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INVESTIGATION OF MICROSTRUCTURAL AND MECHANICAL PROPERTIES OF CARBURIZED GENERAL CONSTRUCTION STEEL

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Abstract. In this study, the effect of surface hardening on microstructure and mechanical properties was investigated by applying box carburizing (cementation) process to samples produced from unalloyed St37 steel, known as structural steel. In the experiment, the samples, which took place at 2 different temperatures at 800 ºC and 930 ºC, were kept in the oven with coal dust in the box for 3, 5 and 10 hours for cementation, with the mouth tightly closed. By examining the microstructure of the cemented samples, the coating thicknesses, hardness changes by making hardness tests, and the amount of wear were examined by performing abrasion tests. As a result of the vickers method hardness tests, it was revealed that the highest hardness values were found in the sample that was cemented for 10 hours at 930 ºC. As a result of the wear tests, 10N and 20N loads were applied to the sample, and the wear amount of the wear device on the material was found by traveling 100 m at a stroke distance of 10 mm. As a result of the wear tests, the applied cementation time and the wear loss are inversely proportional, while the cementation temperature value is inversely proportional to the wear loss. It has been determined that the applied load and the wear loss are directly proportional.

Keywords: *General structural steel; carburizing; surface hardening; St37*

ДОСЛІДЖЕННЯ ВПЛИВУ ЦЕМЕНТАЦІЇ НА СТРУКТУРУ ТА МЕХАНІЧНІ ВЛАСТИВОСТІ МАЛОВУГЛЕЦЕВОЇ СТАЛІ

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Анотація. У цьому дослідженні вплив поверхневого зміцнення на мікроструктуру та механічні властивості досліджували шляхом застосування процесу цементування до зразків, виготовлених із нелегованої сталі Ст37, відомої як конструкційна сталь. В експерименті зразки, що проходили за двох різних температур − 800 та 930 ºC, витримували в печі з вугільним пилом у ящику протягом 3, 5 і 10 годин для цементації, з щільно закритою горловиною. Вивчаючи мікроструктуру зацементованих зразків, досліджували товщину покриття, змінювання твердості при проведенні випробувань, а також величину зносу шляхом виконання випробувань на стирання. В результаті випробувань на твердість за методом Віккерса виявлено, що найвищі значення твердості виявлено у зразку, який цементували протягом 10 годин за 930 ºC. В результаті випробувань на знос до зразка були прикладені навантаження 10Н і 20Н, а величина зносу зношувального пристрою на матеріалі була визначена шляхом проходження 100 м на відстані ходу 10 мм. В результаті випробувань на знос, застосовуваний час цементування та втрати зношування обернено пропорційні, а значення температури цементації обернено пропорційно втратам зношування. Встановлено, що прикладене навантаження і втрати зношування прямо пропорційні.

Ключові слова: *сталь загальноконструкційна; цементація; поверхневе зміцнення; ст37*

INTRODUCTION

While the machine elements used in the engineering field perform their functions, a loss occurs in the materials used as a result of wear, vibration and fatigue. This loss in the material is a negative situation that the manufacturer and the consumer do not want in terms of cost, quality and life of the material.

Today, structural steels have an important place in many production industries such as automotive, white goods, toys, ovens and home textiles. One of the most frequently used materials in the industrial industry in the world and in Turkey is St37 steel. The steel used has been demanding for its manufacturers and consumers in terms of its mechanical properties, easy welding ability, trouble-free cutting and durability.

The effect of surface hardening on the mechanical properties of unalloyed (plain carbon) St37 structural steel, which contains carbon, manganese, phosphorus, sulfur, nickel and copper alloy elements, was investigated using different parameters. Surface hardening process has been applied to the materials by making box carburizing, and it is aimed to gain requirements that will extend the life of the material such as preventing crack formation, increasing the oxidation resistance of the material and creating a surface layer with increased strength values [2].

