THE INFLUENCE OF THERMAL AND THERMOCHEMICAL TREATMENTS APPLIED TO RAPID STEELS CONCERNING WEAR RESISTANCE

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Among the qualities required to rapid steels cutting tool, a major importance is represented by wear resistance. This quality has to be maintained during the entire technological process [1]. Experimental attempts were carried out on 1.3343 rapid steel samples. These were subjected to several operations of thermal and thermo-chemical treatment. The measure of wear is expressed by the mass loss after equal time intervals, between 10 and 40 minutes. In this paper the practical data allow highlighting of several conclusions regarding thermic and thermochemical treatments as well as at heating effects on wear rapid steels.

Keywords: treatment below zero degrees, wear resistance.

1. Introduction

The rapid steels represent a category of metallic materials for tools which allow the application of a vast range of thermic and thermochemical treatments in terms of obtaining a well wear heat resistance and wear resistance [2, 5]. Thus, there has been effectuated heat treatment and thermo-chemical treatment by using vacuum techniques and treatment below zero degrees. This justification resides from the possible benefits linked to the microstructural changes that occur. Vacuum heat treatment ensures a more uniform heating, absence of oxidation and decarburization. Through degassing effect is also achieved some compaction of the material [6, 8, 9]. Below zero degrees treatment reduces the amount of residual austenite, increases the hardness and dimensional stability. The same effects are also obtained through tempering. Tempering produces a metallurgical process, namely precipitation of some extremely fine secondary phase and uniformly distributed, which improves not only the structural appearance, but also the mechanical properties such as hardness and resistance to fatigue.

It has been found also that the number of temperings could be increased with favorable consequences on the performance [11, 12, 13]. Thereby, sometimes it is recommended up to 8-10 consecutive temperings [3, 4, 7]. This aspect is very important also when on tools there is applied a surface heat treatment such as nitriding, nitrocarburizing, oxinitro-carburizing, etc [16, 17, 18, 20].

These thermochemical processes take place at temperatures close to the tempering ones [15, 19]. Therefore, applying such technology counts as one more tempering for the tool mass, with positive effects for the tools assembly. The surface treatments must also benefit of special attention, considering that the wear requests reparation in quasi totality of the exterior layers of tools [21, 22, 23]. Surface treatments mentioned above favors the wear behavior of the material, without adversely affecting the properties of the substrate. Improving the wear resistance by doing these procedures is aimed by manufacturing industry, considering the technical and economic efficiency increase [14, 24].

2. Experimental attempts

The researches have been carried out on rapid steel samples, destinated both for wear resistance, resilience and for studying the metallographic structures. Samples had in forms and dimensions corresponding to the installation used to attempts and were tested to wear resistance and resilience after the thermal and thermochemical treatments. These attempts were done in the same conditions for all cases. In table 1 is presented the chemical composition of steel used.

Table 1

Chemical composition of 1.3343 rapid steel subjected to attempts

Steel type	Chemical composition [%]								
	C	Si	Mn	P	S	Cr	Mo	V	W
1.3343 (Rp5)	0,92	0,28	0,39	0,021	0,0011	3,43	4,71	1,71	5,95

The thermic treatments were effectuated in vacuum furnace, with technical parameters indicated in table 2.

Table 2

Vacuum heat treatments applied to rapid steel

Steel Type	Heat treatment applied	Heating parameters			Cooling	Hardness [HRC]
		Pressure [N/m^2]	Temperature [°C]	Time [s]		
1.3343	Hardening with preheating	10^{-1}	850	2400	-	-
		0,2 ...0,3	1190	360	purified nitrogen	62,4
	Tempering	-	560	3x 3600	purified nitrogen	64,5
				6x3600		65,7

In Figs. 1- 4 are presented the microstructures and X-ray diffraction analysis of samples treated according to Table 2.

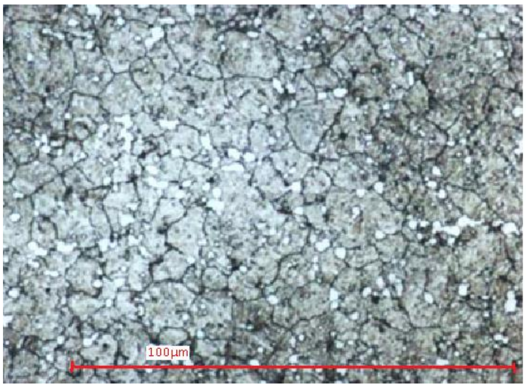


Fig. 1. Optical microscopy of 1.3343 rapid steel vacuum hardened from 1190° C. NITAL Attack

In the structure shown in Fig. 1 the existence is found of the following phases are observed in the structure: martensite of hardening (darkening color), residual austenite (white color in the proportion of about 30-35%) and white globular carbides, some of the medium size and secondary finer size.

