BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LX No. 3A/2008	95-104	Seria Tehnică

Research Concerning the Wear Resistance Improvement Technologies of the Petroleum Equipments

Vlad Ulmanu, Marius Bădicioiu, Mihaela Călţaru, Mihail Minescu

Universitatea Petrol-Gaze din Ploieşti, Bd. Bucureşti 39, Ploieşti
e-mail : vulmanu@upg-ploiesti.ro

Abstract

The petroleum equipment is frequently exposed to severe wear, corrosion and fatigue processes that lead to a drastic reduction of their durability. In order to increase the wear resistance of petroleum equipment, depending on wear type and wear rate, different hardfacing technologies are applied: insertion of carbide buttons, hard metal deposition and coating by using a diverse range of hard materials. The paper presents the experimental facilities and the main results concerning the hardfacing technologies applied for drill pipes and petroleum valve gates, by using the welding and thermal spraying processes.

Key words: *wear resistance, hardfacing, welding, HVOF*

Introduction

Wear, corrosion and fatigue are recognized as a major cause of petroleum equipment failures. In practice, the oil industry attempts to guard against the likelihood of these costly failures by improving the surface characteristics of the components. The wear resistance of the petroleum equipment components is increased by applying different hardfacing technologies.

The major problem raised by the hardfacing process is the selection of the most suitable hardfacing alloy and the hardfacing process. The aim of the present research is to design a proper equipment and experimentally optimize the hardfacing technology for heavy weight drill pipe and petroleum valve gate.

Heavy Weight Drill Pipe Hardfacing

Due to the fact that the heavy weight drill pipes (Fig.1) are the most expensive elements of the drill string their durability is essential for the economical drilling efficiency. The durability of the heavy weight drill pipes in drilling activity is determined by the abrasion wear produced due to friction with the inner surface of the casing or the open hole wall. The worldwide specialists applie the hardfacing technology to improve the heavy weight drill pipes wear resistance [3, 5, 6] . The hardfacing alloy is applied on the surface next to the pin/box of the heavy weight drill pipe and on the central zone of the pipe (Fig. 1).

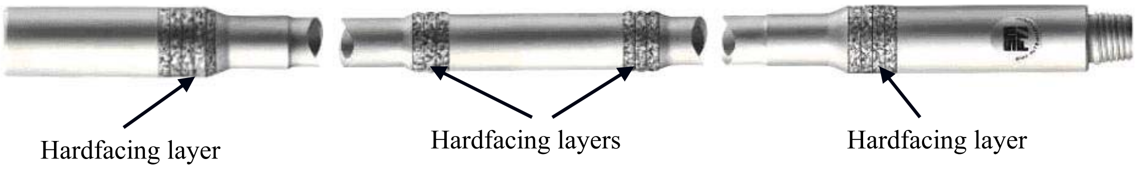


Fig.1. The hardfacing areas of the heavy weight drill pipe.

Materials

In order to study the hardfacing technology the experimental research was carried out with 10 specimens cut from the drill pipe having 80 mm length. A reces grove with 50 mm width and 1.5 mm depth was machined into the specimens and filled flush with hardfacing alloy (Fig.2).

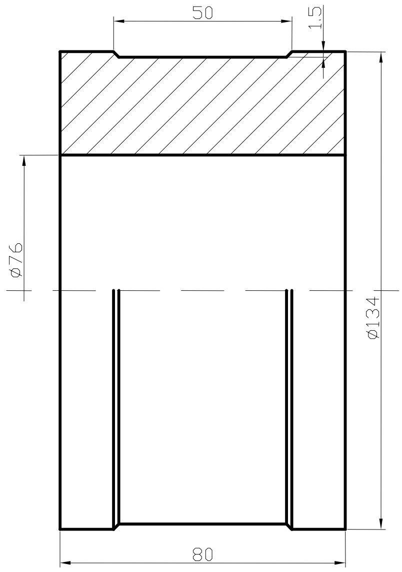


Fig. 2. The specimen utilized in the experimental research.

The heavy weight drill pipe material studied was an alloy steel AISI 4145H delivered as heavy weight drill pipe round bars with D_e = 134 mm outer diameter and D_i = 76 mm inner diameter. The chemical composition and the mechanical characteristics of the AISI 4145H steel are presented in table 1 and table 2.

