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# Spray coating technology for wear-resistant and anti-rust coating on cell brake disc

## Công nghệ phun phủ tạo lớp chịu mài mòn và chống gỉ trên đĩa phanh ô tô

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## Abstract

Brake disc materials are often made from gray cast iron due to their high temperature resistance and damping ability. At the same time, this material is also advantageous in casting and cutting processing, and low cost. There have been tests with some other light alloy materials, but they do not withstand high temperatures (friction) and the price is also high. However, gray cast iron material has the disadvantage of poor corrosion rust resistance and high abrasion, creating a powder film that both limits the effect when braking and pollutes the environment. Therefore, the problem is how this material surface treatment technology solves both of the aforementioned disadvantages simultaneously. The article deals with gas thermal spraying technology for spraying or welding the layer of materials that are resistant to abrasion and grinding in environments with the impact of moisture. The author has proposed inexpensive materials and atmospheric plasma injection technology to lower the cost of products. This technology also has the potential to be applied in new construction or restoration of some duo parts of internal combustion engines.

*Keyword:* Gray cast iron, friction, wear resistance, plasma spray, amorphous materials.

## Tóm tắt

Vật liệu làm đĩa phanh thường được chế tạo từ gang xám do chịu được nhiệt đô cao và khả năng giảm chấn. Đồng thời vật liệu này còn thuận lợi trong gia công đúc và cắt gọt, giá thành hạ. Đã có những thử nghiệm với một số loại vật liệu hợp kim nhẹ khác, nhưng chúng không chịu được nhiệt độ cao (khi ma sát) và giá thành cũng cao. Tuy nhiên vật liệu gang xám lại có nhược điểm là khả năng chống gỉ ăn mòn kém và độ bào mòn cao, tạo ra màng bột vừa hạn chế tác dụng khi phanh, vừa gây ô nhiễm môi trường. Từ đây, vấn đề đặt ra là công nghệ xử lý bề mặt vật liệu này như thế nào để giải quyết đồng thời cả 2 nhược điểm nói trên. Bài viết đề cập đến công nghệ phun nhiệt khí để phun hoặc hàn đắp lớp vật liệu chịu được sự mài mòn và mài nghiền trong môi trường có tác động của độ ẩm. Tác giả có đề xuất loại vật liệu không đắt tiền và công nghệ phun plasma trong khí quyển để hạ giá thành sản phẩm. Công nghệ này còn có triển vọng áp dụng trong chế tạo mới hoặc phục hồi một số chi tiết dạng bộ đôi của động cơ đốt trong.

*Từ khóa*: Gang xám, ma sát, độ chịu mòn, phun plasma, vật liệu vô định hình.

