

# Study on HVOF spraying replacement of EHC repairing technique

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## Abstract

The EHC processing can be prepared wear and corrosion resistance coatings for key parts, such as watercraft engine and some hydraulic pressure system, in conventional manufacturing. However, the EHC processing contains poisonous mass, which pollutes severely water and air and is harmful to human. The EHC processing is hard to conduct on big parts. It takes a long time to deposit thickness coating and its performance does not reach requirement. The researches indicate that properties of the coating prepared by HVOF processing corresponding to that of coating fabricated by EHC processing. The coatings produced by HVOF are conforming to environmental protection. And it has many advantages, such as safety, cleanness, convenience, economy, high efficiency and no poison, which are applied on repairing and strengthening and studying on key parts of ships and nuclear power station.

**Keywords:** HVOF; EHC; replacement; repairing; environment protection

## 1 Introduction

The EHC are used as contact and relative movement surface coatings because of its uniquely mechanical properties, such as high hardness, low friction coefficient, excellent corrosion and wear resistance, and it has a widely application in conventional manufacturing. However, it has some flaws.

The EHC processing can produce many wasters, for example Cr+6, which pollutes air, water and solid. The Cr+6 is very stable and is one of the environmental carcinogens. It can exist in environment, human and organism for a long period. The relative regulations have been promulgated by EA. The Cr+6 and its productions have been not permitted to use in Europe from 1st, July in 1997. With increasing attentions on environmental protection by government, the limitations of the EHC processing are becoming more and more. Then a new technology will be generated to replace the EHC processing.

The EHC coating has excellent mechanical and chemical properties, but it has some limitations. When the processing or controlment not reaches requirement, the flaws such as pores, microcracks, will be produced, which accelerates the corrosion of steel substrate and spalling of the coatings. The Cr electrode potential is -0.74V and that of the Fe is -0.441V. The Cr electrode potential is lower than that of the Fe, but Cr is not an active element. In addition, the Cr coatings have a large

tension stress and the coating is brittle, which is easily pulled out from the substrate.

In equipment repair, the coating must be thickness. The parts are not similar and time is short. Therefore, the EHC processing is not the first choice. But HVOF can solve those difficulties. It can prepare coatings with different chemical compositions, which satisfies with different application requirements. In this paper, three carbide-based materials (WC-Co, NiCr-Cr<sub>3</sub>C<sub>2</sub>, WCCoCr) are used by HVOF processing. The coatings have been compared with the coating prepared by EHC processing. And the coatings are fabricated by HVO/AF spraying system.

## 2 Introduction of HVOF

### 2.1 General situation of HVOF

Since the equipment of JET-KOTE developed by J·A·Browning in eighties of twenty century, the technique of HVOF have been applied in industry for about 20 years. At present, it is still accepted as a successful and efficient thermal spraying method, and has been widely used in the fields such as mechanical processing, petrochemical engineering, aerospace, water conservancy and electric power, mine and metallurgy, communications and transport, equipment maintenance, of which great efficiencies of economy and society as well as military.

HVOF is one of the thriving thermal spraying methods. Presently, most of the equipment used in China are imported from Europe or America. At the first nineties in 20 century, some universities such as Xian Jiaotong University and Second artillery Academy of Engineering have been enjoying the development of HVOF equipments.

The development of HVOF is mainly focused on: increasing the particle velocity, improving the coating quality, optimizing the process and decreasing the cost. For example, the WC-Co and NiCr-Cr<sub>3</sub>C<sub>2</sub> coatings fabricated by HVOF have perfect grain-abrasion, scouring, and sliding wear resistance as well as heat resistance, thus it increased the lifetime of the parts coated for about 2~7 times as the original one.

### 2.2 Basic fundamentals of HVOF

Super-sonic flare spraying, namely high velocity oxygen fuel flare spraying (HVOF), uses the C-H type fuel such as propane and propylene or hydrogen and high pressure oxygen, or uses fluid fuel such as coal oil and alcohol and high pressure oxygen (or the mixture of oxygen and air) burned in special combustion room, and accelerated by special nozzle to form high temperature and high

velocity flame flow, the solid particles are feed to the nozzle, heated and accelerated with the energy of flame flow, the atomized particles are then impinged on the substrate surface to form coating. The key parameter for HVOF is the particle velocity, in a typical process, the velocity of combustion gas is able to reach 1500~2000 m/s, and the average particle velocity is about 300~650 m/s.