Table 1. Chemical characteristics of AISI 4145H alloy steel.

C,%	Mn,%	Si,%	P,%	S,%	Cr,%	Mo,%	Al,%	Ni,%	Cu,%
0.43	0.97	0.31	0.022	0.012	0.99	0.21	0.028	0.11	0.14

Table 2. Mechanical characteristics of AISI 4145H alloy steel.

HB	R_m,N/mm^2	A, %	Z, %
336	1124.7	14	51

A wear resistant flux core tubular wire of 1.6 mm diameter was used for hardfacing the specimens [1, 2]. The deposit characteristics are presented in table 3. The deposit hardness is very important in the drilling process because a value higher than 57-62 HRC will cause an excessive wear of the casing. This restriction represents criterion for choosing the most suitable hardfacing material [1, 2].

Table 3. The deposit characteristics

Chemical composition of the deposit											Hardness
C, %	**Mn, %**	**Si, %**	**P, %**	**S, %**	**Cr, %**	**Mo, %**	**Nb, %**	**Ni, %**	**B, %**	**Fe, %**	**HRC**
0.45 -0.85	1.5-2.1	0.50 - 0.85	0.020	0.020	5.0-7.0	0.35-0.85	-	-	-	rest	57-62

The metal active gas welding process (MAG) was used to hardbanding the heavy weight drill pipe. The shielding gas was 80 % Ar and 20 % CO_2.

Hardfacing research methodology

In order to hardfacing the surface of the heavy weight drill pipe the following specific welding procedure were applied:

a) *Material preparation*. After turning the specimen by using a lathe machine a visual inspection of the weld surface was performed to ensure it is clean and without rust, dirt, grease, oil etc.

b) *Preheating the specimen*. Before to starts the hardfacing process, the specimen was pre-heated at 100 degree Celsius. Inadequate preheating of the parent steel may cause undesirable cracking in the parent metal.

c) *Hardfacing the specimen*. Three welding beads were intermittently hardfaced on specimen by using the welding equipment presented in figure 3.

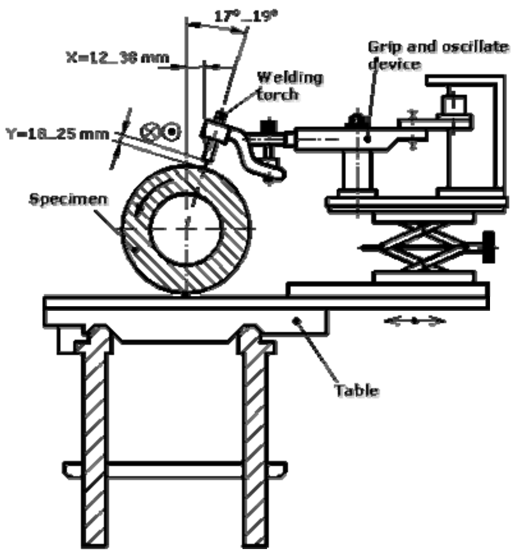


Fig. 3. The welding equipment scheme.

The welding equipment allows the following movements: continuous rotation of the specimen, axial feed of the welding torch and oscillate the welding torch. The welding equipment has the following components: constant direct current (DC) power supply capable of furnishing a current of 180…400 Amperes and 20…30 Volts, with the wire positive (DCEP); griping and rotating device able to grip and rotate the heavy weight drill pipe at a constant rotating speed of between 0.2 to 1.2 rotation per minute; grip and oscillate device able to oscillate the welding torch parallel to the pipe surface with the amplitude of

15 to 25 mm and at approximately 60 to 90 oscillations per minute, and to incline the welding torch, in the direction of the rotation, between 17…19 degrees as measured from the centre-line of the heavy weight drill pipe.

The technological parameters of the hardfacing regime are presented in table 4. In order to avoid the superheating of the parent metal it was necessary to wait until the temperature of the specimen decreases below 300 ^{o}C, before applying to the next welding bead.

Table 4. Technological parameters of the hardfacing regimes.

