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INVESTIGATION OF THE INFLUENCE OF THE LEVEL OF CARBON AND NITROGEN POTENTIAL AT HIGH TEMPERATURE CARBONITRIDING OF Mn-Cr STEEL

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Abstract: High temperature carbonitriding is a process of heat treatment that is used to increase the surface hardness of components, in order to reduce wear. The worm press for production of vegetable oil was chosen as an example of a system in which the high temperature carbonitrided components, made of Mn-Cr steel, are also built in. In exploitation, the extraction cage knife is exposed to a significant influence of the abrasive media, and the fatigue of material. A decrease of installed capacity efficiency is the result of local damages of components due to wear. The determined dimensional criterion of seizure makes the process of high temperature carbonitriding very suitable for the production of components that are used in the given exploitation conditions. The possibility of changing the level of carbon and nitrogen potential, as well as the effect on the possible life of extraction cage knives, were analysed. The use of a different carbon and nitrogen potential at the high temperature carbonitriding of test samples results in an extremely favourable flow of hardness at the cross-section. It can be observed that the achieved course of hardness is an extremely important indicator that had a significant impact on the final decision on the suitability of the observed process of thermochemical treatment for the intended purpose.
Keywords: heat treatment, thermochemical treatment, Mn-Cr steel, carbonitriding, high temperature

INTRODUCTION

In the worm presses for production of vegetable oil, the extraction cage consists of built-in knives (Figure 1).

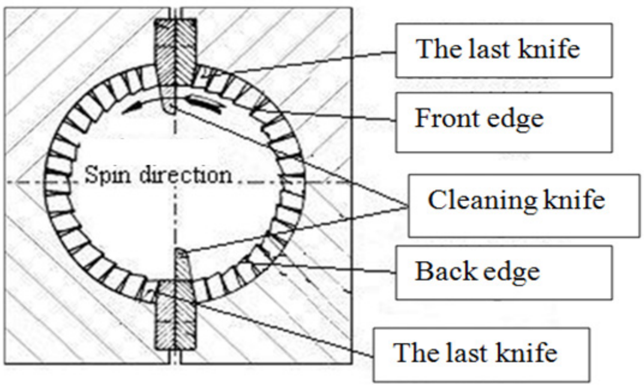


Figure 1. Cross-section of extraction cage knives of worm press

Due to the presence of abrasive media and the appearance of fatigue of material that the extraction cage knives are exposed during exploitation, they were usually made by the cladding procedure. The costs of production by cladding, and extremely strict dimensional criterion of seizure and the problems during exploitation (Figure 2), emphasize the need to examine the use of other methods of production and prolonging life.

Taking into consideration the previous experiences, it can be assumed that the high temperature carbonitriding could give the optimum results, both from the production, but also from the standpoint of behavior in exploitation. The high temperature carbonitriding is a thermochemical surface treatment. The simultaneous diffusion of carbon and nitrogen in the surface forms different depths of martensite, according to the applied temperature. Even though this is an industrial process, which is used to harden the surface of components in order to reduce the wear, the wear mechanism was not intensively studied. Furthermore, there is little information on the wear of materials and their properties, which vary from the surface to the core. First of all, it is necessary to *determine the suitability of high temperature carbonitriding process for application on the steels for cementation that would have not only an affordable price, but also the required properties. If the satisfactory properties of layer are determined, the subsequent testing and the analysis of wear intensity will be performed.*

Figure 2. Damaged extraction cage knife – made by cladding

MATERIAL AND METHODS

Steels for cementation

Steels for cementation belong to the group of structural steels. They usually contain from 0,1 up to 0,2%C before carburisation, and can be non-alloyed or low-alloyed. Steels with that low carbon content during hardening cannot achieve sufficiently high hardness, which is necessary to achieve resistance to abrasive wear. Therefore, steels for cementation, after the chip forming treatment with the addition for grinding of surfaces, which should be grinded after the cementation (gear teeth, fits for bearing, crosshead guides, etc.), are subjected to carburisation. Carburisation in granulate, salt bath or gas results in the increased amount of carbon from 0,8 up to 0,9%C in the surface layer of material. Thus enriched surface edge of material becomes hardenable, i.e. by quenching from a suitable temperature of austenitization, it takes the structure of high-carbon martensite, resistant to wear [1]. The hardnesses after quenching can reach between 60 and 65 HRC. The process of cementation consists of the carburisation and hardening of carburised part, as well as the low-temperature tempering. After camentation, the core of material stays ferritic-pearlitic if the product is not hardened, i.e. it becomes low-carbon martensitic if the core is hardened. Both these structures of core have a high toughness, i.e. after the process of cementation, steel will have a hard surface with good wear resistance, and with relatively tough core.