METHOD

In this study, surface hardening process was applied to st37 structural steel, whose chemical properties are specified in table 1, at 800 °C, 930 °C, at the parameters of 3,5 and 10 hours, with box carburizing. After these processes, the wear behavior and hardness values of the material were examined.

Table 1

Chemical compositions of St 37 structural steel [5]

Element	Weight (Max)
C	**0,2**
Mn	**1,4**
P	**0,04**
S	**0,04**
N	**0,012**
Cu	**0,55**

The test parameters of St37 steel determined in the study are given below.

- Sample cemented in an oven at 800 °C for 3 hours
- Sample cemented in an oven at 800 °C and 5 hours
- Sample cemented in an oven at 800 °C and 10 hours
- Sample cemented at 930 °C and 3 hours in an oven
- The sample cemented in the oven at 930 °C and 5 hours
- Sample cemented at 930 °C and 10 hours in an oven

EXPERIMENTS

Hot Coating. Bakelite coating was applied to 6 different specimens that had undergone cementation at 180 °C for 5 minutes. These processes were carried out in the CitoPress − 10 hot molding device. The purpose of this application is to enable the sample to be examined more efficiently under the microscope. Another purpose is to better hold the part in the sanding and polishing application.

Fig. 1. Bakelite coated specimen

Sanding and Polishing. Some deformations may have occurred on the surface of the sample after the cutting and cementation process. In order to eliminate these problems and to reveal the original internal structure, the hot-coated sample is processed in an automatic sanding and polishing device called tegramin − 30. Figure 2 shows the treated sample [4].

Fig. 2. Sample with sanding and polishing processes

Microstructure Review. It is the examination of the structure of the material and the determination of its properties. It is an instrument in which the transitions of phases such as cementite, pearlite, ferrite, bainite and martensite in the structure of the sample can be seen relatively.

Hardness Tests. Certain hardness values were obtained by applying 100 grams of loads to the samples with the Vickers hardness measurement method in a micro hardness measuring device.

Scanning Electron Microscope (SEM). The wear type and properties were determined by taking visuals with SEM from the worn surfaces of the samples that were subjected to the wear test.

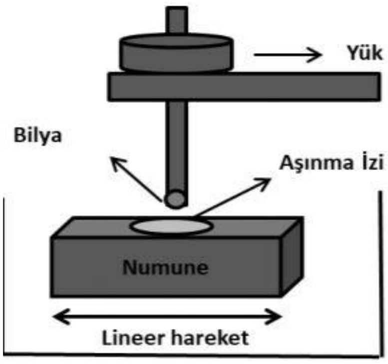

Fig. 3. Schematic representation of the wear test [4]

Wear Tests. Abrasion tests were carried out on un-cemented specimen, cemented at 800 ºC for 3 hours, cemented at 800 ºC for 5 hours, cemented at 800 ºC for 10 hours, cemented at 930 ºC for 3 hours, cemented at 930 ºC for 5 hours, was applied linearly to the specimens cemented at 930 ºC for 10 hours using wolfram carbide ball carbide. Samples of 10 mm × 10 mm size and 50 mm length from St37 structural steel were fixed on the plate of the test device. Loads were applied to the samples with a stroke length of 10 mm on the 10N and 20N samples and a total distance of 100 m was taken. The area of the wear scar was measured [1].

The wear volume and wear rate of the samples can be calculated according to the formula given in (1) and (2). We find the velocity by dividing the product of the wear mark area and the length of the wear mark by the distance traveled [4].

• Wear rate = Wear mark volume/ Distance traveled (1)

• Wear mark volume = (Abrasion mark area x wear mark length) / distance traveled (2)

FINDINGS AND CONCLUSIONS

Microstructure Review. Cementation process was carried out on St37 steel samples, which has the most common usage areas among general structural steels, using 6 different parameters.