Technological parameters	**Values**
Polarity	reverse
Amperage, A	260 ± 10
Voltage, V	24 ± 1
Shielding gas, l/min	13.5
Filler metal speed, m/min	4.5
X distance (from figure 3), mm	20
Y distance (from figure 3), mm	20
Rotating speed of the specimen,rot/min	0.6
Welding speed, m/h	14.5
Oscillating the welding torch: - oscillating speed, oscillation/min - oscillation amplitude, mm	 60 25
Preheat temperature, ^{o}C	100
Interpass temperature, ^{o}C	350

d) *Controlled cooling of the specimen*. After finishing the hardfacing process, hardfaced specimen was slowly cooled to avoid the cracks in the weld beads.

e) *Post welds material inspection*. After cooling the quality of the deposition was investigated. Metallographic samples were cut from the hardfaced specimen (Fig. 4) and prepared by polishing and metallographic etching in order to investigate them.

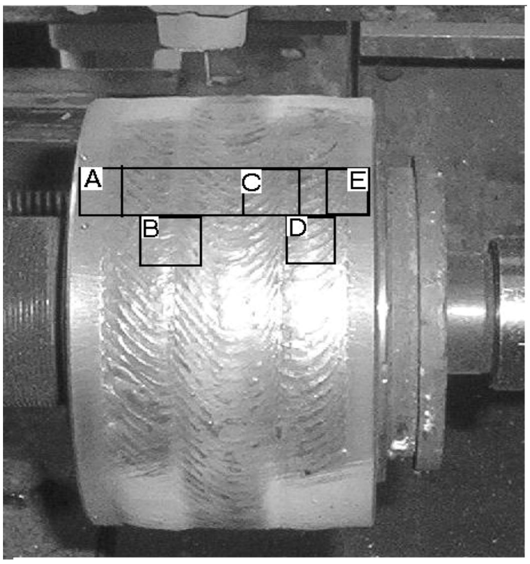


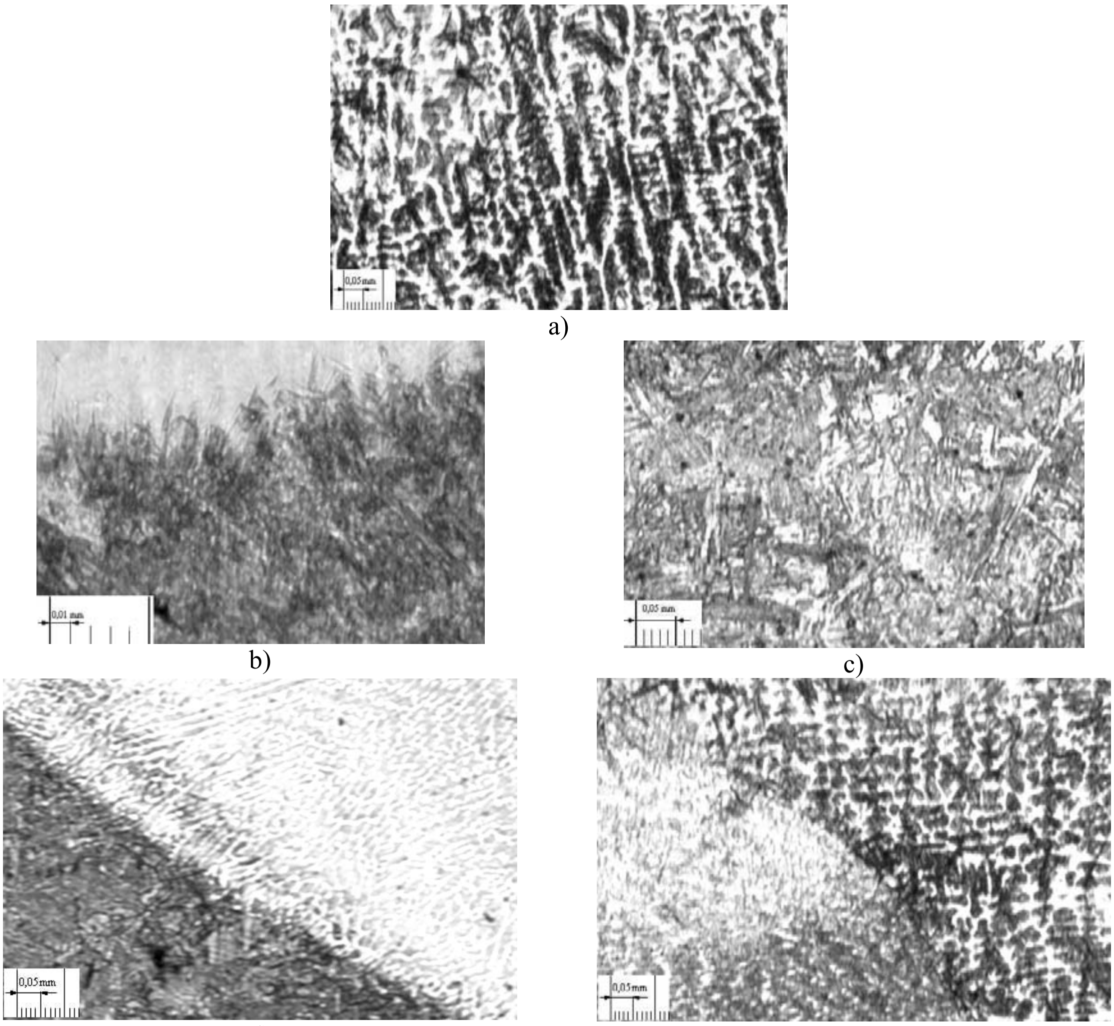
Fig. 4. The metallographic samples (A, B, C, D, E) marked on the hardfaced specimen.