Figure 1 shows the schematic graph of the HVOF/AF multifunctional super-sonic flame spraying system used in this study. The process of this system can be described as that, using the coal oil as the fuel, oxygen (or mixture of oxygen and compressed air) as the combustion improver, these gases controlled by controller were transferred to the spray gun, mixed, ignited and burned in the combustion room, the burned gas was accelerated to super-sonic (above 5 Mach) by Laval nozzle. Subsequently, the particles were fed to the low-pressure region in the nozzle, accelerated and heated by the high energy of the supersonic jet, and then deposited on the substrate surface to form coating. The velocity and temperature of the jet were controlled by adjusting the flux of coal oil and combustion improver, and the particles velocity and temperature changed correspondingly.

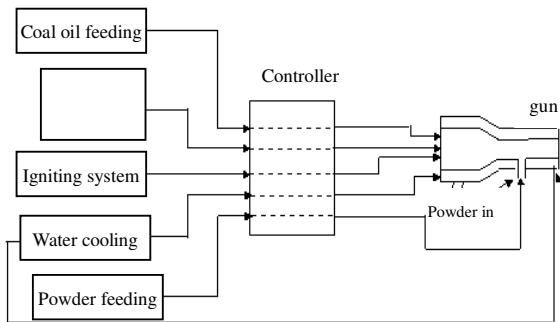


Fig. 1 Schematic of HVOF/AF multifunctional super-sonic flame spraying system

### 3 Comparison between HVOF coating and EHC film

Different from other thermal spraying techniques, HVOF has the characteristics such as providing low flame temperature ( less than 3000 °C), high particle velocity (300~650 m/s), low porosity (less than 3%) and high bonding strength (> 70MPa). HVOF is more available to spray the materials that will be adverse to improve coating properties if longer heating time is performed, for example, carbide-based powders, if HVOF was used for depositing these materials, phase transitions, oxide and carbon loss can be controlled in a very low degree, thus the coating properties such as hardness, wear resistance and bonding strength are improved.

EHC film has the advantages such as good luster, reliably working at 400 °C and corrosion resistance to some degree. The iron alloy parts are usually EHC treated because this process can improve the harness of the parts surface, wear resistance scrape resistance and corrosion resistance as well as heat resistance.

In this study, three types of HVOF coating and EHC film were compared.

#### 3.1 Typical HVOF processing parameters

Table 1 shows the parameters of the HVOF/AF functional supersonic flame spraying system used in a specified experiment. It must be concerned that the parameters are different for different spraying materials. In addition, optimizing the spraying parameters is depended on the manipulator to some degree.

Table 1 Typical parameters of the HVOF/AF functional supersonic flame spraying system

Object	Unit	Value
Coal oil flux	L/h	16
O2 flux	m <sup>3</sup> /h	38
Powder flux	kg/h	7.2
N2 flux	m <sup>3</sup> /h	0.8
Cooling water pressure ( flux)	MPa(m <sup>3</sup> /h)	0.4(4)
Spray distance	mm	380

#### 3.2 Comparison between three HVOF coatings and EHC film

Table 2 shows the parameters of three HVOF coatings and EHC film used widely in industry. It can be shown that HVOF coatings have more high hardness, wear resistance and bonding strength. Generally, the wear resistance of WC-metal composite coating prepared by HVOF is about 10 times of that of EHC film, the bonding strength of the HVOF coating is about 2 times of that EHC film. Table 2 additionally shows that the corrosion resistance of the WC-Co HVOF coating is not very good. Therefore the alternative coating, WC-Co/NiCrMo coating was developed out, which can be used in corrosion environment. The WC-Co/NiCrMo coating has a high hardness, about HV300675~775, bond strength, >80MPa, and the thickness can be as high as 2.6 mm.

EHC film have medium corrosion resistance, but the corrosion electrolyte can penetrate to the film/substrate interface because of the micro-cracks. With the expanding of micro-cracks, the film will scraped from the substrate and worsen the corrosion of substrate.

