THE LABORATORY TESTING OF STEEL 20MnCr5

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Abstract: *In this paper the laboratory tests on the selected steel for cementation 20MnCr5 was perfomed. The influence of the contact load resistance to the adhesion wear of high-temperature carbonitrided MnCr steels was analyzed. As a representative example was selected a tribosystem drive/driven gear of reducers in which are expressed high contact loads. For the purposes of these tests, the samples were first high-temperature carbonitrided, and then they are carried to the appropriate chemical and metallographic analysis, control of the surface hardnesses and the resistance to the adhesion wear. The aim of this paper was to observe the representative tribosystem as much possible to define its working parameters in order to determine the optimum conditions for testing the influence of the contact load on resistance to the adhesion wear. The analysis results show that high-temperature carbonitrided steel where the atmosphere of furnace at the beginning of carburizing was enriched with nitrogen, and finally with carbon showed significantly greater resistance to the adhesion wear compared to steel that at the beginning of carburizing had atmosphere of furnace rich in carbon, and finally with nitrogen.*

Keywords: *STEEL 20MnCr5, MICROSTRUCTURES, HARDNESSES, ADHESION WEAR*

1. Introduction

Tribology is the scientific-expert discipline that deals with the phenomena and processes on surfaces which are in mutual interaction, direct or indirect contact and relative motion [1]. The study of friction and wear problems as well as the role of lubrication, tribology approaches as parts of a one whole in which the phenomena and processes are mutually connected and have a significant influence on the economy of technical resources that are produced and used. Tribological problems are present in all branches of the industry. The termination of a functional work of parts may occur due to breakage, due to wear and due to corrosion effects [2]. One of the more common types of wear that occurs in practice is the case of adhesion wear. This wear is reflected in the transition of material from one friction surface to the other in conditions of immediate contact of the metal surfaces body in relative motion. Any wear caused by adhesion can be described in three phases: I - formation of the adhesion compound, II - breaking of the adhesion compound, III - rupture and eventual breaking of particles [3]. The aim of this paper was by chemical and metallographic analysis and flow of surface hardnesses and resistance tests to the adhesion wear on the selected high-temperature carbonitrided samples to investigate the dependence of the measured wear intensity on the applied contact loads. In selecting of the material samples and materials of the counter body, should take care of their compliance modeled on observed representative tribocouple gear. Expected tests and analysis should provide insight into the properties of steel achieved by the processes of high-temperature carbonitriding and their resistance to the adhesion wear conditions at different load levels.

2. The properties of steel 20MnCr5

Steel 20MnCr5 belongs to a group of steel for cementation. These steels represent a structural steels which after machining by particle separation are carburizing on the edge of the layer. After carburizing of the edge layer, by hardening is achieved high resistance to wear of the edge layers and the increased toughness of the non-carburized core [4]. Steels for cementation mainly contain from 0,1 to 0,2 % carbon before carburizing, and may be a non-alloyed or low-alloyed. The edge layer after process of carburizing contain from 0,8 to 0,9 % carbon, and with hardening is achieved hardness from 61 to 64 HRC. After the process of cementation carburized core remains a ferrite-perlite structure, if the material is not hardenabilitied. In the case of hardenability the low-carbon martensite is formed. Both of these microstructures are characterized by high toughness with high wear resistance.

After the process of cementation the surface layers contain high-carbon martensite. The most common application of steel 20MnCr5 is in the production of gears, shafts and axles of machines, camshafts etc. [5]. Declared mechanical properties of steel 20MnCr5 are shown in Table 1 [6].

Table 1: *Mechanical properties of steel 20MnCr5.*

Steel mark	Properties			
	Hardness, HB	$R_{p0,2}$, MPa	R_m, MPa	A_5, %
20MnCr5	152 ÷ 201	685	980 ÷ 1280	7

3. Experimental tests

In the experimental part of this paper, as an representative example of the tribosystem was selected gear assembly of the reducers, Figure 1.

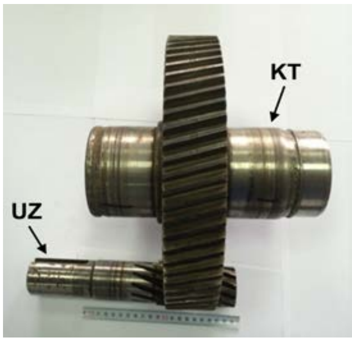


Fig. 1 *The representation of tribosystem drive/driven gear.*

In this assembly drive/driven gear are expressed to a high contact loads. The drive gear (sample UZ) is made from steel for cementation 20MnCr5, while the driven gear (counter body KT) is made from steel for improvement 42CrMo4, Figure 2.