Experimental results and discussion

The quality of the deposit was verified by macroscopic analyses, metallographic analyses by optical microscopy and Rockwell hardness measurements.

The macroscopic analyses of the hardfaced specimens showed that a flat profile of the weld beads has been obtained. The deviation from this kind of profile can cause premature wear of the casing, when the profile is convex, or premature wear of the heavy weight drill pipe, when the profile is concave [4]. Also, the surface of the weld bead doesn't contain visible cracks.

The microscopic studies made indicate that the weld bead presents a dendritic casting structure (Fig. 5a). The parent metal in the adjacent weld bead area has a martensitic-bainitic structure (Fig. 5b and 5c) and below the influenced thermal area it has a sorbitic structure. There were no cracks propagated into the parent metal. Figures 5d and 5e shows the weld beads/parent metal transition area at the last weld bead and the weld beads overlaps. The weld bead is consistently tie-in with the edge of each preceding weld bead and with the parent metal.



a) b) c) d) e)

Fig. 5. Metallographic structures:
a) dendritic casting structure for the weld bead material; b) martensitic structure in the transition area to the parent metal; c) bainitic structure of the parent metal in the adjacent fusion line; d) the weld beads/parent metal transition area; e) the weld beads overlaps (Attack: Nital)

The Rockwell hardness measurements indicate a weld bead hardness of 53…57 HRC.

Petroleum Valve Gate Hardfacing

The valves represent the key elements in the petroleum and gas transportation, in the production process from the well and through the complex pipe network, determining the safety operating conditions and the environmental protection. The construction and the exploitation of the valves used in petroleum industry rise complex problems, one of them being their tightness. The principal component which influences the valve tightness and the good operation is gate-seat assembly (Fig. 6) [9, 10, 11, 12, 13].

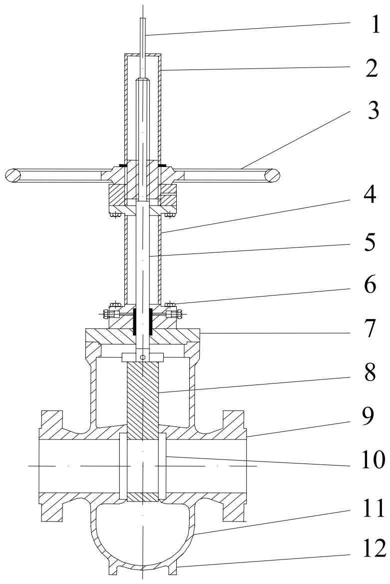


Fig. 6. Slab-Gate/through-conduit rising-stem gate valve:
1-stem indicator, 2-stem enclosure, 3-handwheel, 4-yoke, 5-stem, 6-yoke bolting, 7-bonnet, 8-gate, 9-raised faced, 10- seat ring, 11- body, 12-support ribs or legs.

