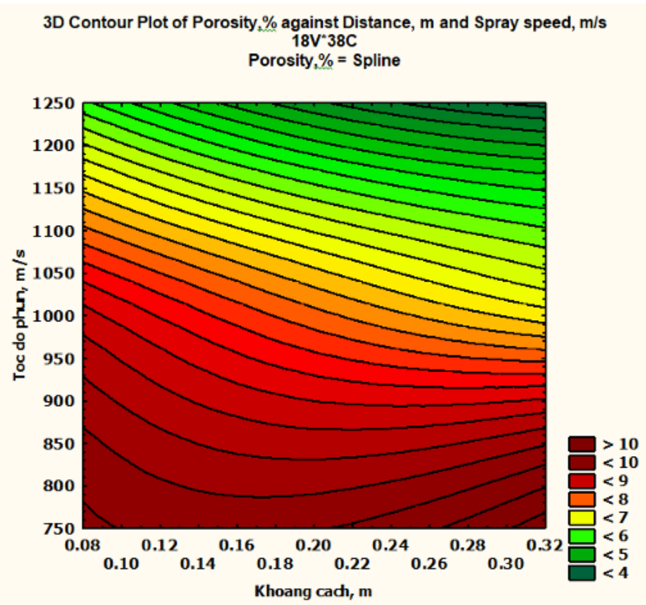


Figure 4.2. Porosity plot in the relationship between spray speed and spray distance

CONCLUSION

From the above results, it is possible to establish relationships between technological factors, in which the influence of spray speed parameters, spray distance on the porosity of the coating is investigated. The results show that the coating quality reaches the best value when spray speed V2 = 1000mm and spray distance L2 = 300mm. The figures and graphs can be used for reference, and can be used to look up and choose the optimal technological parameters when spraying.

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