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Researches Regarding the Machinability Characteristics of the Tungsten Carbide Layers Made Using the HVOF Process

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Abstract

This paper presents the technology and the parameters for grinding with abrasive diamond wheels of the working surfaces of the seat-gate assembly, from the structure of the industrial valves, hardened by means of tungsten carbide hardfacing using the High Velocity Oxygen Fuel (HVOF) process. The evaluation of the machinability characteristics of the tungsten carbide layer deposed by using the high velocity oxygen fuel process has been performed by means of establishing the roughness, thickness and hardness of the machined layer, and also by determining the eventual surface defects for two grinding alternatives using diamond wheels, performing either only one operation (finishing) or two operations (roughing and finishing).

Key words: *tungsten carbide, HVOF, grinding*

Introduction

The thermal spraying coatings are generally used with the aim at increasing the durability of some components, competing with thermo-chemical treatments or with hard chroming process. The High Velocity Oxygen Fuel (HVOF) process is considered to be a leading one in the field of thermal spraying coating processes because on one hand it ensures the achievement of a good connection between the deposed layer and the parent metal, and on the other hand it leads to obtaining some high density layers (porosity < 1.5 %), with great hardness (min. 55 HRC), which confers outstanding performances in corrosive and/or abrasive working environments.

The main elements on which the tightness and the proper functioning of a valve depend upon are the components seat and gate. Because the seat and gate elements work in hard conditions, high pressures and highly corrosive and abrasive environments, wear processes of the working (sealing) surfaces appear, leading to tightness loss and a premature substitution of the valve, with severe technical, economical and ecological consequences. The importance of ensuring the tightness of the valves for the petroleum industry for a time period as long as possible, in the above mentioned severe operating conditions, has imposed the hardening of the working surfaces of the seat and gate components by hardfacing with hard materials. The very severe quality requirements (the thickness of the deposed layer below 0.2 mm, the hardness greater than 55 HRC, porosity smaller than 1.5%, the roughness of the final surface smaller than 0.25 μm) imposed to the surfaces of the seat-gate assembly hardfaced with hard alloys are totally fulfilled in the case of tungsten carbide hardfacing by using the High Velocity Oxygen Fuel (HVOF) process.

Because the achievement of the tightness of the seat-gate assembly, in the conditions of some very high pressures and repeated manoeuvres, imposes the attainment of a very high roughness, planarity and dimensional precision, the present paper studies the technology and the machining parameters for the surfaces of the parts hardfaced with tungsten carbide using the High Velocity Oxygen Fuel (HVOF) process.

Machining of the Surfaces Hardfaced with Tungsten Carbide Using the High Velocity Oxygen Fuel Process

Materials

The experimental research work has been performed on the following specimens:

- real parts of the gate type, 2 1/16 inch, made of steel grade AISI 4130 (table 1), hardfaced with tungsten carbide (table 2) using the high velocity oxygen fuel process, with the parameters presented in table 3;
- real parts of the seat type, 2 1/16 inch, made of steel grade AISI 4130 (table 1), hardfaced with tungsten carbide (table 2) using the high velocity oxygen fuel process, with the parameters presented in table 3.

Table 1. Chemical composition of the steel grade AISI 4130

Chemical analysis per product, [%]							
Fe	**C**	**Si**	**Mn**	**P**	**S**	**Co**	**Pb**
97.1	0.3161	0.3335	0.6524	0.0108	0.0057	-	-
Cr	**Mo**	**Ni**	**Cu**	**Al**	**V**	**Ti**	**W**
0.9932	0.1488	0.0921	0.1588	0.0436	0.0065	-	-

Table 2. Chemical composition of the sintered powder of tungsten carbide in cobalt-chromium matrix, type WC 10Co 4Cr

Chemical element	**C**	**Co**	**Cr**	**W**	**Others**
Concentration, %	5.13	10.21	4.19	79.96	0.51

