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Equipment and Industrial Applications of Tungsten Carbide Hardfacing by Using the High Velocity Oxygen Fuel (HVOF) Process

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Abstract

The paper presents the equipment used for tungsten carbide hardfacing by using the high velocity oxygen fuel process (HVOF) process and the applicability of this process to the components frequently subject to an intense abrasive wear. There are many industrial applications of the HVOF hardfacing process like: steel rolls, agricultural rasp bars, machine parts, pump housing, mid-span stiffeners (gas turbine engine blades), aircraft flap tracks, sucker rod couplings, extrusion dies and exhaust fans, wear rings, etc. One of the most popular applications in petroleum industry is the tungsten carbide hardfacing of the industrial valves gates sealing surfaces, whose equipment and technology are presented in this paper.

Key words: *tungsten carbide, HVOF*

Introduction

In order to increase the wear resistance of the components subjected to corrosion and erosion, the working surfaces are hardfaced with hard alloys by using processes that can be classified into two main groups: hardfacing process by welding technology and hardfacing process by thermal spraying technology.

Choosing the right hardfacing process depends on several factors, of which the most important are the type of material to be deposited, the type of the parent material and the coating thickness and properties.

Due to the high input in welding technology, which can affect the parent metal as well as the coating, thermal sprayed coatings are extensively used for a large range of industrial applications.

There exist a wide range of materials that can be thermal sprayed, for different applications.

The commonly used materials for hardfacing surfaces subjected to abrasive wear are tungsten carbides.

During the hardfacing process with tungsten carbide two interrelated process take place: oxidation and dissolution of the carbides. Oxidation causes the formation of pores and accelerates the dissolution of the carbides, due to the exothermic oxidation reactions. Dissolution of the carbides leads to weakening of the matrix (metal support) and reduces the resistance to wear by reducing the amount of the metal carbides. This phenomenon increases with increasing temperature and duration of the maintenance process and decreases with increasing grain carbides dimension.

In order to obtain very hard dense coatings, the High Velocity Oxygen Fuel (HVOF) thermal spray process is used, in spraying tungsten carbide in powder form. This is justified by the fact that the HVOF processes provides a high kinetic energy and a low heat energy, leading to very strong, dense and with low residual tensile stresses coatings.

The paper presents the industrial equipment, the coating process parameters and the tungsten carbide layer properties obtained by applying the HVOF technology for hardfacing of the industrial valve gates sealing surfaces.

Equipment for High Velocity Oxy-Fuel (HVOF) thermal spraying

The HVOF principle

The process consists of spraying at extremely high velocity the coating material in powder form, melted in a flame, onto the parent metal surface (Fig.1). The particles reach a supersonic speed (approximately 2500-2700 m/s), and a very high kinetic energy. This does not require the particles to be fully molten when contacting the coated surface.

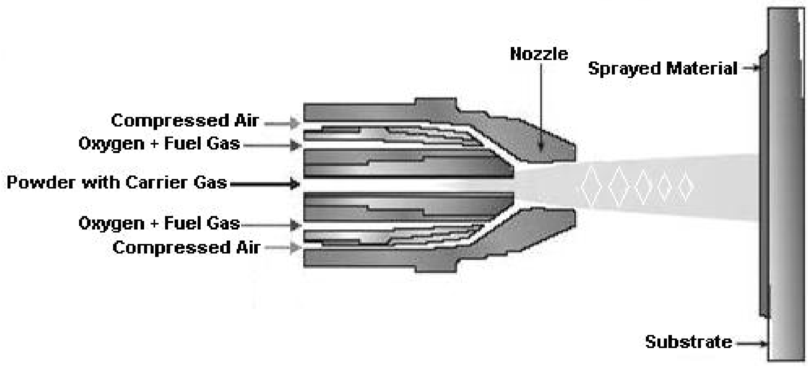

Fig.1. Principle of the High Velocity Oxigen Fuel Process (HVOF)

Compared with other hardfacing processes, the high velocity oxygen fuel process (HVOF) allows to obtain very small layer thickness min. 0,05 mm (Table 1).

Table 1. The minimum hardface layer's thickness obtained by using different hardfacing processes

No.	Hardfacing Process	Deposition rate, kg/h	Minimum hardface layer's thickness, mm
1	Hardfacing by Oxy-Fuel Gas Welding	≤ 1	1.5
2	Hardfacing by Shielded Metal Arc Welding	1-4	3
3	Hardfacing by Gas Tungsten Arc Welding	≤ 2	1.5
4	Hardfacing by Gas Metal Arc Welding	3-6	2
5	Hardfacing by Plasma Transferred Arc Welding	≤ 10	2
6	Hardfacing by Submeged Arc Welding	10-30	3
7	Hardfacing by Electroslag Welding	15-35	4
8	Hardfacing by Flame Spraying	2-6	0.1
9	Hardfacing by Electric Arc Spraying	12	0.1
10	Hardfacing by High-Velocity Oxy/Fuel Spraying HVOF	0,5	0.05
11	Hardfacing by Plasma Arc Spraying	4,9	0.1

Comparatively with other hardfacing processes, the porosity by using the HVOF process is smaller than 1% when the tungsten carbide powder is sprayed (Table 2).