Materials

The experimentally researches regarding the valve gate hardfacing with tungsten carbide by using the high velocity oxygen fuel (HVOF) process, were made on parallelepiped specimens with 60 x 30 x 135 mm dimensions (Fig.7), manufactured by steel AISI 410SS-75K (utilized in the gate-seat subassembly construction) [3].

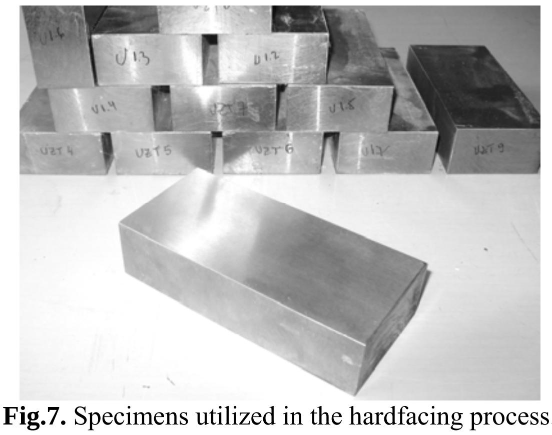


Fig.7. Specimens utilized in the hardfacing process.

The chemical composition of the AISI 410SS-75K steel is presented in table 5. The surfaces of the specimens were ground before the hardfacing process, and the value of the surface roughness was R_a= 1,15 μm.

Table 5. Chemical composition of the steel AISI 410SS-75K.

Grade	Chemical analyses on the product							
AISI 410SS-75K	Fe, %	C, %	Si, %	Mn, %	P, %	S, %	Cr, %	Mo, %
	85,7	0,228	0,159	0,123	0,028	0,027	12,19	0,096
	Ni, %	Al, %	Co, %	Cu, %	Pb, %	Ti, %	V, %	W, %
	0,208	0,006	0,165	0,255	0,002	0,006	0,055	0,057

In order to hardface the specimens a sintered powder of tungsten carbide in cobalt-chrome matrix was used, type WC 10Co 4Cr [8]. 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 6.

Table 6. Chemical composition of the powder.

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

Research of hardfacing technology

In order to hardfacing the surface of the valve gate the following specific welding procedure were applied:

a) 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.

b) Pre-heat treatment. Before hardfacing the specimen was preheated at 100^0C by using the high velocity oxygen fuel gun type 2700DJH, from in order to reduce or elevate the thermal stresses.

c) Spraying process. In the experimentally work the specimen was hardfaced with 20 layers by using the high velocity oxygen fuel equipment. The equipment utilized for the experimental researches consists in the following principal elements: propane bottles (contain the fuel gas necessary to the flame), oxygen bottles (contain the oxygen utilized like oxidant agent in the burn process), nitrogen bottle (contains the gas necessary to transport the powder from the powder unit to the HVOF gun), compressed air unit (utilized to accelerate the molten particles to the specimen surface and to cool the head HVOF gun), flowmeter unit (controll the flowrate of the oxygen, propane and compressed), water cooling control unit (the HVOF gun is cooled with water and this unit monitories the water pressure in the hardfacing process time), the powder feed unit (supplies the gun with the powder necessary to the process, at a precise flowrate), HVOF spraying gun and the spray booth and exhaust system. In figure 8 is presented the high velocity oxygen fuel gun type 2700DJH utilized in the experimentally works. In the hardface process the high velocity oxygen fuel gun type 2700DJH was handled manually. The technological hardfacing parameters utilized in the experimental reserches are presented in table 7. The specimen temperature, between the layers, was kept below 160^0C. At the end of the process the specimen was cooled in air at the room temperature.

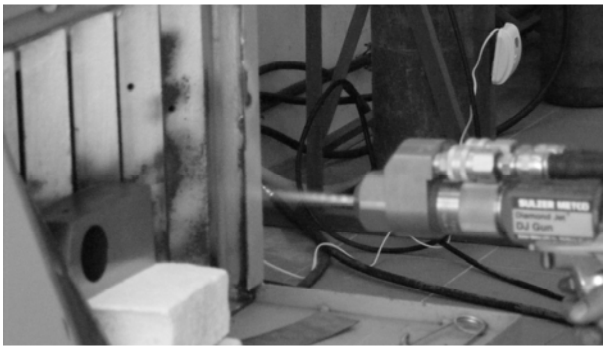


Fig. 8. HVOF spraying gun used in experimental work.