This experiment, called carburizing, was carried out in solid media. The samples placed in the box were covered with charcoal and the box was tightly closed. After waiting for 3,5 and 10 hours in ovens at 800 ºC and 930 ºC, the materials were cooled. The microstructures of the non-carburized sample are shown below.

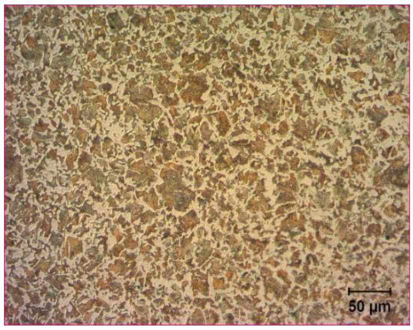

Fig. 3. Internal structure of St 37 steel ×200

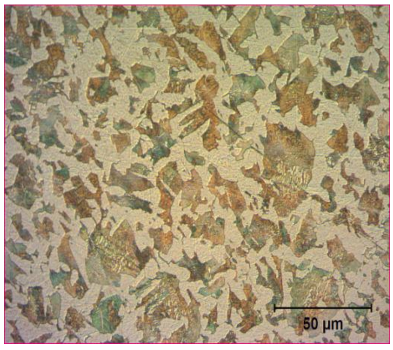

Fig. 4. Internal structure of St 37 steel ×500

Coating Thicknesses. After the surface of the St37 steel was hardened by cementation, the depths were measured at different temperatures and at different times. These depth measurements are also shown below.