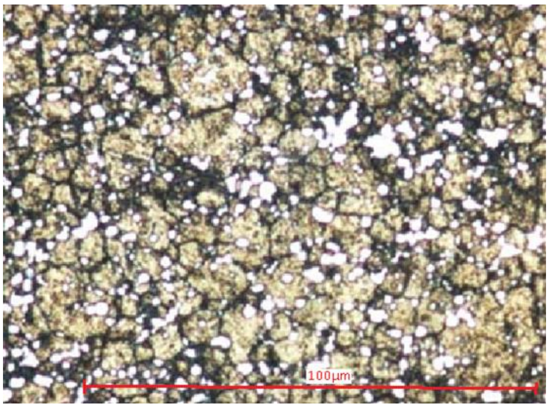


Fig.2. Optical microscopy of 1.3343 rapid steel vacuum hardened from 1190°C and temperings. NITAL Attack

In the Fig. 2 is presented the structure the same steel after hardening and multiple annealings. As a result of annealings occurred the transformation of residual austenite to the utmost extent, to martensite (after a secondary transformation). At the same time, occurred the precipitation of some carbides by combining carbon and alloying elements form the matrix. As a consequence, the appearance of the microstructure is darker.

The transformation mentioned is emphasized using the SEM analysis and the X ray diffractions (Figs. 3 and 4).

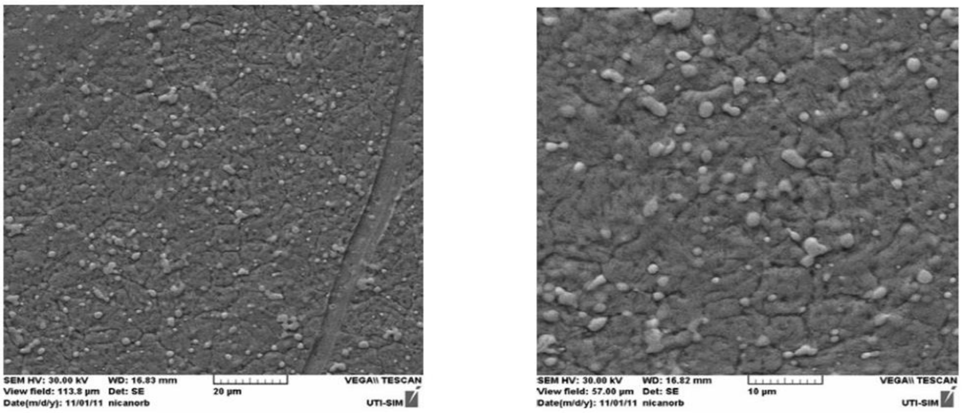
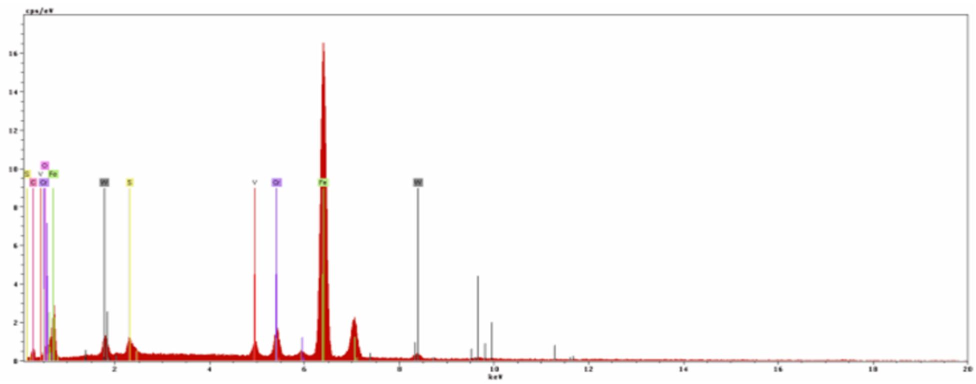