Table 7. Technological parameters of the hardfacing regim.

Technological parameter	Adopted value
Oxygen pressure, bar	10,0
Oxygen flowrate, m^3/h	14,3
Compressed air pressure, bar	6,2
Compressed air flowrate, m^3/h	17,8
Propane pressure, bar	4,8
Propane flowrate, m^3/h	2,5
Nitrogen pressure, bar	9,7
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
Spray distance, mm	200 ÷ 250
Number of layers	20
Maximum temperature of the specimen surface after three successive layers, ^0C	160

d) Quality Control. After cooling the quality of the deposition was investigated. Metallographic samples were cut from the hardfaced specimens (Fig. 9) and prepared by polishing and metallographic etching in order to investigate them.

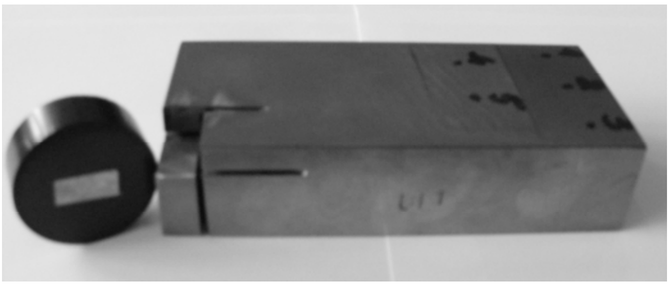


Fig. 9. Hardfaced specimen and metallographic sample.

Experimental results and discussion

After cooling, the harfaced specimens were analyzed and tested in order to verify the quality deposition. The quality deposition was verified by: macroscopic analyses, metallographic analyses by optical microscopy and electro scanning microscopy (SEM), Rockwell hardness and micro hardness measurements.

The analyses made indicate that the adhesion between the substrate and the layer is good (Fig. 10). The average thickness of the layer is 0.34 mm and the average porosity is 6.6 %. It is a big porosity but the quality requirements for the coating characteristics, after the final grinding of hardfaced specimens, are achieved because almost half of the layer (the superior part with the big porosity) will be removed by the final processing operations. Taking into consideration this fact the measurement made in the inferior part of the layer, on a thickness of 0,18 mm, indicate a porosity of 0,98 %.

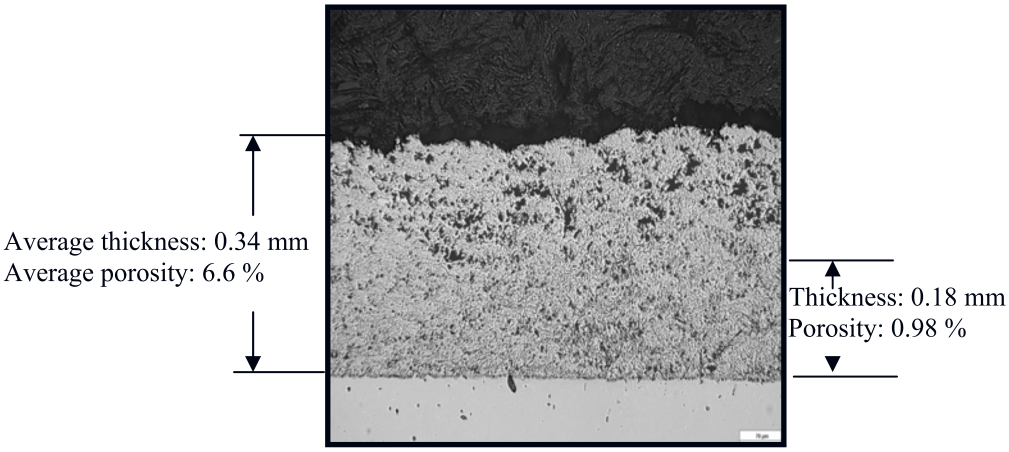


Fig. 10. The hardfaced layer/parent metal transition.

The electro scanning microscopy analyses indicate that the layer contains three phases α, β and γ presented in figure 11 with the chemical compositions presented in table 8. The α phase is non affected tungsten. The β and γ phases are chemical compounds on C, Cr, Co and tungsten basis.