Table 2. The porosity of the hardfaced layer by using different hardfacing processes

Hardfaced layer's characteristic	Hardfacing material	Hardfacing by Powder Flame Spraying	Hardfacing by HVOF	Hardfacing by Wire Electric Arc Spraying	Hardfacing by Plasma Arc Spraying
Porosity, %	Ferrous alloys	3-10	< 2	3-10	2-5
	Nonferrous alloys	3-10	< 2	3-10	2-5
	Ceramics	5-15	---	---	1-2
	Carbides	5-15	< 1	---	2-3

HVOF equipment components

Three main groups of equipments are used: equipment for preparation of the pieces for hardfacing, equipment for hardfacing, auxiliary equipment.

Equipments for preparation are utilized for cleaning and grit blasting of the pieces that will be hardfaced.

Equipments for hardfacing (Fig. 2) are utilized for spraying the powder material on the surface of the pieces that will be hardfaced. In this group are: the *gas supply system*- capable to deliver the gases necessary to the process to a desired pressure and flowrate, *powder feed system* - capable to adjust and to supply, at a desired feed rate, the powder necessary to the process, *hardfacing gun* - capable to spray the powder at a high speed to the surface of the pieces that will be hardfaced, and *industrial robot* - capable to achieve controlled movement of the hardfacing gun.

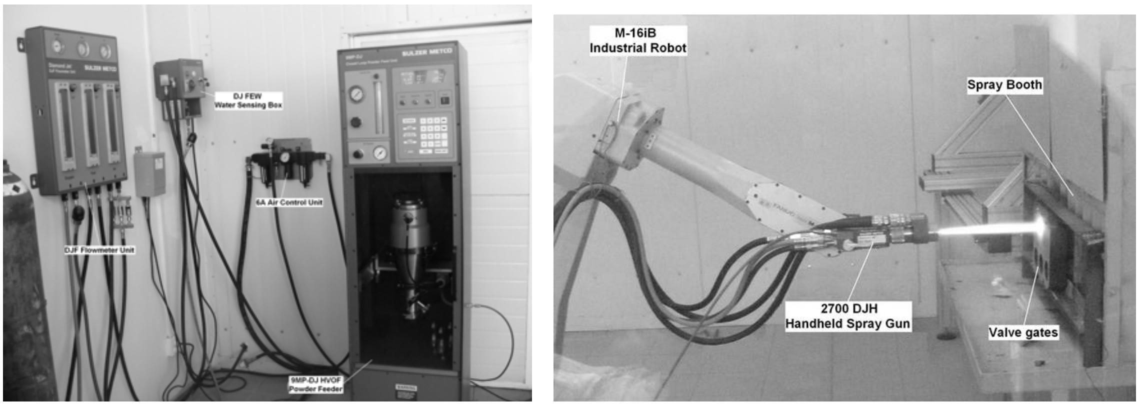

Fig.2. HVOF equipments.

Auxiliary equipments are designed to generate cooling water and compressed air needed for hardfacing process itself and for the preparation of the pieces, respectively, for evacuation of the fumes and the airborne materials.

Industrial Application of the Tungsten Carbide Hardfacing by Using the High Velocity Oxy-Fuel (HVOF) Process

The hardfacing process with tungsten carbide by using the HVOF technology is used especially to hardface the pieces frequently subjected to an intensive degradation process by abrasive wear.

One of the areas where the High Velocity Oxy-Fuel – HVOF process has major practical applications is the petroleum industry.

Hardfacing Application of Tungsten Carbide Using the High Velocity Oxy-Fuel – HVOF Process at the Sealing Surfaces of Industrial Valves

The valves represent the key elements in the petroleum and gas transportation in the production process from the well through the complex pipe network, determining the safety operating conditions and the environmental protection. The valves used in petroleum industry rise complex problems, one of them being their tightness for very high pressures. The main component which influences the valve tightness and the good operation conditions is the gate-seat assembly (Fig.3).