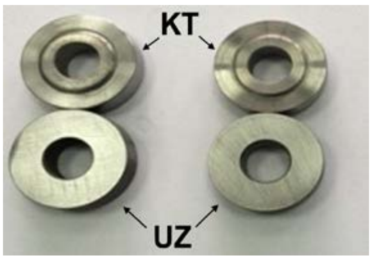


Fig. 2 *Samples for laboratory testing.*

By this selection of materials and test conditions, it was attempted to imitate the real machine elements in the process, both in terms of the material from which they were made and in view of their working conditions.

3.1. The experiment plan

Plan of the experimental tests performed on samples of steel 20MnCr5, marked with 421 and 422 was showed in Table 2.

Table 2: *Plan of the experimental tests.*

Sample mark	Tests perfomed on steel 20MnCr5					
	VTKN	KA	MG	HV1	Testing of wear resistance	Traces of wear
421	+	+	+	+	+	+
422	+	+	+	+	+	+

* VTKN - high-temperature carbonitriding; KA - chemical analysis; MG - metallographic tests.

3.2. The heat-chemical treatment

Tables 3 ÷ 5 are showing parameters of high-temperature carbonitriding steel 20MnCr5. High-temperature carbonitrided samples are marked with 421 and 422 and they are provided for resistance testing to the adhesion wear. Before high-temperature carbonitriding soft annealing was performed, the parameters are shown in Table 3. The parameters of high-temperature carbonitriding are shown in Table 4. After completion of the ten-hour carburizing, directly hardening and subsequent low-temperature loosening are perfomed, Table 5.

Table 3: *The selection of parameters of the previous heat treatment of steel 20MnCr5.*

Name	Parameters	
Previous heat treatment Soft annealing	Duration	40’
	Temperature	660 °C
	Cooling	In furnace

Table 4: *The selection of parameters of the heat-chemical treatment of steel 20MnCr5.*

Name	Parameters	Process 1	Process 2
High-temperature carbonitriding	Duration of carburizing	300’	300’
	Temperature of carburizing	920 °C	920 °C
	C_{pot}	0,5 % C	1,0 % C
	NH_3	10 %	5 %

Table 5: *The selection of parameters of the subsequent heat treatment of steel 20MnCr5.*

Name	Parameters	
Subsequent heat treatment Hardening	Austenitization temperature	820 °C
	Duration	45’
	Cooling	Oil
Subsequent heat treatment Loosening	Loosening temperature	180 °C
	Duration	40’
	Cooling	In furnace

The high-temperature carbonitriding of samples was perfomed using the variable potential of the carbon (C) and nitrogen (N), or with a combination of parameters of the process 1 and process 2. Carburizing was conducted in the furnace with natural gas as a carrier of carbon and ammonia as a carrier of nitrogen at a temperature of 920 °C.

On the sample 421 are first applied parameters of process 1 and then parameters of process 2, while on the sample 422 are first applied parameters of process 2 and then parameters of process 1. The duration of each process was amounted by 300’. The only difference is in the order of their application.

3.3. Testing of the chemical composition

Testing of the chemical composition was performed on steel 20MnCr5. Chemical analysis was used to determine the composition of steel used for high-temperature carbonitriding. To determine the chemical composition a spectrometric method was used, and the test was performed with the device „Belec“, Figure 3.

Fig. 3 *Device for chemical analysis.*

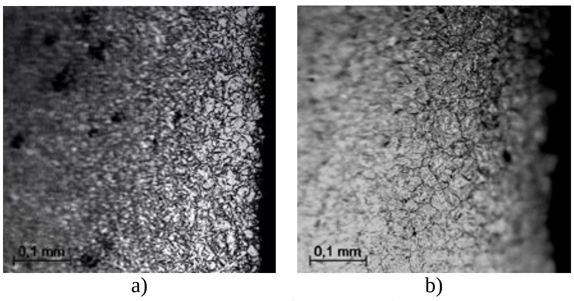
Results of the chemical composition testing of steel 20MnCr5, as well as the values prescribed by standard are shown in Table 6.

