EFFECT OF CASE HARDENING PROCESS PARAMETERS OF ALLOY STEELS ON THEIR WEAR CHARACTERISTICS

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Abstract: Cane chains are very important transmission elements which are carefully designed according to fatigue strength and wear resistance. To increase the life of cane chains, the resistance of the surface failure should be increased. In this investigation, experiments were carried out to evaluate the wear resistance using wear test rig designed and manufactured for this purpose. Three types of steels were used, namely 16MnCr5, 17CrNiMo6, and 18MnCrB5. Discs manufactured from these steels were carburized for different periods of time (6, 10, and 12 hours). Tempering process was carried out at different temperatures to obtain hardness values of 48, 52, and 56 HRC. The accumulated weight loss was measured and the wear rates were determined for each case hardened steel at the constant normal test load of 800 N. The accumulated weight loss was measured as a function of the number of revolutions. Wear rate was calculated and presented with case hardened depth and hardness for all steels. The hardness distribution and carbon content of carburized layer was presented as a function of the distance from the surface. Carburized layer microstructure and carbide percentage were presented and measured. From test results, it was concluded that the wear rate for all steels under investigation decreases with the increase of their case hardness. Minimum wear rate was obtained at hardness 56 HRC. Wear rate for all steels decreases with the increase of carburizing time tending to reach a minimum at carburizing time 10 hours. Wear rate for steel 16MnCr5 is less than that of the wear rate for 17CrNiMo6 and 18MnCrB5 by about 15% and 45% respectively under the same testing conditions. Carburized layer, carbon content and case depth increase with the increase of carburizing time.

Keywords: Heat Treatment, Carburizing, Case Hardening, Alloy Steel, Cane Chain, Wear Rate, Sugar Industry.

1. Introduction

Chains are very important transmission elements which are to be carefully designed for efficient working of machines. All parts of chains are subjected to elaborate machining, heat treatment [1], grinding and assembling. Chains are the most important elements in the sugar company.

The parts of chains are manufactured as follows: Rollers should not only have excellent wear resistance but also rigidity; therefore, case hardened alloy steels are used as the material for rollers. Since pins require high wear resistance and toughness, case hardened alloy steels [2], which are rigorously selected and the surface is hardened and ground. Bushes require also wear resistance, case hardened alloy steels with external and internal surfaces hardened and ground.

Chains usually work under the most severe conditions. They are subjected to high tensile load since they are transmitting a large quantity of canes. High wear resistance is necessary to prevent them from wearing away in service. Thus, steels of which chains are made must be properly heat treatable.

Wear resistance is considered as the most important parameter for proper selection of the material to be used for chains manufacturing. Hardness, microstructure and chemical composition of steel play a marked role in wear resistance. Although hardness and relative wear are linearly proportional for most of the commercial metals, the same simple relation does not hold for a range of steels where it becomes necessary to consider chemical composition as well as hardness.

Many papers discuss the wear rate with different case depth and case hardness for different steels [3]. The aim of this work is to study the best heat treatment for chain components with regard to hardness and case depth for the three selected steels 16MnCr5, 17CrNiMo6, and 18MnCrB5. Carburizing process was carried out for 6, 10, and 12 hours, with final hardness values of 48, 52, and 56 HRC, depending on the tempering temperature to select the most suitable material which results in the lowest wear and longer life of chain.

2. Experimental work

2.1. Wear Testing Machine

A rolling contact wear testing machine was constructed purposely for this investigation and presented in Figure 1.
2.2 Calibration curve of spring
Calibration curve for two springs to apply the required load between the drive and the driven rollers are presented in Fig. 2.

![Calibration curve of spring](image)

Fig. 2. Calibration curve of spring

2.3 Test specimens
Specimens were obtained in form of round bars 80 mm diameter, for tested materials 16MnCr5, 17CrNiMo6 and 18MnCrB5 and then cut to 15 mm length, which was machined as presented in Figure 3.

![Shape and dimensions of specimens](image)

Fig. 3. The shape and dimensions of specimens.

Wear resistance experiments were performed for specimens with heat treatment under dry rolling condition. In this work 54 discs were used, 18 discs from each tested materials, divided into 9 groups; 2 discs for each group. Each group of two discs was subjected to a specific heat treatment conditions. The chemical compositions of tested steels are given in table 1.

<table>
<thead>
<tr>
<th>Table 1 Chemical composition for tested materials.</th>
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<tr>
<td>Steel</td>
</tr>
<tr>
<td>16MnCr5</td>
</tr>
<tr>
<td>17CrNiMo6</td>
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<tr>
<td>18MnCrB5</td>
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2.4 Heat treatment of specimens
The heat treatment technique used in this investigation was liquid carburizing followed by hardening and tempering as presented in Figure 4. Discs and other small specimens examinations were heated in liquid carburizing at the temperature of 915°C[4], for a predetermined period of time. The specimens hardening at temperature 860°C and kept for 1 hour to be hardened by oil quenching. After quenching the discs were tempered to obtain the hardness 48, 52 and 56 HRC respectively.

![Applied heat treatment cycle of test discs](image)

Fig. 4. Applied heat treatment cycle of test discs.

2.5 Wear Measurements
Before each test, the discs were carefully cleaned. The discs were mounted in such a way to always have the same orientation in order to be sure that rolling has occurred in the same starting and direction throughout the test. Tests were carried out using a constant load of 800 N created by means of two springs, as shown in Fig. 1. Tests were also carried out at the constant speed of 1500 r.p.m., corresponding to a rolling velocity of 4.71 m/s at the surface of the discs.