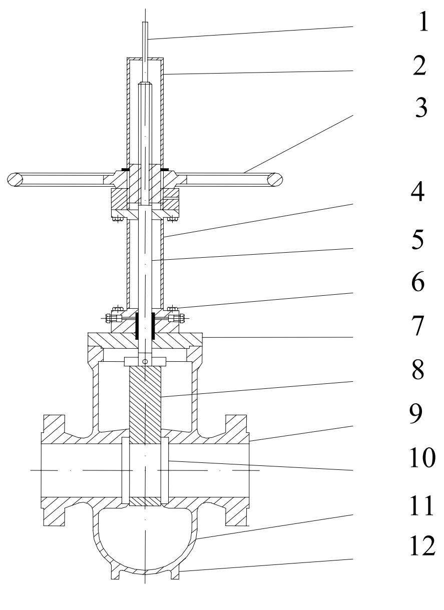

Fig.3. Slab-Gate/through-conduit rising-stem gate valve:
1-stem indicator, 2-stem enclosure, 3-handwheel, 4-yoke, 5-stem, 6-yoke bolting, 7-bonnet, 8-gate, 9-raised faced, 10- seat ring, 11- body, 12-support ribs or legs

The durability of the gate-seat assembly is assured by using high-strength heat treated materials or by hardfacing the gate-seat contact surfaces using hard materials. In practice, hardfacing the gate and the seat is avoid by using the same materials, because there is the possibility of the seize phenomenon to occur. So, usually for the seat hardface alloy on cobalt base Stellite type is used and for the gate hardface tungsten carbide dispersed in a cobalt-chrome matrix. In order to hardface the gate the main process used is hardfacing by pulverization.

The sealing elements of the industrial valves for the petroleum industry are manufactured by steel types AISI 410 and AISI 4130. For this research the gate of the industrial valves were manufactured from AISI 4130 steel, with the chemical compositions presented in Table 3.

Table 3. Chemical composition of the AISI 4130 steel.

Grade	Chemical analyses on the product					
AISI 4130	Fe, %	C, %	Si, %	Mn, %	P, %	S, %
	97,1	0,3161	0,3335	0,6524	0,0108	0,0057
	Ni, %	Al, %	Cu, %	V, %	Cr, %	Mo, %
	0,0921	0,0436	0,1588	0,0065	0,9932	0,1488

The surfaces of the specimens were ground before the hardfacing process, and the value of the surface roughness was R_a= 1,15 µm.

In order to hardface the specimens a sintered powder of tungsten carbide in cobalt-chrome matrix was used, type WC 10Co 4Cr. The average size of the powder was 22 ÷ 62 µm. The chemical composition of the powder used in the experimentally work is presented in table 4.

Table 4. Chemical composition of the powder

Chemical element	Concentration, %
C	5,13
Co	10,21
Cr	4,19
W	79,96
Other	0,51

The experimental hardfacing technology using tungsten carbide is presented below.

Surface preparation. After grinding, the surface of the specimen was cleaned by washing, drying and degreasing the surfaces in order to obtain a surface without impurities (any impurities influence negatively the adhesion between the substrate and the hardfaced layer).

Pre-heating. Before hardfacing the specimen was preheated at 93°C by using the high velocity oxygen fuel gun type 2700DJH. Pre-heating the substrate may reduce or elevate thermal stresses, depending on the exposure temperature. Thermal stresses occur when there is a difference in the thermal expansion coefficient between the substrate and the deposited material.

Spraying process. In the experimentally work the specimen was hardfaced with 20 layers according parameters presented in table 5.

Table 5. Technological parameters of the hardfacing regime

Technological parameter	Adopted value
Oxygen pressure, bar	10,3
Oxygen flowrate, m^3/h	15,9
Compressed air pressure, bar	7,6
Compressed air flowrate, m^3/h	17,9
Propylene pressure, bar	6,9
Propylene flowrate, m^3/h	4,7
Nitrogen pressure, bar	10,3
Nitrogen flowrate, m^3/h	0,8
Water cooling pressure, bar	min 2,8
Water cooling flowrate, m^3/h	min 0,6
Spray rate, g/min	38,4
Spray distance, mm	250
Speed travel gun, mm/s	100
Number of layers	20
Maximum temperature of the specimen surface, ^{0}C	235

After cooling, the harfaced specimens (Fig.4) were analyzed and tested in order to verify the quality of the layer by: macroscopic analyses, metallographic analyses by optical microscopy and electro scanning microscopy (SEM), and micro hardness measurements.

The main results are the following:

- The adhesion between the substrate (parent metal) and the layer is good.
- The average thickness of the layer is 0, 44 mm and the average porosity is 1,46 %.
- The SEM analyses indicate that the layer contains three phases α, β and γ (Fig.6). In table 6 the chemical compositions of these phases are presented. The α phase is not affected tungsten carbide. The β and γ phases are chemical compounds on C, Cr, Co and W basis.
- The micro hardness of the layer is 1979…2815 μHV_{100}.