Fig. 5. Sample treated at 800 °C for 3 hours ×200

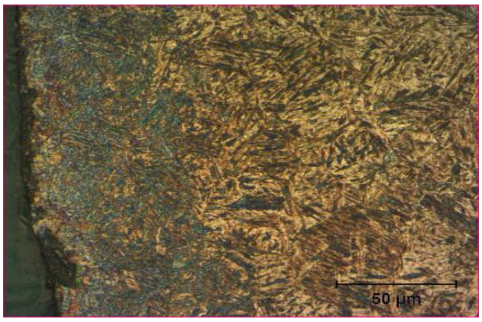

Fig. 6. Sample treated at 800 °C for 3 hours ×500

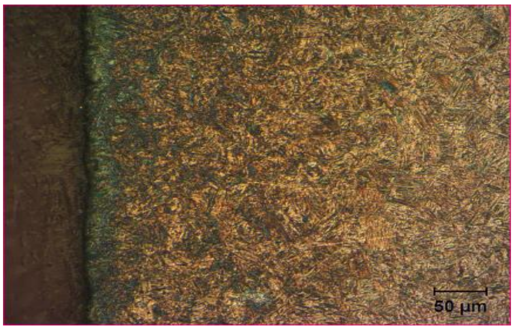

Fig. 7. Sample treated at 800 °C for 5 hours ×200

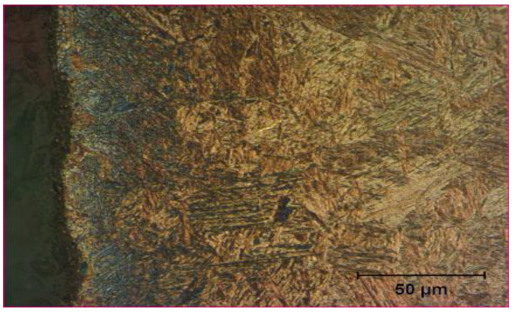

Fig. 8. Sample treated at 800 °C for 5 hours ×500

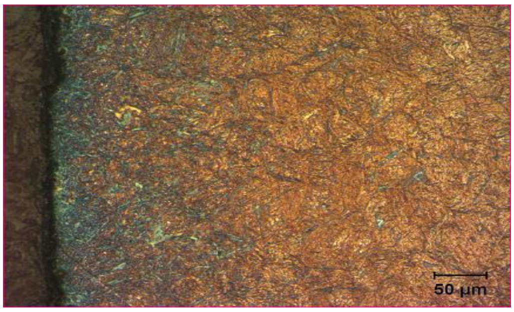

Fig. 9. Sample treated at 800 °C for 10 hours ×200

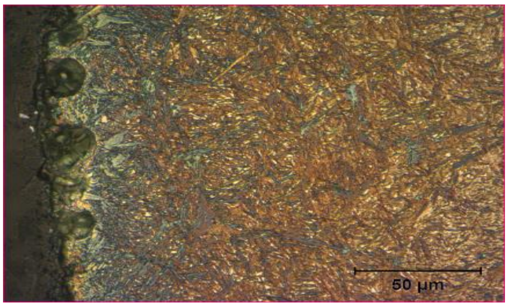

Fig. 10. Sample treated at 800 °C for 10 hours ×500

Fig. 11. Sample treated at 930 °C for 3 hours ×200

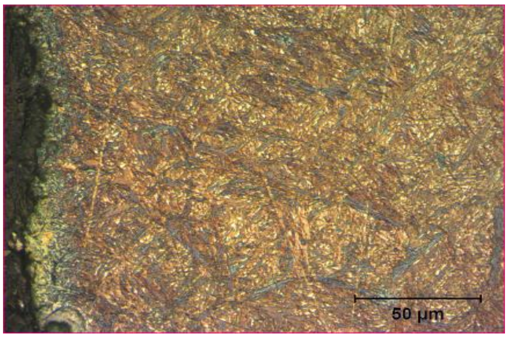

Fig. 12. Sample treated at 930 °C for 3 hours ×500

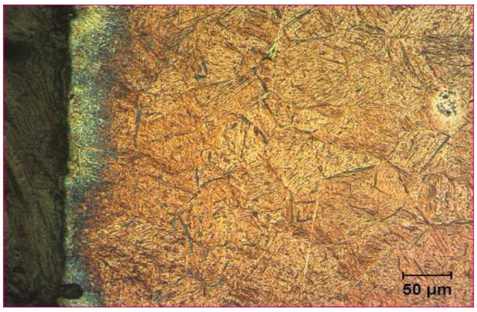

Fig. 13. Sample treated at 930 °C for 5 hours ×200

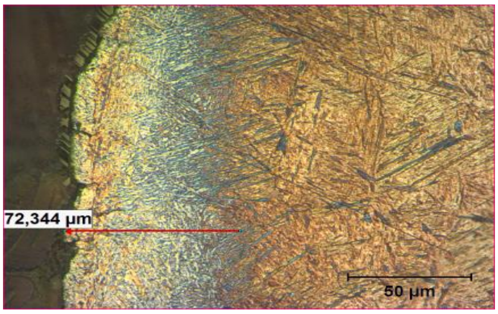

Fig. 14. Sample treated at 930 °C for 5 hours ×500

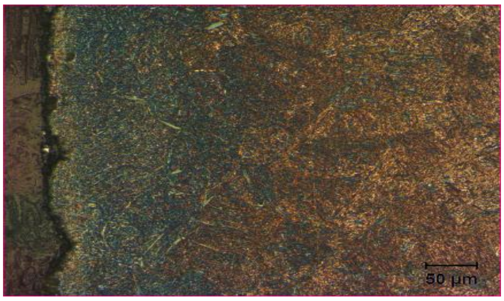

Fig. 15. Sample treated at 930 °C for 10 hours ×200

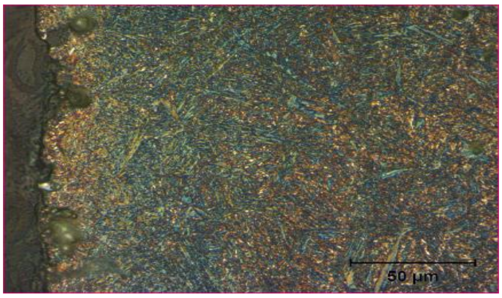

Fig. 16. Sample treated at 930 °C for 10 hours ×500

As a result of microstructure examinations in ×200 and ×500 dimensions after surface hardening processes of 6 different samples, the sample with the most carbon diffusion is St37 steel, which was treated at 930 °C for 10 hours in Figure 15. Depending on the increase in temperature and time, the amount of carbon diffused into the structure of the sample increased.