Fig.3. SEM image of 1.3343 rapid steel vacum hardened from 1190 °C and Temperings



Element	AN	series	Net	[wt.%]	[norm. wt.%]	[norm. at.%]	Error in %
Iron	26	K-series	108672	67,58664	75,78524	68,36992	1,742471
Tungsten	74	L-series	3824	6,63803	7,443257	2,039763	0,224193
Molybdenum	42	L-series	5419	4,649083	5,213041	2,737611	0,241754
Carbon	6	K-series	1713	4,315193	4,838647	20,29669	0,873543
Chromium	24	K-series	9229	4,004636	4,490418	4,351081	0,8501
Vanadium	23	K-series	4377	1,988216	2,229397	2,204936	0,224469
			Sum:	89,18179	100	100	

Fig.4. X-ray diffraction analysis of 1.3343 rapid steel vacum hardened from 1190 °C and temperings.

Several samples were subjected to cooling below zero degrees, followed by one tempering, according to Table 3.

Table 3

Heat treatment with intermediary cooling below zero degrees

Treatment below zero degrees			Tempering			
Temperature [°C]	Duration [s]	Hardness [HRC]	Temperature [°C]	Duration [s]	Hardness [HRC]	Resilience KCU [J/cm^2]
-40°C	4320	65,3	560	3600	64,8	4,8

Several samples were subject to cooling below zero degrees, followed by one tempering, according to table 3. Cooling below zero degrees was effectuated shortly after vacuum hardening, avoiding in this way the stabilization of residual austenite. In Figs. 5 and 6 are presented the micrographics of samples treated according to Table 3.

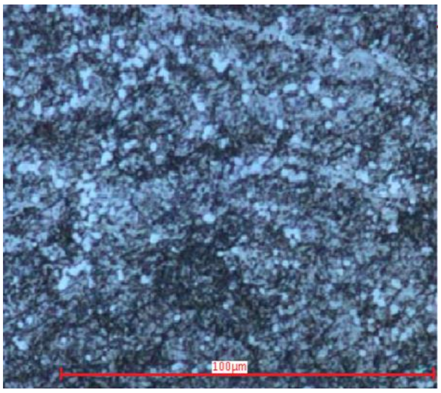


Fig. 5. Optical microscopy of 1.3343 rapid steel vacuum hardened from 1190° C and cooled below zero degrees. NITAL Attack

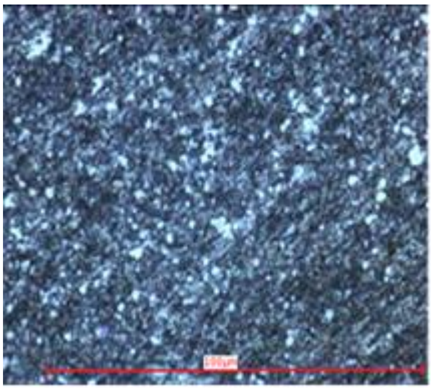


Fig.6. Optical microscopy of 1.3343 rapid steel vacuum hardened from 1190° C, cooled below zero degrees and 1 tempering at 560° C. NITAL Attack

The micrographics showed the presence of residual austenite after vacuum hardening and its decrease after tempering, as well as after treatment below zero heat. Finally, the structures are composed of fine martensitic mass with uniform inclusions of carbures: eventually, residual austenite in small quantities may still exist. In order to improve the microstructure and the mechanical characteristics, on some samples were still carried out several consecutive temperings after hardening in vacuum and temperings to 560°C. Thus, there were studied the structure and hardness obtained on samples with up to 6 temperings. Figs. 7 and 8 illustrate the metallographic aspect of some of these samples.

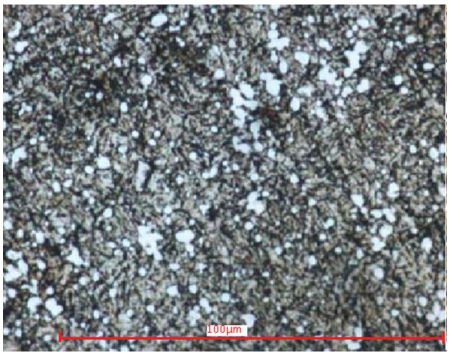


Fig.7. Optical microscopy of 1.3343 rapid steel vacuum hardened from 1190°C and 3 consecutive temperings at 560° C. NITAL Attack