With alloyed steels, hardening is preferred, because the cemented steels are low-tempered at the temperatures below 220 °C, and greater toughness of the core can be achieved only by the low-carbon martensite. The aim of alloying is to improve hardenability of steel at quenching of carburised object. Due to better hardening of the core, we get the structure of low-carbon martensite, which provides high strength properties of core, its increased fatigue strength and high toughness (diagrams in Figure 3). Alloying elements have an impact on the process of carburisation of edge of object, i.e. on the speed of the process of carburisation, carbon content in the edge of carburisation of object, depth of carburised boundary layer. Non-carbide-forming elements, like nickel, silicon and cobalt, accelerate the diffusion of carbon in austenite, but also lower the solubility of carbon in the boundary layer, while carbide-forming elements, like chromium, molybdenum, vanadium and manganese, lower the diffusion coefficient of carbon in austenite, and thus increase the carbon content in the boundary layer [1], [2], [3].

One of the main problems when choosing the parameters for the process of carburisation and hardening is how to determine the correct temperature of quenching. Considering the fact that at the same time, there are areas with a high carbon content (the edge with over 0,8%) and low carbon content (core with less than 0,2%), it is necessary to choose a compromise temperature of quenching. The temperature of quenching should be lower than the ideal one for the core (the temperature at which the boundary layer overheats causing a coarse-grained martensite and increased fragility) and higher than the ideal for the high-carbon edge (at which there is incomplete hardening of the core). In this respect, the least problems occur with non-alloyed steels, in which the so called direct hardening, i.e. quenching with the temperature of carburisation, is permitted. From such non-alloyed steels, the products of smaller dimensions, and the products for secondary purposes that are exposed to lower impact stresses, are manufactured [1], [2], [3], [4].

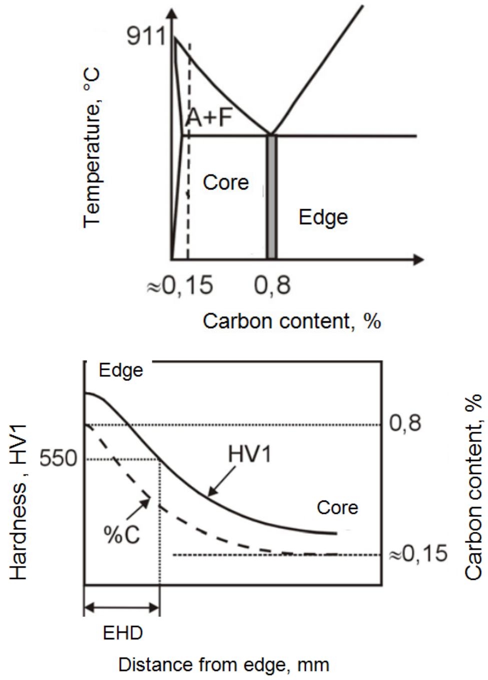


Figure 3. Carbon content (a) and hardness (b) during carburisation [1]

The process of carburisation can be performed in the granulate, molten cyanide salts and in a gaseous medium. The process of hardening can be done directly or after the process of carburisation, so called single hardening. Direct hardening is usually applied after carburisation in salt bath, and single hardening after slow cooling in granulate or gas. The hardening is followed by the low temperature tempering in the temperature interval from 170 up to 220°C.

When choosing the steels for cementation, the determining factor is the dimension of finished product. Since it is possible to achieve a high surface hardness (that guarantees wear resistance) on all steels for cementation, there is a special request for the approach to the hardenability of core.

The main characteristic of Mn-Cr steels for cementation is that despite the high percentage of chromium, and due to the presence of manganese, they are not prone to separation of carbides in the boundary layer. The presence of manganese and chromium increases hardenability, so these steels are used for the medium size products, such as gears and shafts of machine tools. Mn-Cr steels are sensitive to overheating, and therefore, after carburisation, they are slowly cooled and re-austenitizated and quenched, and then tempered [2], [3].

In order to investigate the influence of the level of carbon and nitrogen potential (on the properties of steel), the high temperature carbonitriding of Mn-Cr steel for cementation will be made, (chemical composition is shown in Table 1).