Table 2 Properties comparison between three HVOF coatings and EHC film

Coating type	HVOF			EHC
	WC—Co (88/12)	WC—CoCr (86/10/4)	Cr <sub>3</sub> C <sub>2</sub> —NiCr (75/25)	
Composition				Cr
Harness HV <sub>300</sub>	1376	1274	1080	800

Indensity (g/cm <sup>3</sup> ) <sub>20°C</sub>	13.5	—	11.6	7.1
Maximal serving temperature (°C)	530	530	800	350
SFCE corrosion resistance (corrosion rate mg/h)	24h corrosion (16.7)	— (9.2)	No corrosion (3.2)	(—)
Wear resistance (ASTM-G-65) (wear lost mg/cm <sup>2</sup> )	0.1×10 <sup>-14</sup> (3.8)	0.1×10 <sup>-14</sup> (4.0)	— (11.5)	1×10 <sup>-14</sup> (—)
porosity (%)	< 1.5	< 1	< 1	< 1.5
Bond strength (MPa)	70	70	90	35

Note: “—” means no experimental data.

Some high hardness, perfect wear resistance coatings can be prepared by HOVF, and some corrosion resistant coatings can also be prepared by HVOF, which have been validated by the applications in the “four pipes” of combustion electric plant boilers.

#### 4 Limits of HVOF

The most obvious characteristic of HVOF is that high particle velocity can be provided by this process, but at the same time, the temperature of the particles is relatively lower because of the short heating time during atomizing. Some significant advantages can be gained by HVOF on one side, but on the other side, shortcoming also brings forth.

##### 4.1 Limited powders types available for spraying

Numerous applications have shown that, carbides are the most available spraying materials, for example, WC—Co, NiCr—Cr<sub>3</sub>C<sub>2</sub>, WCCoCr, etc. during the spraying, the high particle velocity and low temperature make it is possible that oxidation and carbon loss are controlled in a very low degree. Therefore, hardness and wear resistance of the coating are improved. When some metal-based powders such as NiCrBSi, are sprayed, the particle are heated nearly to the melting point, the bond strength is therefore much less than that of the WC based HVOF coatings.

##### 4.2 Small powder size

Because the particle velocity is very high, while the flame temperature is low, the powders are heated to fusion state within very short time (about within millisecond level), the powders with bigger size are very difficult to fusion, and the deposition efficiency is very low.

Applications confirmed that, with the same spraying parameters, the deposition efficiency of Ni6040WC

powder with -150/+300 grid is only a quarter of the powder with 300/+400 grid.

#### 4.3 Heel and splashing

During the sparing, it was very easy for the fusion powders that cohered on the inlet wall of the nozzle, and then heel was formed, which is very adverse for the process reliability. In some times, the heel was surged by the high velocity gas flow and then deposited on the coating surface along with other small particles. The heel and splashing is a highly challenging problem for the manipulators. If the heel was deposited, the part has to be omitted or sprayed again. There are several factors resulted in heel and splashing, for example the design of nozzle, materials coated, machining precision, powder size and melting point, flux and flux rate of fuel gas (or liquid fuel) and combustion improver.

#### 5 Typical application of HVOF substituting EHC

Wearing is one of main failure mode of equipment component, and always coexisting with erosion, which is the main factor of effecting lifespan of equipment component. At present, manufacturing has step in the new period of fast development in China, therefore, the need for materials and coatings of wear resistance is progressive. HVOF technology has more characteristics of modern engineering technique compare with EHC, so it has been applied widely. Some applying research and invention had been done about spraying instead of plating in maintain and guarantee and increase of service life of equipment and remanufacture. Some applying instances is given as following.

##### 5.1 application in maintaining ship craft

In service and waste components of ship craft had been increased in life and remanufactured with advanced surface engineering technology, which is saving and environmental protection, so it has enormous economic and society benefits. HVOF technology spray wear resistance and erosion resistance coating to maintain cylinder rod of ship is given in Figure2. The coating thickness is 2mm, and some region is bigger than 4mm. Repairing turbine rotor is given in Figure3, and repairing hydraulic cylinder plug of steering engine is given in Figure4.