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## 1. Introduction

The bowl manufacturing industry is always associated with weight reduction to save fuel. This concerns each component, including the disc brake assembly. There are 2 types of materials for making brake discs: aluminum alloy and cast iron (gray cast iron or modified cast iron). With the best technology, brake discs are made from an aluminum alloy and then sprayed with stainless steel material, both reducing friction and increasing rust resistance [1]. The research team has applied the technology of spraying arc wire with stainless steel wire. However, the adhesion of the spray layer is not guaranteed, so only a thin layer can be sprayed and easily peeled after 1000 thermal cycles. Arc spraying also causes corrosion when tested for rust resistance. Finally, the solution is to use two sprayed layers: the duplex material spray bonding by cold spray technology, and the finish coating is arc spraying, combining the benefits and drawbacks of both methods and reducing weight by nearly 50%. The material for making the engine body can be an aluminum-silicon alloy. The disadvantage of this material is its low hardness, so it does not meet the lubrication requirements. The alternative solution is to squeeze the barrel bushing made of gray cast iron into the cylinder. The second solution is to spray wear-resistant material into the inner surface of the cylinder. With this second solution, there are several types of spraying materials and special equipment for spraying the inside of the cylinder [2]. Thus, economically, this group of materials is not very attractive, even if it is possible to raise the content of the alternative element Fe. However, it should also be seen that the advantage of this solution is that the weight of car brake discs has been reduced from 4.28 kg to 1.77 kg, under the condition that the coefficient of friction is considered equivalent to that of gray cast iron materials (0.42 and 0.36, respectively), while the wear rate of gray cast iron materials ($1.294 \pm 0.166 .10^{-5}$ $mm^3/m$) is larger than that of duplex line stainless steels ($0.751 \pm 0.166. 10^{-5}$ $mm^3/m$). Following the second concept, it is understood that cast iron materials are easy to process (casting workpieces) and have high hardness, good heat absorption, and good damping, accompanied by low material prices. Adherents of this concept claim that aluminum alloy materials have a lower melting point than cast iron materials and a high cost. However, the disadvantage of cast iron materials is poor rust resistance and a fairly high wear rate compared to aluminum alloy materials. Not to mention the dust caused by brake disc wear that pollutes the environment. Therefore, spray technology is investigated to address these disadvantages [3]. In this direction of research, there are several groups of materials and spraying technologies that have been published only within the last 10 years, showing their application potential. The first group of materials, oxide systems ($Al_2O_3$, $TiO_2$, and $Cr_2O_3$), is of interest because it meets both requirements for wear resistance and rust resistance [4, 5]. The results of the study of the correlation between the mechanical properties and wear resistance properties of spray layers from this group of ceramic system materials are published in [6], [7], and [8]. The results of the injection survey of $Al_2O_3$-$TiO_2$ component material ($Al_2O_3$-wt%10–13$TiO_2$) using plasma spraying method on brake disc billets made of gray cast iron material (GG20/EN-GJL-200) achieve a lifetime 18 times longer than that of unsprayed brake discs, according to the minimum thickness criterion [9]. However, the research results are limited to only 2 survey parameters: microscopic hardness and friction coefficient. The second group of materials is the carbide system (WC, $Cr_2C_3$) on the substrate bonded with metals or their mixtures, such as Ni, Co, Cr, and Fe, forming the cermet material system [10,11,12]. This group of materials meets the criteria for wear resistance, including toughness and good adhesion, but the material cost is high (Ni and Co metals) and is often sprayed with a high-speed combustible-oxygen spraying device (the criteria for wear resistance, including toughness and good adhesion, but the material cost is high (Ni and Co metals) and is often sprayed with a high-speed combustible-oxygen spraying device (HVOF), which is quite expensive. Not to mention, there have been studies by the US Department of Health warning of the risk of cancer caused by WC-Co fine dust produced at high temperatures [13, 14]. A new, promising group of materials is a slag self-forming alloy system: Ni-Cr-boron-Si mixed with element Fe [15, 16]. Most especially in the solution using plasma spray technology, very little is known about plasma gases with ordinary air but mainly with expensive inert gases such as argon, helium, or their mixtures. From this analysis, it is shown that the solution of spraying iron (Fe) alloy systems, plasma spraying using gas to create plasma with air, is a new direction. The problem with this new solution is oxidation in the air. The value of the solution is to select reasonable technological parameters, accompanied by nozzle structural improvements, to meet a number of criteria for spray layer features such as hardness, wear resistance, and porous pitting. This is the goal of this author's new study.

## 2. Research methodology

The study was carried out, using SG-100 TAFA – Praxair (USA) plasma spraying equipment. There are 4 types of sprayed materials, fine powder, particle size: 40- 70 µm. The chemical composition of the material is determined using X-ray energy dispersion spectroscopy - SM- 6610 LV (Japan), given in Table 1. The substrate for spraying is gray cast iron: GG20/EN-GJL-200 according to DIN EN 1561.

**Table 1**. Chemical composition (in wt%) of sprayed materials

| Code | C | Cr | B | Mo | Nor | Mn | Yes | Nb | In | In |
|---|---|---|---|---|---|---|---|---|---|---|
| H-4 | 0.11 | 32.9 | 0.10 | 3.30 | 5.0 | 1.05 | 0.70 | - | - | - |
| B-5 | 0.06 | 35.3 | 0.40 | 3.50 | 10.5 | 1.05 | 0.91 | - | - | - |
| H-10 | 0.41 | 12.5 | - | 0.70 | - | 0.54 | 0.66 | 0.73 | 0.35 | 6.10 |
| X-5 | 0.73 | 5.0 | 0.25 | 4.20 | - | 1.25 | 0.84 | 0.54 | 1.20 | - |