Table 1. Chemical composition of 20MnCr5 steel [5]

Proportion of chemical element, %	C	Si	Mn	Cr
Composition of sample	0,19	max. 0,4	1,25	1,15
According to EN 10084:2008	0,17÷0,22	max. 0,4	1,1÷1,4	1÷1,3

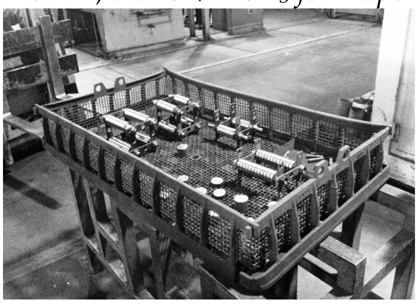
High temperature carbonitriding

The high temperature carbonitriding is a thermochemical treatment where the surface layers of steel in the austenitic condition are enriched simultaneously by carbon and nitrogen. After hardening, the object is quenched in oil or water, and low temperature tempered [2].

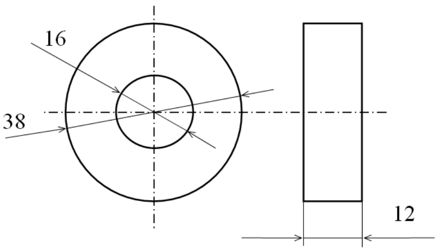
The high temperature carbonitriding process is carried out between 700 °C and 900 °C, and with the lower temperature of carbonitriding, nitrogen enrichment prevails over carbon. With the increase of temperature of carbonitriding, the amount of diffused carbon is increased, and the amount of diffused nitrogen is decreased. The structure of layers is carbon-nitrogen martensite, and the outer part of the layer is a zone of carbonitride compounds. The process of high temperature carbonitriding can be performed in liquid, solid or gaseous agents. Temperature, duration of the procedure and the chemical composition of steel have the most significant effect on the process of high temperature carbonitriding. Nitrogen in the carbonitrided edge increases wear resistance, and if a zone of compounds is created in a carbonitrided layer, fatigue strength of machine parts will be increased. The process of high temperature carbonitriding is carried out in liquid or gaseous media. Liquid media are salts for carbonitriding, which are the mixtures of alkaline cyanides, cyanates, carbonates, chlorides and activators. The high temperature carbonitriding in gas atmospheres is a process of cementation with the same gas atmosphere, which is enriched by the gas with nitrogen (ammonia NH_3). The procedure is used as a substitute for the cementation of objects sensitive to measuring.

Unlike nitriding, the carbonitrided components are more resistant to high specific pressures and impacts. The materials that can be used for the carbonitriding are the steels for cementation, improvement, sintered iron and cast iron [3].

The test samples in a form of disc are shown in Figure 4. The process of high temperature carbonitriding was performed in the protective atmosphere of a furnace, rich with earth gas and ammonia, at the constant parameters of temperature (920 °C) for the duration of 10 hours. The use of different values of carbon potential (C_{pot}) and nitrogen potential (N_{pot}) was planned. C_{pot} values were read directly on the measuring equipment which is part of the furnace. For Experiment 1, C_{pot} = 0.5% C, and for Experiment 2, C_{pot} = 1.0% C. N_{pot} values were regulated by the flow of ammonia. They were as follows: 10 % NH_3 for Experiment 1, and 5 % NH_3 for Experiment 2.



a) Test samples (prepared for the furnace)

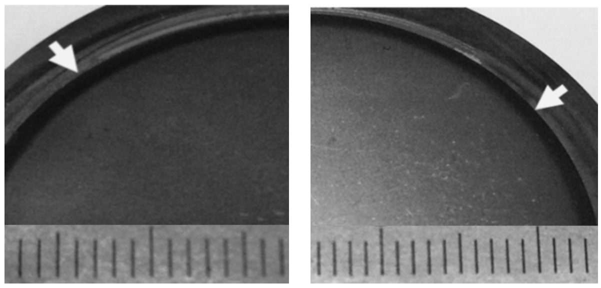


b) Test sample (shematic representation)
Figure 4. Test samples for high temperature carbonitriding

RESULTS AND DISCUSSION

Using HV1 method, the hardness measurement was performed at the cross-section of test samples (Figure 5). A characteristic dark edge (marked by the arrows) can be noticed on the surface layer of the test samples sealed in polymer.