##### 5.2 application in maintaining equipments of nuclear power station

Nuclear power industry is newborn thing in china, and nuclear power has no minor things. Surface engineering technology had been applied to solve some difficulties in equipments working process of one building nuclear power station, which work had been high praised by experts. HVOF technology spray nickel-base alloy coating to maintain plunger rods is given in Figure5. The repaired plunger rods are about 30, which applying effect is good, and its life is more than three times of original production.



Fig. 2 (a) Worn and Corroded surface of the cylinder rod before maintenance



Fig.5 (a) As-sprayed plunger levers

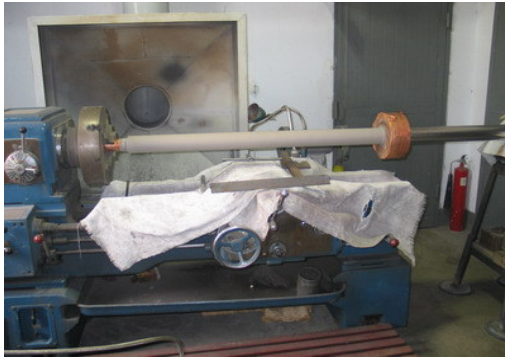


Fig. 2(b) An as-sprayed cylinder rod

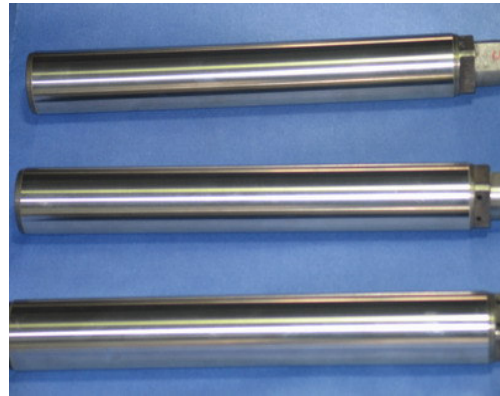


Fig.5 (b) Grinding processed plunger lever-



Fig.3 Rebuilding a rotor of steam turbine

### 5.3 Application in introduced equipment components research and imitating

Soft foundation and hard coating, material surface and matrix had been designed and rebuild as one system, which performance is excellent than material and matrix, which cost is low and benefit is high. According this way, HVOF technology is used to spray WC-Co coating to maintain cylinder rods about 10, which life is more than 5 times than original production.

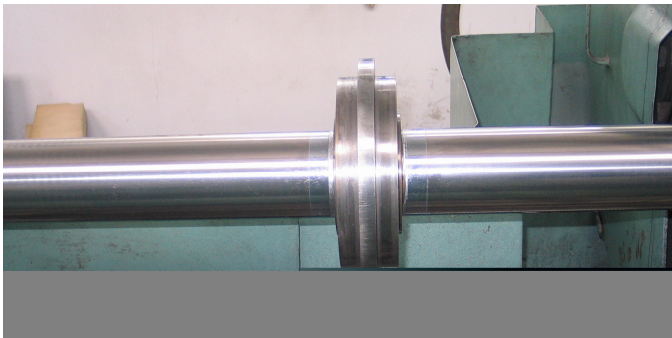


Fig.4 Rebuilt the hydraulic cylinder of the control actuator



Fig.6 (a) During the spraying process of a cylinder rod



Fig.6 (b) The grinding processed cylinder rods

## 6 Conclusions

1) Test and experience prove that the coating prepared by HVOF is similar or better than EHC. The coating has high hardness and high bond strength, and it has excellent performance of wear resistance and erosion resistance. In the field of equipment maintaining, increase of service life of equipment and remanufacturing, the dominance of spraying instead of plating is obvious and the applying effect is apparent.

2) HVOF technology has limitation compare with EHC technology, for instance, small parts need large-lot production and internal coating preparing.

3) Before using some coating, the coating body system should be design according to work condition, advance technology, cost and effect.

4) The emphasis of this article is preparing proper coating, gaining high performance by low cost, increasing reliability and workability of the key components of equipment, reducing time of stop machine and lossing limited resource.

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