Table 6: *The chemical composition of steel 20MnCr5.*

	Chemical composition, %					
	C	Si	Mn	P	S	Cr
Declared [7]	0,17 ÷ 0,2	max. 0,4	1,1 ÷ 1,4	max. 0,025	max. 0,035	1 ÷ 1,3
Tested	0,18	0,35	1,23	0,021	0,028	1,26

3.4. Metallographic tests

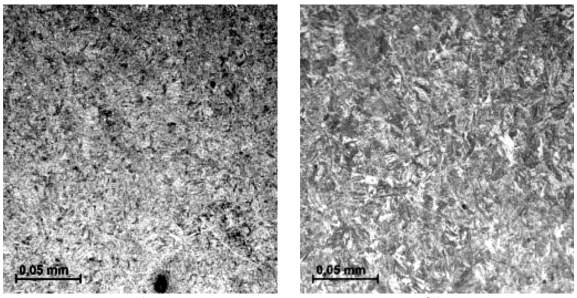
Metallographic tests and recordings of the microstructures were carried out on the cross-section of high-temperature carbonitriding steel 20MnCr5 on samples 421 and 422. Microstructures of the edge of high-temperature carbonitriding steel 20MnCr5 are shown in Figure 4. In Figure 4.a, on the edge of cross section of sample 421 rough martensitic structure can be seen, while in Figure 4.b, on the edge of cross section of sample 422 finely distributed nitride can be detected.



a) b)

Fig. 4 *The microscopic appearance of the edge of steel 20MnCr5.*
a) sample 421, etched 3 % nital;
b) sample 422, etched 3 % nital

Microstructures of the core of high-temperature carbonitriding steel 20MnCr5 are shown in Figure 5. In Figure 5.a is shown the fine grained structure of the core of sample 421, in contrast to coarse grain structure of the core of sample 422, shown in Figure 5.b.



a) b)

Fig. 5 *The microscopic appearance of the core of steel 20MnCr5.*
a) sample 421, etched 3 % nital;
b) sample 422, etched 3 % nital

3.5. Hardness tests

To image the mechanical properties was complete, after metallographic tests were measured values of surface hardnesses by device „TH 720“, Figure 6.

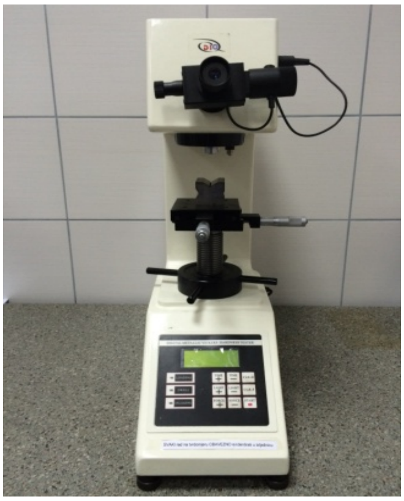


Fig. 6 *Device for hardness testing „TH 720“.*

The hardness flow of high-temperature carbonitriding steel 20MnCr5 was measured with Vickers method HV1 on the cross-section of the samples 421 and 422, and the direction of measurement was from the surface edge to the core. The results are shown in Table 7.

Table 7: *The measurement results of the surface hardnesses of steel 20MnCr5.*

Distance from the edge, mm	HV1	
	Sample 421	Sample 422
0,10	646	707
0,20	645	671
0,30	650	669
0,40	655	668
0,50	664	665
0,60	693	651
0,70	704	637
0,80	641	617
0,90	642	603
1,00	623	605
1,10	578	571
1,20	553	559
1,30	533	520
1,40	496	513
1,50	489	505
2,00	452	459
2,50	447	456
5,00	441	452

3.6. Resistance testing to the adhesion wear

Resistance testing to the adhesion wear was carried out on the device „SMT-1 2070“ by method disc/disc, Figure 7.

Fig. 7 *Device for testing of the adhesion wear „SMT-1 2070“.*

Method disc/disc is a laboratory test method. Test samples used for testing by this method are shown in Figure 8. During testing the lower sample (UZ) and the upper counter body (KT) rotate independently of each other. Their mutual contact is realized on the peripheral surface. There is a possibility of selecting the appropriate rotational speed of the sample UZ and counter body KT from the available range 75 ÷ 1500 r/min and selecting the appropriate load from the available range 0 ÷ 5000 N.

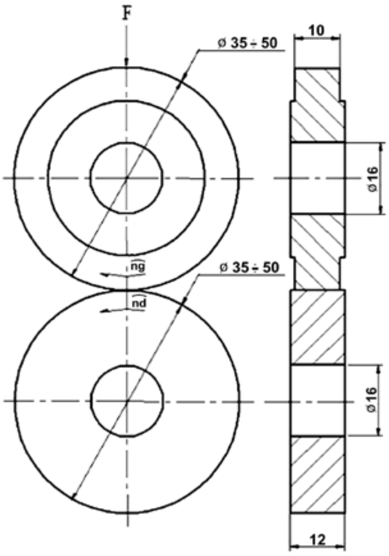


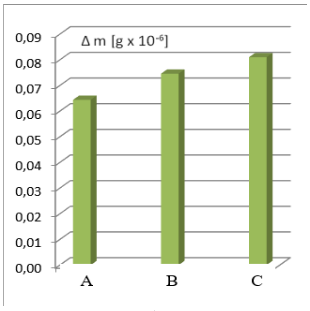
Fig. 8 *Test samples for resistance testing to the adhesion wear by method disc/disc.*