Table 3. Technological parameters for hardfacing using the HVOF process

Technological parameter	**Value**
Oxygen pressure, bar	10.2 ± 0.1
Oxygen flowrate, m^3/h	15.7 ± 0.2
Compressed air pressure, bar	7.0 ± 0.5
Compressed air flowrate, m^3/h	17.4 ± 0.4
Propylene pressure pressure, bar	6.7 ± 0.2
Propylene flowrate, m^3/h	4.5 ± 0.2
Nitrogen pressure, bar	10.2 ± 0.1
Nitrogen flowrate, m^3/h	0.8 ± 0.1
Water cooling pressure, bar	2.9 ± 0.1
Water cooling flowrate, m^3/h	0.7 ± 0.1
Spray rate, g/min	38.0 ± 0.5
Spray distance, mm	250
Travel speed of the gun, mm/s	100
Number of deposed layers	20
Preheating temperature, ^0C	90…150
Temperature of the surface of the part after every five layers deposed in succession, ^0C	160…238

For the correct selection of the machining operations and, respectively, of the tools and materials needed for the machining of the surfaces hardfaced with tungsten carbide, the following aspects have been taken into account:

- *the hardness of the material that must be machined* – taking into account the fact that the layer which has to be machined is made of tungsten carbide, and its hardness is within the range 57÷65 HRC, the use of abrasive diamond tools / materials has imposed itself;
- *the final roughness of the surfaces* – the assurance of the operating conditions of the seat-gate assembly (smooth sliding and tightness) has imposed that the sealing surfaces of the two elements from the assembly should have a roughness R_a of max. 0.25 µm. Usually such roughness is obtained as a result of successively applying two machining operations: plane grinding until a roughness of 0.4 µm is obtained, followed by lapping until the desired roughness, within the range 0.025…0.25 µm, is obtained. Due to the advanced manufacturing technologies of the abrasive diamond tools, the machining of the tungsten carbide layer at a roughness in the range 0.025…0.25 µm can be only achieved by plane grinding using abrasive diamond wheels, with the diamond's grain size corresponding to the required surface quality.
- *the ratio quality/price* – the values of this ratio justifies, from the economical point of view, the proper selection of the operations to be applied in order to machine the sealing surfaces of the seat-gate assembly, respectively the selection of the optimal tools and materials for machining. The increase of this ratio can be obtained by performing an as low as possible number of machining operations which are using tools/materials with high durability.

Taking into account these technical-economical aspects it was ascertained that the machining of the tungsten carbide hardfaced layer should be performed by means of plane grinding using abrasive diamond wheels, for which the characteristics are presented in table 4.

Table 4. Characteristics of the diamond grinding wheels

Characteristics	**Type of diamond wheel**	
	1A1S-350-30-5 3D151 1Q15CVPMF-X1C 75/6/1	**1A-350-15-4 77D46 R60B52N/ 10F/BA-50M/S**
External diameter, mm	350	350
Width, mm	30	15
Diamond layer thickness, mm	5	4
Grain type (FEPA symbolization)	Standard (3D)	Standard (77D)
Grain size (FEPA symbolization), µm	125÷150 µm (151)	38÷45 µm (46)
Hardness of the cutting layer (FEPA symbolization)	Hard (Q)	Very hard (R)
Diamond concentration (FEPA symbolization), carat/cm3	3.3 (75)	2.8 (60)
Type of bond (FEPA symbolization)	Ceramic bond with medium porosity (CVPMF)	Bond based on synthetic resin (B52N)

The grinding methodology for the surfaces hardfaced with tungsten carbide

In order to achieve the desired roughness of the surface, two options have been considered for performing the machining of the layer, as follows:

- the machining of the layer only with one diamond wheel with grain size D46;
- the machining of the layer by means of two grinding operations:
    - roughing with a diamond wheel with grain size D151;

- finishing with a diamond wheel with grain size D46.