Hardness Values

The hardness values of St 37 steel without cementation process are 260 HV.

Vickers hardness values are shown in Table 2 as a result of the hardness tests performed on 6 different samples of 8×8×10 mm dimensions. These values were determined by applying a 100 gr load to the samples for 20 seconds. After the surfaces of the samples were sanded, operations were carried out.

When the averages of the hardness values of the samples in 3 different experiments were examined, it was seen that the hardness value of the sample that was cemented at 930 ºC and 10 hours reached the highest values.

As can be seen from Table 2, the hardness on the surfaces of the cemented samples is directly proportional to the furnace temperature value. However, when the waiting times of the samples with the same temperature values were examined, it was seen that the time parameter was directly proportional to the hardness value.

Table 2

Hardness values of the samples as a result of the test

	800 ºC 3 hours	800 ºC 5 hours	800 ºC 10 hours	930 ºC 3 hours	930 ºC 5 hours	930 ºC 10 hours
Experiment 1	377 HV	391 HV	471 HV	503 HV	718 HV	841 HV
Experiment 2	368 HV	434 HV	478 HV	528 HV	771 HV	912 HV
Experiment 3	386 HV	438 HV	475 HV	512 HV	746 HV	908 HV
Average	377 HV	421 HV	474 HV	514 HV	745 HV	887 HV

Wear Values. A linear abrasion test was carried out on 6 different samples of 8×8×25 mm dimensions. The trace lengths on the samples, on which two different loads of 10N and 20N were applied, were adjusted to be 10 mm and a total of 100 m was traveled. In accordance with ASTM G133 standard, the areas of wear traces measured from the device that has been tested for back-and-forth wear are given in Table 3. Average values were taken by making 3 different measurements.

As a result of the abrasion test of 6 different specimens cemented at 800 and 930 ºC, the areas of the worn areas are given in Table 3. Accordingly, if the load applied to the samples increases while the temperature is the same, the amount of wear increases in direct proportion. As the hardness values of the samples increased with the increase of cementation time, the wear areas on the surface decreased. As can be seen in the figure, the most exposed sample is the material that has been cemented for 3 hours at 800 ºC with a load of 20 N. Since the applied force load is increased and the cementation time is short, the wear is at the highest level in this sample.

The wear loss of the material at 930 ºC, where the applied weight is 10 N and cemented for 10 hours, is at the lowest level compared to other samples.

Table 3

Areas of wear marks on the sample

	800 ºC 3 hours	800 ºC 5 hours	800 ºC 10 hours	930 ºC 3 hours	930 ºC 5 hours	930 ºC 10 hours
10 N	0,017 mm²	0,011 mm²	0,002 mm²	0,0023 mm²	0,00075 mm²	0,00041 mm²
20 N	0,042 mm²	0,040 mm²	0,004 mm²	0,005 mm²	0,002 mm²	0,0015 mm²