The oxygen content of the spray layer is determined by the instrument G8 Galileo (Germany) based on the principle of complete incineration and extraction analysis of the sample material. Wear resistance is determined according to ASTM G133. In the study, attention was paid to the quantities of spray particle rate and plasma flow enthalpy to assess the influence of the kinetic energy and heat energy of the spray flow on the basic features of the spray layer. Particle rate measurement with a high-speed imager (Shimadzu HPV-1, Japan). The method of measuring enthalpy follows [17]. The empirical data are processed using software that calculates according to the minimum squares method to obtain the empirical formula. There is a nozzle structural enhancement to increase the spray power to 80 kW, to increase the mechanical properties of the spray layer, i.e., to indirectly improve the wear resistance of the surface, and to improve the spray efficiency due to the concentrated plasma flow. This is a structure with intermediate cavities installed on the nozzle body to increase the spray voltage. The difficulty in fabrication and assembly is that these intermediate chambers must be insulated and concentrically cooled throughout the system (see Figure.1)

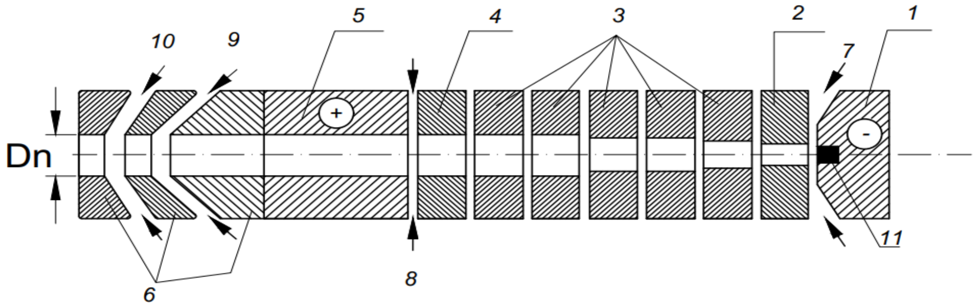


**Figure 1**. Improved nozzle construction

1. Cathode ; 2- 3-4 Intermediate cavity ; 5- Anode; 6- Powder suction; 7- Incoming gas; 8-Shielding gas; 9- Powder loading gas; 10- Swirl plasma flow; 11- Cathode electrode; $D_n$ – injection nozzle diameter

### *2.1. Case study 1*

Change: air flow, voltage, and current (i.e. change in plasma capacity), keep the same spray distance of 130 mm, evaluate the effect of parameters on oxygen content before and after spraying (Table 2).

**Table 2**. Spray mode assesses the degree of oxidation

| Regime | Current of plasma (A) | Power supply voltage (V) | Air flow rate (g/s) |
|---|---|---|---|
| 1 | 130 | 220 | 1.2 |
| 2 | 185 | 190 | 1.3 |

### *2.2. Case study 2*

The spray parameters given in Table 3, the spray distance is 150 mm, to determine the amount of element burn and spray layer hardness.

**Table 3**. Spray mode assesses the amount of burn of alloying elements

| Regime | Current of plasma (A) | Power supply voltage (V) | Air flow rate (g/s) |
|---|---|---|---|
| 1 | 120 | 200 | 2.34 |
| 2 | 160 | 190 | 2.34 |

### *2.3. Case Study 3*

Keep the same amperage, change in air flow, measure wear (dry friction) and spray layer adhesion strength according to Table 4.

**Table 4.** Spray mode evaluates wear resistance, spray layer adhesion, X-5 material

| Order | CLine- I, A | Flow rate - G, g/s | Wear resistance in relative units | Adhesion strength, MPa |
|---|---|---|---|---|
| 1 | 160 | 0.55 | 22 | 23 |
| 2 | 160 | 1.13 | 54 | 40 |
| 3 | 160 | 1.76 | 39 | 35 |
| 5 | 185 | 0.75 | 30 | 46 |
| 6 | 185 | 1.42 | 68 | 56 |
| 7 | 185 | 1.76 | 40 | 54 |

**Table 5**. Oxygen content before and after spraying

| Material | Regime | Oxygen content, % | |
|---|---|---|---|
| | | In powder to spray (pre-spray ) | In the spray layer (after spraying) |
| H-4 | 1 | 0.20 | 1.75 |
| | 2 | 0.21 | 1.16 |
| B-5 | 1 | 0.29 | 1.35 |
| | 2 | 0.31 | 0.08 |
| H-10 | 1 | 0.19 | 1.25 |
| | 2 | 0.20 | 0.92 |
| X-5 | 1 | 0.13 | 2.20 |
| | 1 | 0.13 | 1.60 |
| | 2 | 0.15 | 1.55 |

## 3. Results and discussion

From Table 5, it is seen that the oxygen content is markedly increased in the spray layer. The reason is that the spraying process in an atmosphere without protective gas, using plasma gas, results in oxidized powder particles. However, in the second mode (Table 3), due to the increase in injection power, the particle speed increases, the flight time in the plasma stream decreases, and the oxidation level decreases. The degree of oxidation affects the spray layer hardness and has a two-sided effect on the friction process. Hardness and wear resistance measurement results are shown in Table 6.