The machining of the specimen surfaces hardfaced with tungsten carbide using two diamond wheels

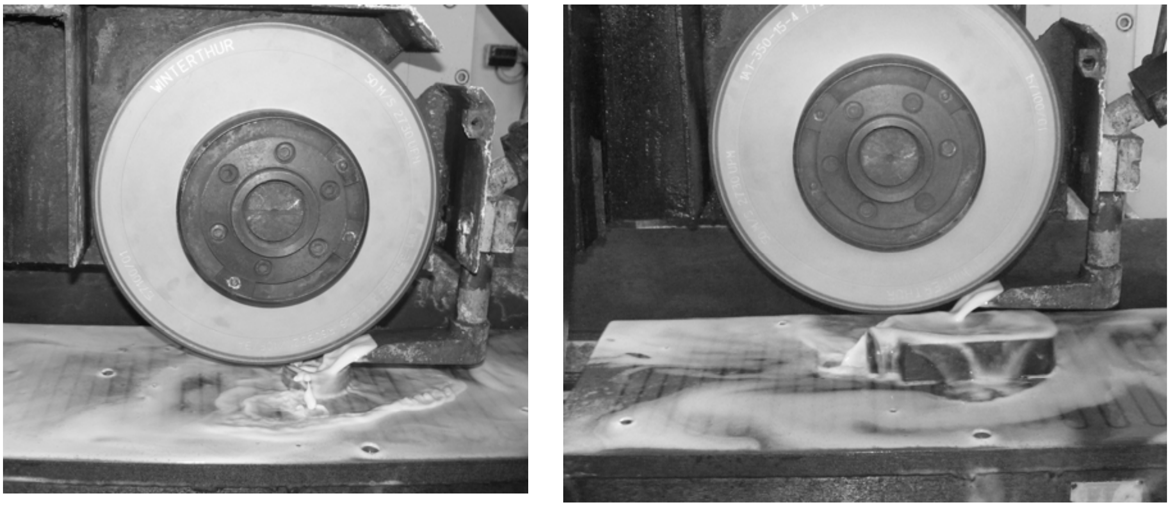
In the framework of these experiments the abrasive wheel 1A1S-350-30-5 3D1511Q15 CVPMF -X1C 75/6/1, produced by the company Winterthur Technology Group, has been used for the rough grinding operation while the abrasive wheel 1A-350-15-4 77D46 R60B52N/10F/BA-50M/S, produced by Winterthur Technology Group, has been used the fine grinding operation.

The working regime parameters, defined following the researches performed, are indicated in table 5.

Table 5. Parameters for the cutting regime (roughing and finishing)

Cutting parameters	**Measurement unit**	**Diamond grinding wheel**	
		1A1S-350-30-5 3D151 1Q15CVPMF-X1C 75/6/1	**1A-350-15-4 77D46 R60B52N/ 10F/BA-50M/S**
Cutting depth	mm	0.015	0.01
Longitudinal feed of the part	m/min	10	10
Transversal feed of the grinding wheel	mm/stroke	20	10
Cutting speed	m/s	28	28
Passing number	-	10	9

Figure 1 shows two images taken during the grinding process of the specimens' surfaces hardfaced with tungsten carbide.



a) b)

Fig. 1. The grinding process of the specimens hardfaced with tungsten carbide:
a) machining of the seats surfaces; b) machining of the gates surfaces.

Machining of the specimens surfaces hardfaced with tungsten carbide using only one abrasive diamond wheel

In the framework of these tests, the machining of the tungsten carbide layer of the specimens hardfaced using the high velocity oxygen fuel process has been performed with only one diamond wheel (the wheel 1A-350-15-4 77D46 R60B52N/ 10F/BA-50M/S).

The scope of these tests has been to obtain the desired surface roughness (max. 0.254 µm) by means of using only one type of abrasive tool, so that to diminish the machining time and, implicitly, the manufacturing costs.

The working regime parameters, defined as a result of the performed tests, are given in table 6.

Table 6. Parameters for the cutting regime (finishing)

Cutting parameters	**Measurement unit**	**Diamond grinding wheel 1A-350-15-4 77D46 R60B52N/ 10F/BA-50M/S**
Cutting depth	mm	0.01
Longitudinal feed of the part	m/min.	10
Transversal feed of the grinding wheel	mm/stroke	10
Cutting speed	m/s	28
Passing number	-	24

Figure 2 shows the specimens hardfaced with tungsten carbide machined by grinding with diamond wheels.

Fig. 2. Specimens hardfaced with tungsten carbide machined by grinding

Experimental Results

After grinding the tungsten carbide layer, analyses and tests have been performed to verify its quality. The quality check of the layer after grinding consisted in determining the roughness and the thickness of the machined layer, identifying the surface defects, and establishing the hardness of the surface.