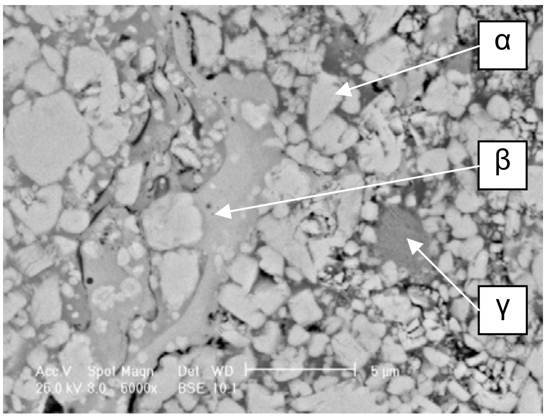


Fig. 11. Microstructure of the layer examined by electro scanning microscopy (SEM).

Table 8: 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

The Rockwell hardness measurement determined on ground hardfaced specimen indicate a value of 58…61 HRC.

Conclusions

The experimental researches were performed in order to establish the wear resistance improvement technologies of the petroleum equipments.

The heavy weight drill pipe hardfacing technology was developed by using the metal active gas welding process.

The petroleum valve gate hardfacing technology was developed by using the high velocity oxygen fuel thermal spraying process.

References

1. Ciocârdia, C., Drăgulănescu, E., Drăgulănescu, I. - *Aliaje dure sinterizate din carburi metalice*, Editura tehnică, Bucureşti, 1985.
2. Herşcovici, F. - *Materiale dure*, Editura Tehnică, Bucureşti, 1970.
3. Nicolescu, A. - *Contribuţii la mărirea durabilităţii în exploatare a garniturilor de foraj cu racorduri sudate în condiţiile forajului de mare adâncime*, Teză de doctorat, I.P.G, Ploieşti, 1980.
4. *Recommended procedures manual for the preparation, application and inspection of ARNCO 100XT™*, Hardbanding, Version 1.0, November, 1999.
5. Ulmanu, V. - *Fabricarea, repararea şi întreţinerea utilajului chimic şi petrochimic*, Editura didactică şi pedagogică, Bucureşti, 1981.
6. Ulmanu, V. - *Tehnologia fabricării şi reparării utilajului petrolier*, Editura ILEX, 2002.
7. Ulmanu, V., Zecheru, Gh., Drăghici, Gh., Dumitreacu, A., Călţaru, M., Bădicioiu, M. - *Tehnologii neconvenţionale de înaltă precizie pentru creşterea durabilităţii robinetelor, cu aplicaţii în industria petrolieră, Etapa I - Studii şi cercetări teoretice privind identificarea problemelor specifice construcţiei şi exploatării robinetelor din industria petrolieră*, Contract de cercetare 71-076/2007.
8. *** *AMDRY® 5843 - Ttungsten carbide in acobalt-chromium alloy matrix for wear resistant coatings*, Technical Bulletin #10-660, October 2000, Sulzer Metco. February, 1993
9. *** ANSI/API 600 - *Bolted Bonnet Steel Gate Valves for Petroleum and Natural Gas Industries*.
10. *** ANSI/API 603 - *Corrosion-Resistant, Bolted Bonnet Gate Valves - Flanged and Butt-Welding Ends*.
11. ***ANSI/API Specification 6A - *Specification for Wellhead and Christmas Tree Equipment*.
12. *** API 598 - *Valve Inspection and Testing*.
13. *** API 602 - *Compact Steel Gate Valves - Flanged, Threaded, Welding, and Extended-Body Ends*.

Cercetări privind tehnologiile de creştere a rezistenţei la uzare a echipamentelor petroliere

Rezumat

Echipamentul petrolier este expus frecvent la procese severe de uzură, coroziune şi oboseală ce conduc la reducerea drastică a durabilităţii acestora. In vederea creşterii rezistenţei la uzare a echipamentului petrolier, în funcţie de tipul şi viteza de uzare, sunt aplicate diferite tehnologii de durificare: inserţie de butoni de carbură, depunere de metalului dur şi încărcare folosind o gamă diversă de materiale de durificare. Articolul prezintă cercetările experimentale şi principalele rezultate privind tehnologiile de durificare aplicate prăjinilor de foraj şi sertarelor robineţilor petrolieri, prin utilizarea procedeelor de sudare şi pulverizare termică.