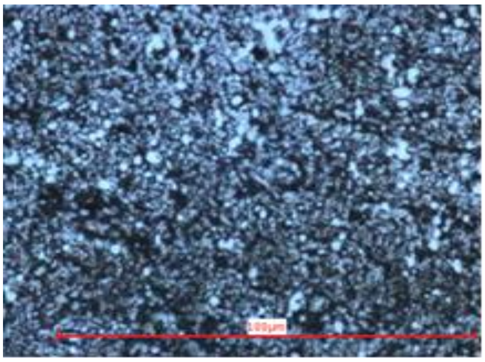


Fig.8. Optical microscopy of 1.3343 rapid steel vacuum hardened from 1190° C and 6 consecutive temperings at 560° C. NITAL Attack

In all temperings there were kept the same operating parameters, namely temperature and duration (it is estimated that the effective holding at the regime temperature was of one hour) according to data in table 4.

Table 4

The influence of consecutive temperings on properties of 1.3343 rapid steel

Tempering parameters		3 consecutive temperings		5 consecutive temperings		6 consecutive temperings	
Tempe rature [°C]	Duration [s]	Hardness [HRC]	Resilience KCU [J/cm^2]	Hardness [HRC]	Resilience KCU [J/cm^2]	Hardness [HRC]	Resilience KCU [J/cm^2]
560	3600	64,3	5,7	64,2	5,5	64,1	5,5

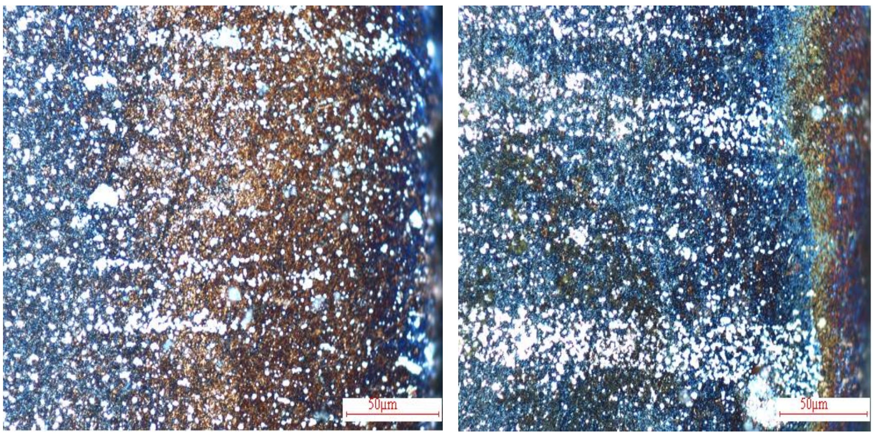
The studies have also as objective to test the wear resistance of the structures subjected to thermochemical treatment. These are presented in table 5. It can be noticed that some surface treatments were carried out on samples which were previously heat treated through the classic process (hardening + tempering.).

Table 5

Thermal and thermochemical treatment applied to 1.3343 rapid steel

Heat treatment	Thermochemical Treatment	Time [s]	Temp. [°C]	Medium	Cooling	Layer Hardness [$HV_{0,5}$]
Vacuum hardening from 1190° C and 3 temperings at 560° C	Ion Nitriding	54000	530	20%N_2+80 %NH_3	N2	925
	Plasma Nitriding	54000	530	50%CO+2 5%NH_3+25 %N_2	N2	1132

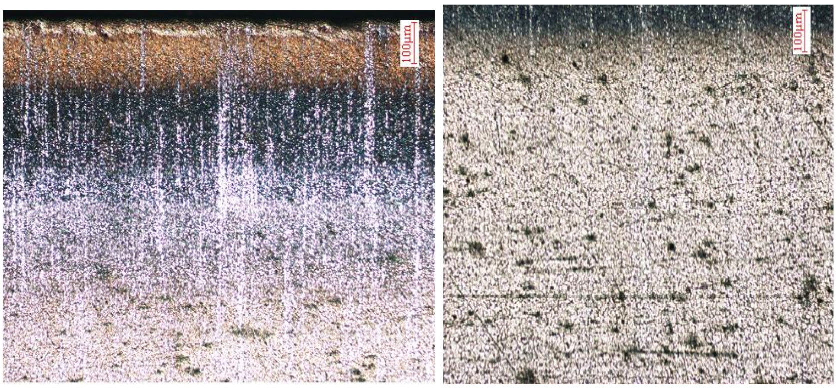
The layers microstructures obtained by diffusion are shown in Figs. 9 and 10 below.