In order to establish the roughness of the machined surfaces of the specimens hardfaced with tungsten carbide the SURTRONIC type profilometer has been used. The obtained values have been processed with the help of TalyProfile Lite 2.1 software. Following the machining of the layer by means of two plane grinding operations, respectively roughing with an abrasive diamond wheel with grain size D151 followed by finishing with an abrasive diamond wheel with grain size D46, a medium roughness R_a=0.603 µm has been obtained after roughing and a medium roughness R_a= 0.156 µm resulted after finishing. Following the plane grinding operations for the machining of the layer with only one abrasive diamond wheel with grain size D46, a medium roughness of the specimens surfaces R_a= 0.254 µm has been obtained.

The thickness of the tungsten carbide layer obtained following the grinding operations has been of approximately 0.20 mm (see fig. 3).

In order to identify the surface defects, the non-destructive testing of the parts has been used by means of liquid penetrant examination. The inspection performed has shown that grinding the specimens surfaces with the used working parameters does not lead to the appearance of the defects specific to grinding (burning of the surface, cracks in the machined layer etc.), respectively to the rapid wear of the diamond wheel (rapid deterioration of the cutting edges, elimination of the non-dulled grains etc.).

The hardness measurements made on the specimens' surfaces have revealed hardness values within the range 57…65 HRC, fulfilling in this way the quality requirements imposed to the working surfaces of the seat-gate assemblies, hardfaced with tungsten carbide. The hardness tests have been performed with the EMCO TEST M4C 025G 3M type durometer, on the surfaces of the layer after grinding.

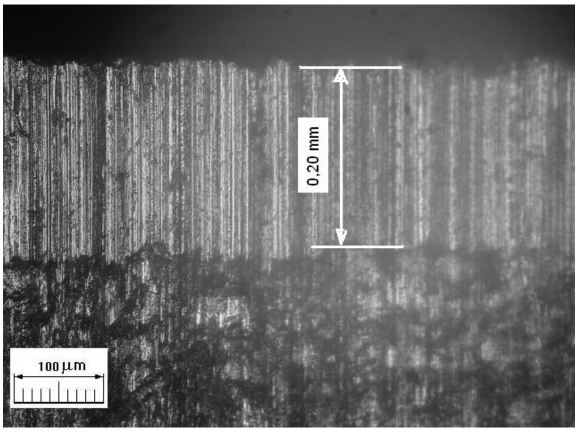


Fig. 3. Thickness of the tungsten carbide layer.

Conclusions

The evaluation of the machinability characteristics of the tungsten carbide layer deposed using the high velocity oxygen fuel process has been performed by means of determining the roughness, thickness and hardness of the machined layer, and also by identifying the eventual surface defects for two different grinding options using abrasive diamond wheels, either with only one operation (finishing) or with two operations (roughing and finishing).

Both machining options lead to a roughness corresponding to the technical conditions imposed to the working surfaces of the seat-gate assembly, hardfaced with tungsten carbide. The thickness measurements for the deposed layer have pointed out a thickness of about 0.20 mm, and the hardness measurements have revealed hardness values within the range 57…65 HRC, which leads to the conclusion that the quality requirements imposed to the working surfaces of the seat-gate assembly hardfaced with tungsten carbide are fulfilled.

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Cercetări privind caracteristicile de prelucrabilitate ale straturilor din carburi de wolfram realizate prin procedeul HVOF

Rezumat

În acest articol se prezintă tehnologia şi parametrii de prelucrare prin rectificare cu discuri abrazive diamantate a suprafețelor de lucru ale subansamblului scaun-sertar, din componența robineților industriali, durificate prin încărcare cu carburi de wolfram utilizând procedeul de pulverizare cu flacără cu viteză mare HVOF. Evaluarea caracteristicilor de prelucrabilitate ale stratului din carburi de wolfram depus prin pulverizare cu flacără cu viteză mare s-a efectuat prin determinarea rugozității, grosimii şi durității stratului prelucrat, precum şi prin determinarea eventualelor defecte de suprafață pentru două variante de rectificare cu disc abraziv diamantat, dintr-o singură operație (finisare) sau din două operații (degroşare şi finisare).