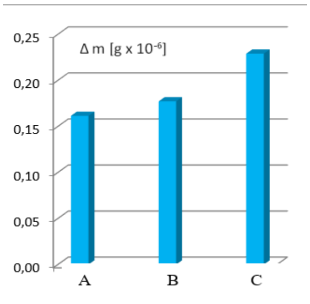
Test parameters of the adhesion wear resistance of steel 20MnCr5 are shown in Table 8. Marks A, B and C represent parameters of resistance test to the adhesion wear with method disc/disc. Samples of steel 20MnCr5 marked with 421 and 422 during the resistance test to the adhesion wear are loaded with different forces to the constant speed of rotation.

Table 8: *Test parameters of the adhesion wear resistance.*

Mark	A	B	C
F [N]	400	1200	2000
v [o/min]	600	600	600

In Figure 9 by histogram are presented mass loss of steel 20MnCr5 for samples 421 and 422 at selected conditions of the resistance test to the adhesion wear.

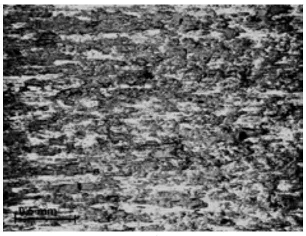




a) b)

Fig. 9 *The histogram representation of the mass loss of steel 20MnCr5.*
a) sample 421;
b) sample 422

After perfomed resistance tests to the adhesion wear of steel 20MnCr5, the traces of sample 421 and sample 422 were recorded, Figure 10.



a) b)

Fig. 10 *The representation of the traces wear of steel 20MnCr5.*
a) sample 421;
b) sample 422

4. Analysis of the results

Selection of representative gear's tribocouple are defined frameworks for analyzing of high-temperature carbonitriding MnCr steel, with a focus on the resistance to the adhesion wear. Analysis of the results obtained by testing the chemical composition of steel intended for high-temperature carbonitriding, followed by resistance testing to the adhesion wear, it was established that it is a steel 20MnCr5, Table 6. In Figure 4.a, on the edge of cross section of sample 421, etched with 3 % nital, with an increase 200:1, rough martensitic structure can be seen, while in Figure 4.b, on the edge of sample 422, also etched with 3 % nital and with the same increase, finely distributed nitride can be detected. In Figure 5.a, etched with 3 % nital and with an increase of 500:1 is shown the fine grained structure of the core of sample 421, in contrast to coarse grain structure of the core of sample 422, shown in Figure 5.b. Values of the measured hardnesses of the edge of sample 421 and sample 422 are higher than 700 HV1, while the values of the measured hardnesses of the core range about 450 HV1, Table 7. From the histogram in Figure 9 can be seen that to increase the force to the constant speed of rotation, an increase in mass loss of high-temperature carbonitriding steel 20MnCr5. After completion of resistance testing to the adhesion wear, the traces of wear of sample 421 and sample 422 are recorded, Figure 10. There is an appearance of typical adhesion wear on sample 421 and sample 422, with note that the sample 422 has more pronounced presence of surface „craters“ which are probably the consequence of the presence of fragile chemical compound Fe_2N.

5. Conclusion

High-temperature carbonitriding was performed on the steel 20MnCr5, by varying the potential of carbon and nitrogen in the atmosphere of furnace during carburizing. Considering to a relatively unexplored area of the higher contact loads, the emphasis on these tests is placed on the researchs of resistance to the adhesion wear in the conditions of contact load up to 2000 N to the constant speed of rotation. The range of selected loads are provided the opportunity to establishing relation with the available literature data, and make conclusions on a wide area of the influence of high contact loads on resistance to the adhesion wear. At both of the tested samples, with the increase in load during testing of resistance to the adhesion wear by method disc/disc it came to mass loss. Despite the somewhat lower of the surface hardness values it was noticed that a high-temperature carbonitrided steel where the atmosphere of furnace at the beginning of carburizing was enriched with nitrogen, and finally with carbon showed significantly greater resistance to the adhesion wear. His mass loss was up to three times lower compared to the mass loss of steel that at the beginning of carburizing had atmosphere of furnaces rich in carbon, and finally with nitrogen. This behavior can be related with the claim that the variable potential of the high-temperature carbonitriding has a significant influence on the diffusion of carbon than nitrogen diffusion, as well as the fact that in both steel for high-temperature carbonitriding are created the higher share of retained austenite.

6. References

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