**Table 6**. Elemental burnout and spray layer hardness

| Ma te rial | Spray mode | Element content / burn rate (relative to % by wt) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C | Cr | B | Mo | Ni | Mn | Yes | $N_2$ | Nb | W | V | Hardness (HRC) |
| H-4 | 1 | 0.1 | 29.6 | 0.09 | 3.36 | 4.37 | 0.69 | - | 0.4 | - | - | - | 44 |
| | 2 | 9.1 | 10.1 | 10 | (1.82) | 12.6 | 34.3 | - | 33.4 | - | - | - | |
| H-4 | 1 | 0.1 | 29.6 | 0.08 | 3.35 | 4.5 | 0.55 | 0.35 | 0.5 | - | - | | 46-52 |
| | 2 | 9.1 | 10.1 | 20 | (1.52) | 10.0 | 47.6 | 50.0 | 66.7 | - | - | - | |
| H-10 | 1 | 0.09 | 34.1 | 0.88 | 3.4 | 10.5 | 0.27 | 0.67 | 0.5 | - | - | | 41-45 |
| | 2 | (50) | 3.4 | 16.2 | 2.9 | 20 | 46 | 26.4 | 0.0 | - | - | - | |
| H-10 | 1 | 0.09 | 35.1 | 0.27 | 3.49 | 10.5 | 0.92 | 0.67 | 0.5 | - | - | | 41-43 |
| | 2 | (61.7) | 0.45 | 46.0 | 0.3 | 0.0 | 12.4 | 26.4 | 0.2 | - | - | - | |
| B-5 | 1 | 0.37 | 10.5 | - | 0.7 | - | 0.4 | - | - | 0.48 | 0.27 | 5.9 | 34-42 |
| | 2 | 6.1 | 11.2 | - | 5.7 | - | 7.4 | - | - | 23.3 | 22.9 | 3.3 | |
| B- 5 | 1 | 0.37 | 10.6 | - | 0.7 | - | 0.4 | - | - | 0.48 | 0.27 | 5.9 | 46-52 |
| | 2 | 9.8 | 16.0 | - | 0.0 | - | 25.9 | - | - | 34.3 | 22.9 | 3.3 | |
| X-5 | 1 | 0.52 | 5.25 | 0.15 | 4.0 | - | 1.2 | - | - | 0.56 | 1.06 | - | 50-54 |
| | 2 | 28.8 | (5.0) | 40.0 | 4.8 | - | 4.0 | - | - | (3.7) | 11.7 | - | |
| X-5 | 1 | 0.41 | 5.2 | 0.1 | 4.0 | - | 1.0 | - | - | 0.55 | 1.1 | - | 45-52 |
| | 2 | 43.8 | (4.0) | 60.0 | 4.8 | - | 20.0 | - | - | (1.9) | 8.4 | - | |

In case 2 and the results of the analysis from Table 6 show that: for some elements such as Cr, Mo, Ni and W the degree of burn may be due to analysis error, while for elements C, boron, Mn, Si and Nb the burnout is significant. In terms of hardness, X-5 material reaches the highest level. This will be potential material for further research. In case 3, Table 5 results are explained as follows: gas flow has an effect on the particle rate, leading to a change in the degree of melting and particle kinetic energy, a mechanical change in the injection layer. (Due to the framework prescribed by the report, the author does not include particle velocity measurements of sprayed material here).

## 4. Conclusion

1. Iron-based alloy (Fe) materials, which contain up to 90% of this element, have the potential to replace expensive materials, even in the case of plasma spraying that uses air to activate the plasma source.
2. It is necessary to continue experimenting to improve the technology in practical conditions in order to find economically viable solutions in the manufacture of automobile brake discs.
3. The research results are used to improve the nozzle structure to improve spray performance.

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