10th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2006, Barcelona-Lloret de Mar, Spain, 11-15 September, 2006

DUPLEX PROCEDURES OF HEAT TREATMENT OF STEELS

Dragomir Krumes, Ivan Vitez, Radojka Marković
Mechanical Engineering Faculty in Slavonski Brod, University of Osijek
Trg Ivane Brlić Mažuranić 2, Slavonski Brod
Croatia

ABSTRACT
Duplex procedure of heat treatment of steels is a combination of two thermo diffusion procedures with purpose making of resistant layers on wear. There are many combinations of duplex procedures procedures such as carbonizing and boronizing, carbonitriding and boronizing, carbonizing and vanading etc.
This paper elaborate results achieved with procedures carbonizing, boronizing and with duplex procedure carbonizing + boronizing on samples from two steels for quenching and tempering – unalloyed C 45 (Č1530) and alloyed steel 42 CrMo 4 (Č5432).
Key words: *heat treatment steels, carbonizing, boronizing, duplex procedures, comparison of results*

1. INTRODUCTION
Surface layer properties of some machine member can be turned into desired direction by application of thermo chemical heat treatment process. Thereby alternation of chemical composition of surface layers and the appropriate heat treatment increase their resistance to abrasion and adhesion wear and make them corrosion resistant to environmental influences, etc. Such thermo chemical processes always leave the core of the machine part unchanged regarding condition prior to implementation of surface heat treatment. It may remain thermally untreated, or may acquire desired properties by "pure" heat treatment.
Nowadays, research of wear resistance is conducted by combination of thermo chemical processes consisting of several heat treatments. Such thermo chemical processes are duplex and triplex procedures. More frequently used duplex procedures are carbonizing and boronizing, carbonitriding and boronizing and similar. Triplex procedures include borocarbonitriding with application of complex coatings of boron, carbon and nitrogen [1, 2, 3, 4, 5].
This paper gives a comprehensive result of tests obtained by testing of carbonizing and boronizing procedures and duplex procedure of carbonizing + boronizing on samples of two steels for quenching and tempering: unalloyed steel C 45 (Č 1530) and alloyed steel 42 CrMo 4 (Č5432).

2. PROPERTIES OF STEELS SELECTED FOR TESTING
Table 1 gives prescribed chemical composition of selected steel testing samples, and Table 2 their mechanical properties and recommendations for heat treatment [5].

Table 1 Chemical composition of steel C 45 and 42 CrMo 4

Steel designation		Chemical composition, %						
HRN	DIN 17006	C	Si	Mn	P (max)	S (max)	Cr	Mo
Č1530	C 45	0,42÷0,50	0,15÷0,35	0,50÷0,80	0,045	0,045	-	-
Č4732	42 CrMo 4	0,38÷0,45	0,15÷0,40	0,50÷0,80	0,035	0,035	0,90÷1,20	0,15÷0,30

Table 2 Mechanical properties of steel C 45 and 42 CrMo 4 and recommendations for their heat treatment

Steel designation	Mechanical properties after tempering at 600 °C for ø 16÷40 mm				Heat treatment			
	R_m, MPa	$R_{p0.2}$, MPa min.	A_5, % min.	KU J min.	quenching		tempering	
					°C	means	°C	means
Č1530	660÷810	410	16	27	820÷850	water	550÷660	Air, furnace
Č4732	980÷1180	765	11	41	830÷860	oil	540÷680	Air, furnace

3. TEST PLAN AND OBTAINED RESULTS

3.1. Test plan and heat treatment

From each selected steel three test samples ø 20 x 5 mm were made. i.e. one for each thermo chemical treatment (carbonizing, boronizing and duplex carbonizing + boronizing of the same sample). After completion of heat treatments metallographic examination and micro hardness testing of test samples were conducted.
Thermo chemical heat treatments were conducted in laboratory furnace of TO-2 LHT type.
Figures 1, 2 and 3 show all three above specified thermo chemical treatments with inscribed parameters of heat treatments [2].

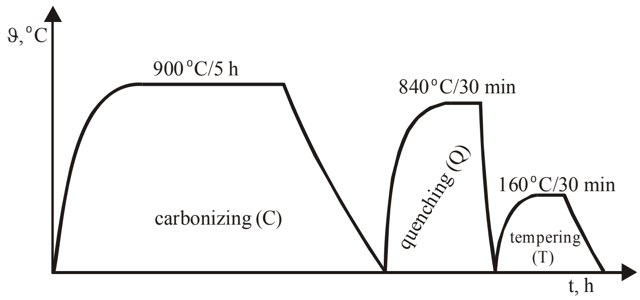

Figure 1. Procedure of carbonizing (C)