Figure 6 shows the hardness measured at the cross-section of samples (high temperature carbonitrided for 10 hours). The achieved effective depth of carbonitriding was 1÷1,3 mm (represented by the points C1 and C2 in Figure 6).



a) Experiment 1 b) Experiment 2
Figure 5. Cross-section of high temperature carbonitrided samples sealed in polymer

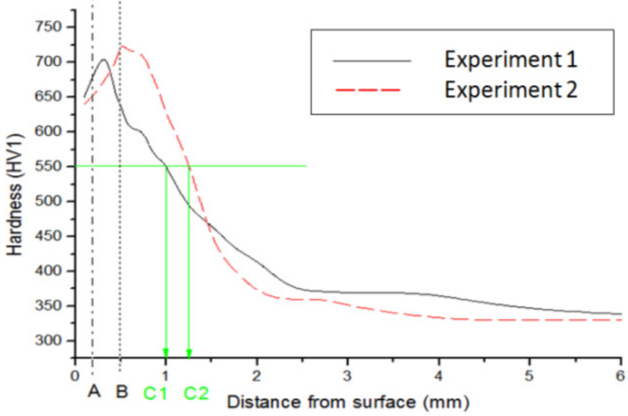


Figure 6. Hardness (HV1) measured at the cross-section of test samples shown in Figure 5

In the components with the rod-shaped form, like an extraction cage knife, there is a risk of deformation at the high temperature carbonitriding, Figure 7. From the flow of hardness, Figure 6, it can be observed that by the use of different levels of carbon and nitrogen potential, different effective depths of carbonitriding are achieved (points C1 and C2, Figure 6). Despite the observed differences, the high temperature carbonitriding still proves to be a very effective procedure of thermochemical treatment. It also allows the subsequent steps of grinding to correct the dimensional deviations caused by deformations up to the level of hardness marked with A for Experiment 1, and the level of hardness marked with B for Experiment 2. The letter symbols (in Figure 7) represent the zones of hardness at depth of high temperature carbonitrided knife of extraction cage, which are taken from the diagram in Figure 6. The maximum permitted level of wear in exploitation is up to the point C1, when using the parameters of Experiment 1, and up to the point C2, when using the parameters of Experiment 2.

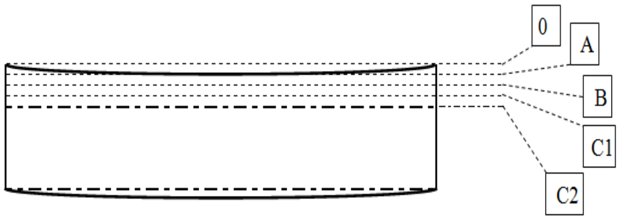


Figure 7. Schematic representation of tolerance areas of the extraction cage knives, where the corrections by machining are allowed

Using the device SMT-1 2070 (Figure 8), it is possible to simulate the conditions most similar to real, operating conditions.

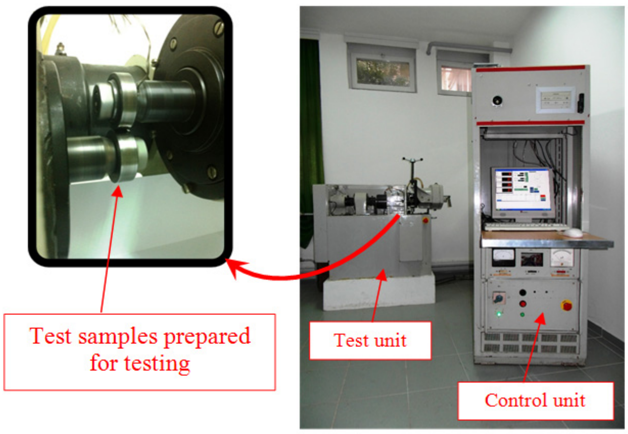


Figure 8. Device for testing of friction and wear, SMT-1 2070

CONCLUSION

The main objective of the high temperature carbonitriding is an increase of surface hardness and wear resistance. Since the dimensional criterion of seizure for the extraction cage knives is approximately 0,2 mm (point A in the diagram, Figure 6), the high temperature carbonitriding can be applied for their production regardless of the level of carbon and nitrogen potential. With regard to the wear resistance, it is necessary to perform the additional tests of prepared samples. The obtained results will give a complete picture of the properties in conditions of wear.

They provide an adequate basis for the future research. The testing for the prepared samples is designed, making it possible to carry out the testing of wear resistance of the layers at the desired depth of layer. By monitoring the wear intensity of adhesive type with the component of sliding, it is possible to get an insight in the current properties, as well as the possibility of better synchronisation of the necessary surface properties of machine elements.

REFERENCES

[1.] Kožuh, S., Specijalni čelici (skripta), Metalurški fakultet Sveučilišta u Zagrebu, pp. 1-57, 2010.
[2.] Krumes, D., Površinske toplinske obrade i inženjerstvo površina, Strojarski fakultet Slavonski Brod, pp. 31-114, 2004.
[3.] Novosel, M., Krumes, D., Posebni čelici, Strojarski fakultet Slavonski Brod, pp. 93-165, 1998.
[4.] Stupnišek M., Cajner F., Osnove toplinske obradbe metala, 1996
[5.] EN 10084:2008

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