The machine was stopped after a predetermined time interval for weighing the discs, after cleaning and dried, using a digital balance of 210 gr capacity and 10^-4 gr accuracy. The accumulated loss of weight in mgr. was plotted against the number of revolutions. Wear rate was calculated using the following equation [5].

\[
\text{Wear rate} = \frac{\text{Accumulated weight of removed metal}}{\text{Load} \times \text{total number of revolutions}}.
\]

2.6 Examinations
Hardness, microstructure and Scanning Electron Microscope examinations were carried out using instruments types HWDM7, TSS capacity 1500 HV, optical Microscope type OLYMPUS X50 – X400 and type JSM 5410. Specimens 29 mm diameter and 15 mm length were prepared grinded, polished and etched using 4% Nital solution.

Carbon percent distribution in the carburized case was measured using Emission Spectrometer, type Thermo Jarrell Ash (TJA) 181, wave spectra 14000 Kv.

3. Results and Discussion
Figure 5 demonstrates the variation of accumulated loss of the driving and driven discs with the number of revolutions for the as received materials under investigation.

![The losses of weight for tested materials, as received](image)

Fig. 5. The losses of weight for tested materials, as received.
of weight of the driving and driven discs versus the number of revolutions at carburizing time (6, 10 and 12 hours) for different materials and different case hardness respectively.

From Figures 6.a and 6.b it is noticed that the accumulated loss of weight increases with increasing the number of revolutions for all materials, also for all case depth and case hardness.

Figure 6.a demonstrates the variation of the rate of wear and case hardness for 16MnCr5 at the different carburizing time.

Figure 6.b demonstrates the variation of the rate of wear and carburizing time for 16MnCr5 at the different hardness.

From Figure 6.a it is clear that the wear rate decreases with increasing the case hardness for all tested materials and carburizing time [6]. Also, the wear rate of 16MnCr5 is smaller than that of the wear rate for 17CrNiMo6 and 18MnCrB5 for all carburizing time and from Figure 6.b it is clear that the minimum wear rate occurred at carburizing time 10 hours for all hardness. Also the wear rate of 16MnCr5 is smaller than that of the wear rate for 17CrNiMo6 and 18MnCrB5 for all carburizing time, and from figure, it is clear that the wear rate will decrease with increasing the case hardness[7], and from Figure 6.b it is clear that the minimum wear rate will occur at carburizing time equal 10 hours for all hardness. Also, the wear rate of the hardness 56 HRC is smaller than that of the wear rate for hardness 52 HRC and hardness 48 HRC for all materials.

Wear rate for material 16MnCr5 is less than that of the wear rate for materials 17CrNiMo6 and 18MnCrB5 by about 15% and 45% respectively at carburizing time 10 hours and hardness 56 HRC. This attributed to the carbides contents for material 16MnCr5 is less than that of the carbides for materials 17CrNiMo6 and 18MnCrB5 respectively, the carbides contents for materials 16MnCr5, 17CrNiMo6 and 18MnCrB5 equal to 38%, 42% and 56% respectively.

The retained austenite for steel 16MnCr5 is regular and quantity is less. The retained austenite for steel 17CrNiMo6 is irregular, its volume and area are bigger. The retained austenite for steel 18MnCrB5 is medium but concentrated and its volume is bigger.

The increase of retained austenite resulting from further increase the case depth decrease the yield and ultimate stress of the material[8]. It also decreases the fatigue limit. This is believed to be the reason for the increase in the wear rate. Also for the greatest case depth and case hardness, the rigidity of the case hardened materials increase and a further increase of weight of removed metal and wear rate.

The increase of retained austenite strongly affects the wear resistance of materials. Martensite for steel 16MnCr5, its distribution is better and quantity is high[9].

From Figures (8, 9 and 10) the retained austenite in material 16MnCr5 is less than that for materials 17CrNiMo6 and 18MnCrB5, and the martensite fraction in material 16MnCr5 is higher than that for materials 17CrNiMo6 and 18MnCrB5. Structure for all materials are martensite, retained austenite and carbide.
X-ray analysis was shown in figure 12. The carbides in the diffusion layer formed by alloying and carburizing were \( \alpha \) – Fe, \( \alpha \)–Fe, C and \( \alpha \)–Fe, Cu. And table 3 shows the types and the phases for material 16MnCr5 [11].

From microstructure, Scanning Electron Microscope (SEM) and X-ray diffraction, it was noticed that the retained austenite for material 16MnCr5 is regular and quantity is less. Furthermore, martensite distribution is better and its area fraction is larger.

Conclusions

1- Wear rate for all materials under investigation decreases with the increase of their case hardness. Minimum wear rate was obtained at hardness 56 HRC.

2- Wear rate for all tested materials decreases with the increase of carburizing time, tending to reach a minimum at carburizing time 10 hours. This may be attributed to the decrease in the retained austenite in the carburized matrix. Further increase of the carburizing time may result in a pronounced increase in wear rate due to larger area of carbides obtained at longer carburizing time.

3- Wear rate for material 16MnCr5 is less than that of the wear rate for 17CrNiMo6 and 18MnCrB5 by about 15 % and 45 % respectively under the same testing conditions.

4- Carburized layer, carbon content and case depth increase with the increase of carburizing time.

5- The appearance of the retained austenite was accompanied by a decrease in both hardness and wear resistance of tested materials.

6- Wear rate for materials 16MnCr5, 17CrNiMo6 and 18MnCrB5 at carburizing time 10 hours and hardness 56 HRC is less than that of the wear rate for the same materials without heat treatment by 55 %, 67 % and 83 % respectively.

References