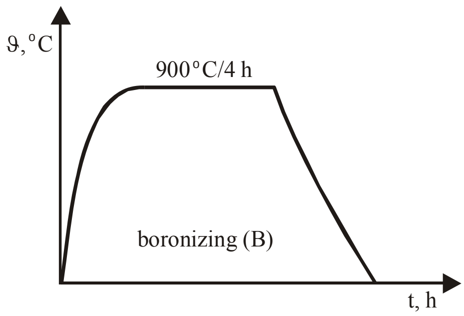

Figure 2. Procedure of boronizing (B)

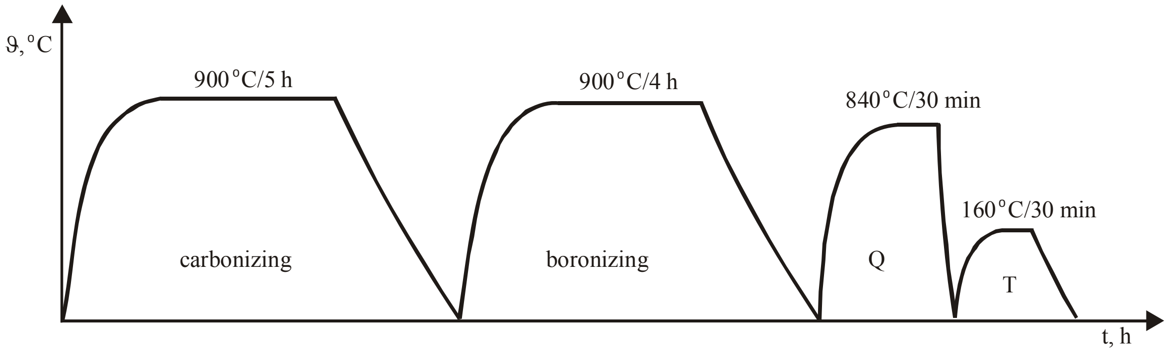

Figure 3. Duplex procedure (C+B)

Carbonizing was conducted in the solid source of carbon – granulate "Durferit KG 6", while "Durborid 3" was used for boronizing. Manufacturer of both of these products is German company "Durferit". From figures 1, 2 and 3 it can be seen, that during duplex heat treatment procedure the same parameters were used as for single thermo diffusion treatments (same cases and solid materials, same temperatures and times, same quenching conditions).

3.2. Metallographic tests

Figures 4 and 5 show the appearance of microstructure of carbonized layers, figures 6 and 7 of boronized layers, while figures 8 and 9 show layers obtained by duplex procedure on tested C 45 and 42 CrMo 4 steel samples, magnification 250 x [2].

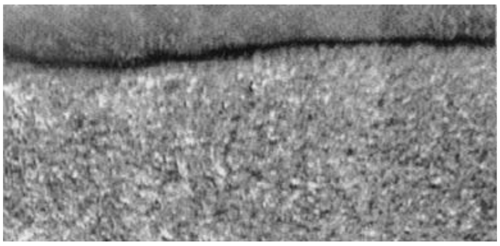

Figure 4. Steel C45-carbonized

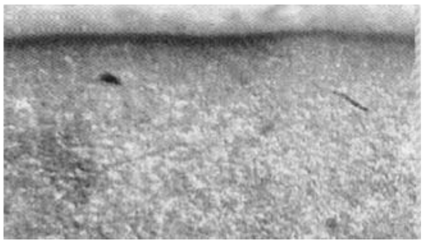

Figure 5. Steel 42CrMo4-carbonized

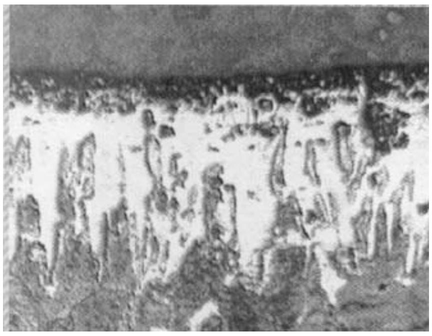

Figure 6. Steel C45-boronized

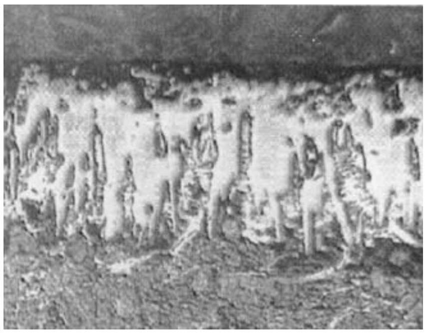

Figure 7. Steel 42CrMo4 - boronized

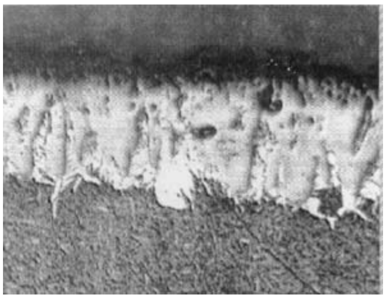

Figure 8. Steel C45-carbonized+boronized

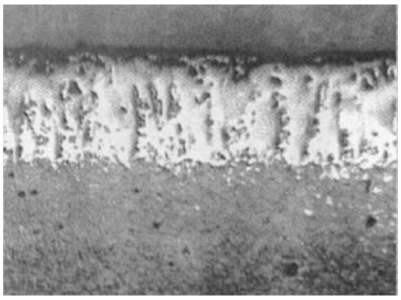

Figure 9. Stel 42CrMo4-carbonized+boronized

3.3. Testing of micro hardness

Micro hardness testing was conducted on all test samples by Vickers HV0,1 method, on hardness testing equipment "Durimet", with 1 N applied load.