Fig.4. Valve seat and valve gate hardfaced with tungsten carbide by using the HVOF process.

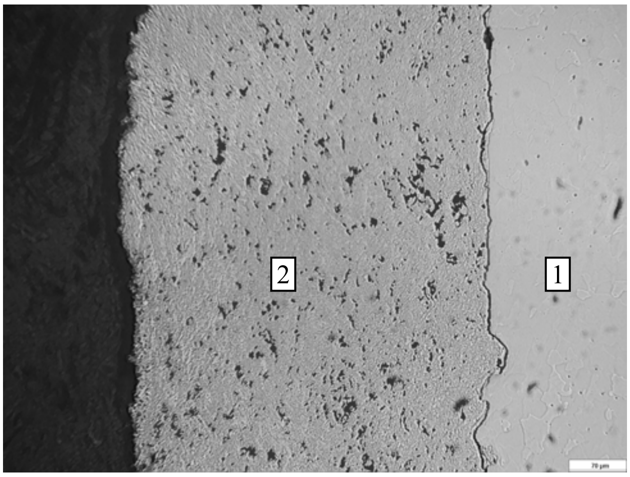

Fig.5. Microphotography for thickness and porosity determination:
1- parent metal; 2- layer.

The results of the macroscopic, metallographic analyses and the hardness measurements indicate that the tungsten carbide layers obtained by using the high velocity oxygen fuel process fulfill the quality conditions imposed to the valve gate hardfaced with tungsten carbide (final thickness of the layer smaller then 0,2 mm, layer porosity smaller then 1,5 % and minimum hardness of 57 HRC).

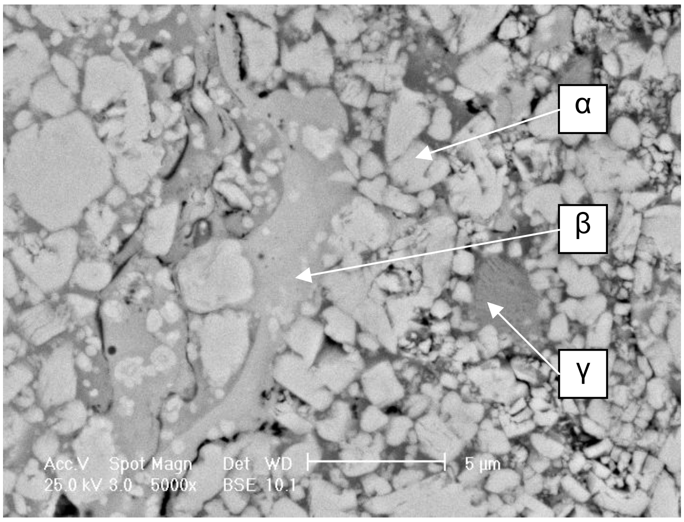

Fig.6. Microstructure of the layer examined by electro scanning microscopy (SEM).

Table 6. Chemical composition of the layer phases.

Phase	*C, %*	*Cr, %*	*Co, %*	*W, %*
α	16,84	-	-	83,16
β	18,32	1,4	9,32	70,97
γ	15,78	7,14	18,12	58,97

Conclusions

Hardfacing with tungsten carbide the pieces subjected to damage by abrasive wear is one of the possibilities to increase their durability.

Because of interdependent processes of oxidation and dissolution of tungsten carbide only a few hardfacing processes can be applied for adequate wear resistance characteristics. For this reason, the hardfacing with tungsten carbide by using the HVOF process is one of the solutions adopted by industry.

The tungsten carbide hardfaced layer obtained by using the HVOF technology presents high hardness, high adhesion to the parent metal, and unaltered chemical composition of carbide particles.

Due to the possibility to obtain smooth layers with small thickness, HVOF process is recommended for hardfacing the sealing surfaces of industrial valves destined to the petroleum industry and to replace the hard chroming process of the petroleum components which works in corrosion-abrasion environments (eg plunger of the mud pump, pistons of the subsurface pump etc.).

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Echipament şi aplicații industriale ale încărcării cu carburi de wolfram utilizând procedeul HVOF

Rezumat

În prezentul articol se prezintă echipamentul utilizat pentru încărcarea cu carburi de wolfram prin procedeul HVOF, precum şi aplicabilitatea lui la durificarea unor piese supuse frecvent la procese intense de degradare prin uzare abrazivă. Pentru exemplificarea aplicabilității industriale a acestui procedeu, se prezintă câteva din rezultatele cercetărilor experimentale efectuate asupra posibilității de încărcare cu carbură de wolfram a suprafețelor de etanşare ale sertarelor robineților industriali.