a b

Fig. 9. Optical microscopy of 1.3343 rapid steel vacuum hardened 1 tempering and ion nitride: a- before wear, b- after wear. NITAL Attack

The successive passage through more zones occured in the microstructure of nitrided layer , depending on the nitrogen content. At the surface there is an area of approximately compact nitride, below and with the darker color is the area with nitrogenus martensite (with nitrogen atoms diffused in the α phase).



a b

Fig.10. Optical microscopy of 1.3343 rapid steel vacuum hardened 1 tempering and plasma nitrocarburized: a- before wear, b- after wear. NITAL Attack

Fig. 10 presents the superficial layer of carbonitrided samples. As a result of concomitant diffusion in this area of carbite and nitrogen, there are large amounts of nitrides and carbonitrides of the alloyng elements. There is also a tendency for white layer formation (which was not the objective of thermochemical treatment).

The 1.3343 specimens in forms and dimensions coresponding to attempts device, thermal and thermochemical treated as shown above, were subjected to wear. All samples were tested in the same conditions, thus the results can be compared. The wear measurement was determined by weighing with precision of 0,001 g. This consisted of pressing a sample on a rotative disc made of sandstone; the heaviness force was of 48 N, the rotation speed of 800 rot / min.

3 Experimental results

A series of data resulted from effectuated tests are presented below in form of table 6 and graph (Figs. 12-14).

Table 6

Wear measurement of thermal and thermochemical treated samples[g]

Time [s]	Vacuum hardened and 3 tempering	Vacuum hardened, treated below 0°C, and 1 tempering	Vacuum hardened, 3 temperings, ion nitriding	Vacuum hardened, 3 temperings, plasma nitrocarburized
36000	0,0065	0,0077	0,0058	0,0045
72000	0,0117	0,0148	0,0106	0,0095
108000	0,0183	0,0209	0,0162	0,0150
144000	0,0235	0,0261	0,0212	0,0182

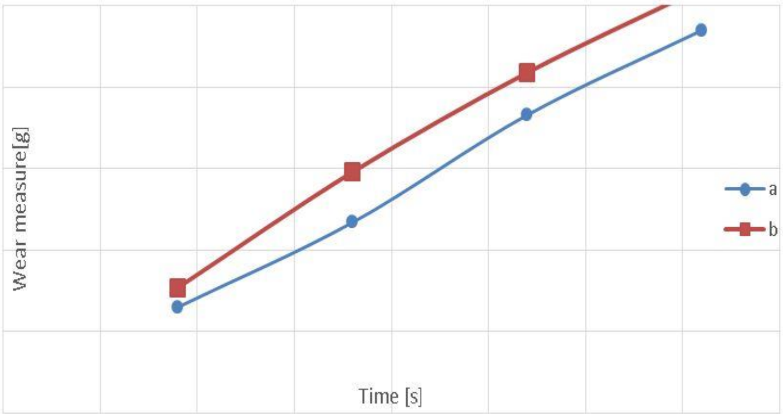


Fig.12. Wear evolution: a) samples vacuum hardened cooled below zero degrees and 1 tempering at 560° C; b) samples vacuum hardened and 3 temperings at 560° C.

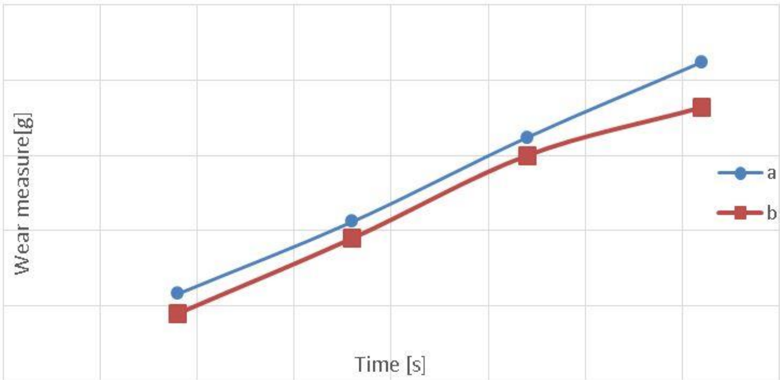


Fig13. Wear evolution: a) samples vacuum hardened, 3 temperings and ion nitrided.; b) samples vacuum hardened, 3 temperings and plasma nitrocarburized.