Table 3 gives information on achieved micro hardness values (average and maximal) with all six test samples, as well as depths of achieved impressions on hard layers.

Table 3 Micro hardness and depth on hard layers

Steel designation	Sample designation	Micro hardness HV0,1		Depths of layers, μm		
		Maximal	Average	Min. av.	Average	Max. av.
C 45	Carbonized	844	704	2000		
	Boronized	2318	818	62	94	127
	Duplex	2026	908	51	65	78
42 CrMo 4	Carbonized	680	563		850	
	Boronized	2158	903	90	103	116
	Duplex	1493	818	85	94	103

Figure 10 gives flow diagram of average micro hardness values for both steel samples treated by duplex procedure [2].

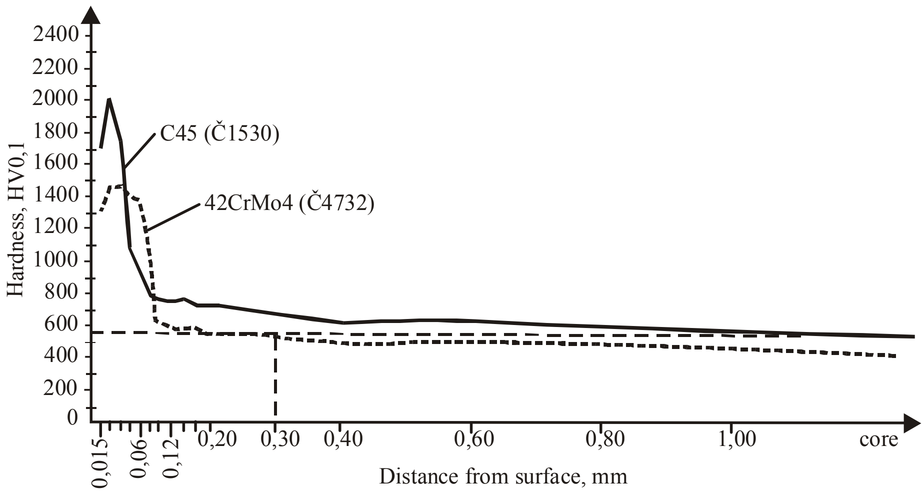

Figure 10. Flow diagram of micro hardness values for both steel samples to duplex procedure

4. CONCLUSION

In figures of micro structure thermo diffusion hard layers can be clearly seen. This has been confirmed by the obtained results of hardness measurement.

Carbonized layers have shown the expected hardness values (over 700 HV0,1). Unalloyed steel had greater depth of carbonized layers and greater micro hardness value. Cause for that may lie in oil quenching, which didn't ensure sufficiently fast quenching of the alloyed steel. Although results lied within the framework of expected, still great depth of carbonized layer on carbon steel which is entirely hardened was a surprise.

On both steels boron layer Fe_2B with toothed intrusion into base material can be observed. Great hardness values of boronized layer were achieved (on average 1700 HV0,1) on both of these steels.

Unalloyed steel C 45 has got boron layer with greater average maximal depth (circa 127 μm). On alloyed steel 42 CrMo 4 depth of boronized layer is more balanced, with less expressed toothed intrusion (51 do 78 μm).

With duplex procedure boronized layer is in both cases somewhat thinner having lesser hardness values than it was the case with only boronized samples.

Testing is to be continued with erosion and corrosion testing, and it is to be expected to display better stability with alloyed steels with duplex layer in relation to single thermo diffusion applied layers.

5. REFERENCE

[1] Krumes, D.: Površinske toplinske obrade i inženjerstvo površina, Strojarski fakultet, Slavonski Brod, 2004.

[2] Madunić, B.: Nanošenje tankih prevlaka na površinu čelika, diplomski rad, Strojarski fakultet, Slavonski Brod, 2005.

[3] www.irb.hr, Institut Ruđer Bošković: Magnetronska depozicija tankih filmova, Datum pristupa: 30.04.2005.

[4] www.sciencedirect.com, Kulka, M.; Pertek, A.: Characterization of complex (B + C + N) diffusion layers formed on chromium and nickel-based low-carbon steel, , Datum pristupa: 15.06.205.

[5] Novosel, M.; Krumes, D.: Posebni čelici, Strojarski fakultet, Slavonski Brod, 1998.