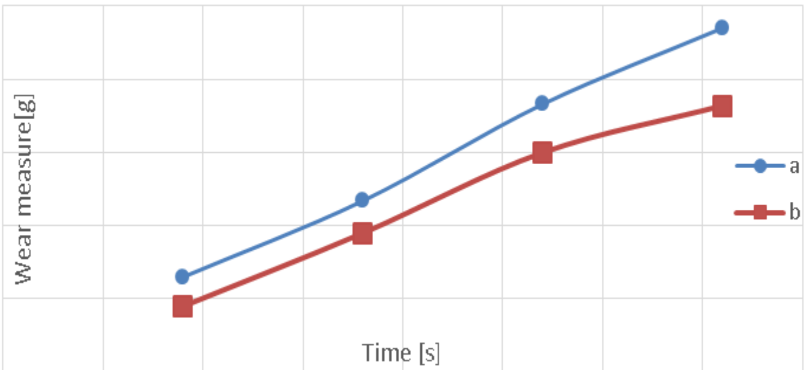


Fig.14. Wear evolution: a) samples vacuum hardened and 3 temperings at 560°C; b) samples vacuum hardened, 3 temperings and nitrocarburized.

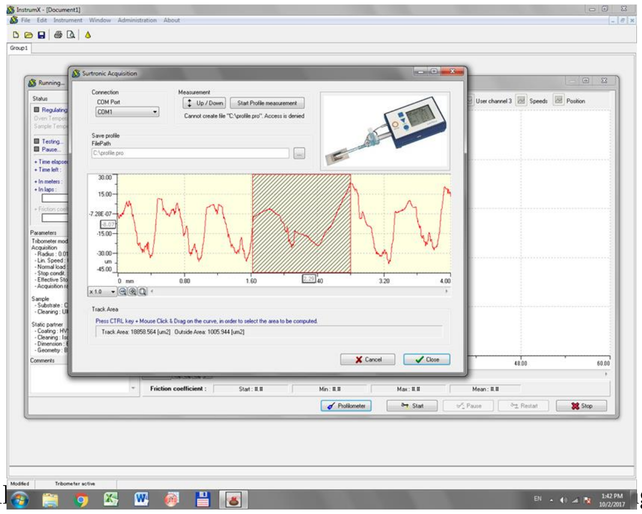


Fig. 15. Profil … g and ion nitrided.

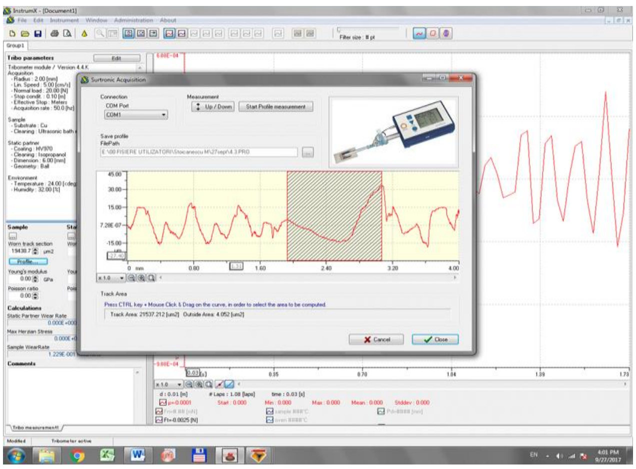


Fig.16. Profileometry of 1.3343 rapid steel vacuum hardened 1 tempering and plasma nitrocarburized.

Wear measure did not exceed the thickness of diffusion layer at thermochemical treated samples as can also be seen from Figs. 9a, 9b and 10a, 10b as well as the profileometry resulting from the measurements shown in fig. 15 and 16.

During abrasive wear attempts it was found a warming of the samples of about 130° C; a laser thermometer was used to measure the temperature. Consider that this warming is relatively low and does not affect the wear resistance, considered at ambient temperature. During the work it has been started from the premise that the increase of the temperings number also influences the resistance to wear. To verify this, samples treated according to table 4 were subjected to the wear test, under the same conditions as those described above. These results are shown in the table 7 and in Fig. 17.

Table 7

Wear measurement of samples on consecutive temperings

Time [s]	Vacuum hardened and 3 consecutive tempering	Vacuum hardened and 5 consecutive tempering	Vacuum hardened. and 6 consecutive tempering
36000	0,0065	0,0077	0,0081
72000	0,0117	0,0132	0,0141
108000	0,0183	0,0198	0,0220
144000	0,0235	0,0247	0,0259

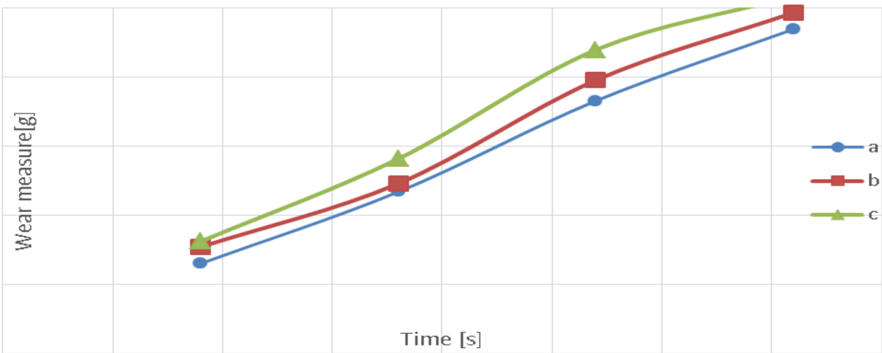


Fig. 17. Wear evolution : a) samples vacuum hardened and 3 consecutive temperings; b) samples vacuum hardened and 5 consecutive temperings; c) samples vacuum hardened and 6 consecutive temperings

Researches reveal that the wear measurement slightly increased with the number of temperings. This is in accordance with the final hardness of the material. The improvement of properties may be seen on the other characteristics, such as resilience.

The influence of higher temperatures that interfere during the work at intensive cutting regimes was emphasized by testing wear resistance at values close to tempering, namely 50%. Heating was performed using an industrial dryer, keeping the temperature steady during the tests. The results for the studied cases are shown below (table 8).

Table 8

Wear measure [g] at cold and warm [at 36000s]

Heat Treatment			
Vacuum hardening and 3 temperings at 560° C		Vacuum hardening, cooling below 0 °C	
at cold	at warm	at cold	at warm
0, 0065	0, 0049	0,0077	0,0058

By heating it was found that the wear measurement decreases after 10 minutes of stress.

6. Conclusions

The heat treatment and the thermochemical treatment represent a major importance for the wear resistance for the rapid steel cutting tools. The current scientific research about rapid steel specimens is subject to a wide range of use in industry.

The thermal and thermochemical treatments have the role of creating the necessary conditions for the landmarks in exploitation. The thermal treatment effectuated in different variants had as an objectiv the finding of solution for technical and economic advantages. From experimental attempts it was found that multiple annealings over the usual three do not lead to significant results.

Over more than three annealings, precipitation of secondary carbides continues to occur. This had as a result the following contrary tendencies: on one hand the increasing of hardness, and on the other hand the decreasing of hardness occured as a result of the annealing effect. More intense was the annealing. At the same time, was diminished softly and the resilience as a result of increasing the martensite quantity and carbides.

The treatment under zero degrees decreases the total duration of the process, but the quality upon the whole is weaker. The thermochemical treatments improve visually superficial hardness and at the same time the wear resistance.

Comparing the results obtained from the wear tests, a correlation between the structures – the thermal treatment – the thermochemical treatment occurred.

The best results were obtained in the wear tests on the samples subject to thermochemical treatment by nitriding and especially by carbonitriding.

By analyzing the results obtained after experimental attempts of abrasive wear on 1.3343 rapid steel thermic and thermochemical treated by different procedures, the followings are emphasized: the best results were obtained on samples heat treated through the obtained process, namely hardening and three temperings, compared to the variant that included treatment below zero degrees; this second variant is shorter, but the cooling at cryogenic temperatures could induce supplementary internal tensions an even microcracks which has a negative influence on the performances; among the more efficient heat treatments it is proven to be the nitrocarburizing; the wear measure has been decreased by heating at 550°C; we consider that this is the result of decreasing the friction coefficient at the contact between steel - sandstone disc. Increasing the number of temperings over 3 does not improve wear resistance. It may count on the improvement of the shock resistance.

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