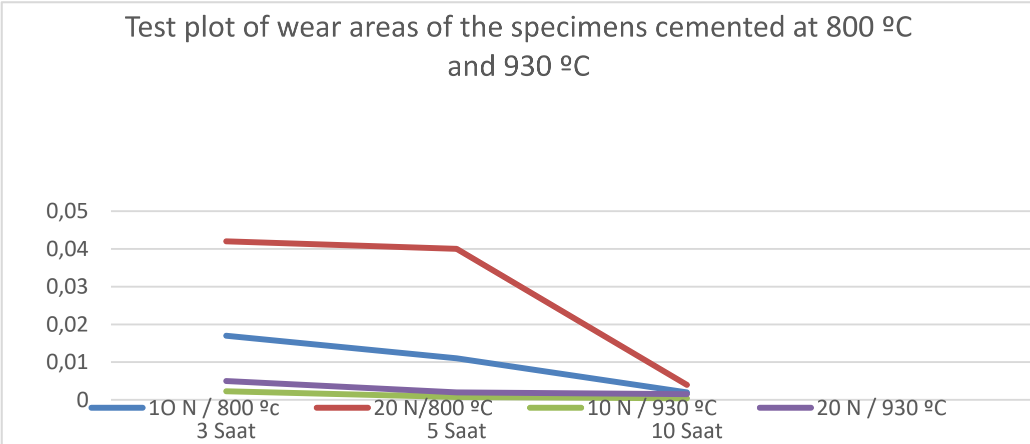

Fig. 17. Change of wear areas depending on parameters

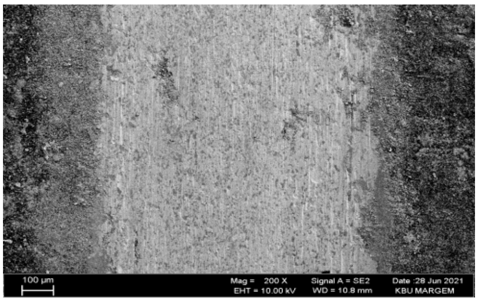

Fig. 18. SEM wear image 800 °C 3 hours 10N weight

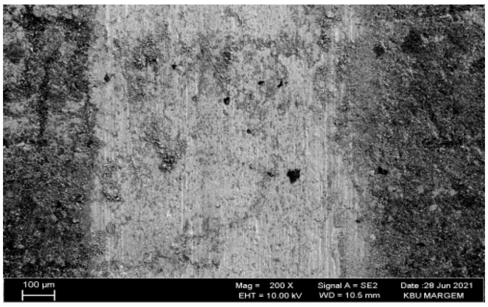

Fig. 19. SEM wear image 800 °C 5 hours 10N weight

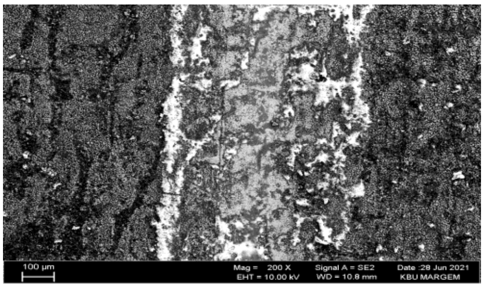

Fig. 20. SEM wear image 800 °C 10 hours 10N weight

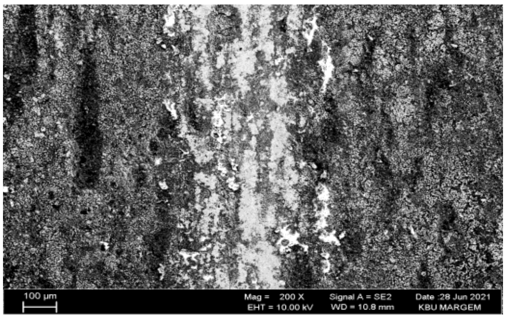

Fig. 21. SEM wear image 930 °C 3 hours 10N weight

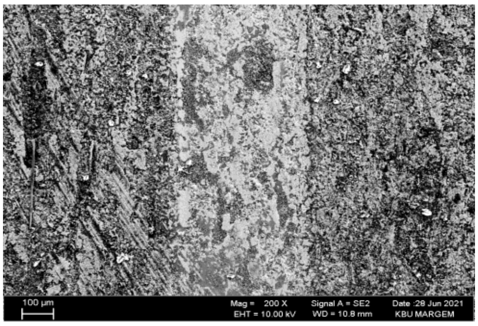

Fig. 22. SEM wear image 930 °C 5 hours 10N weight

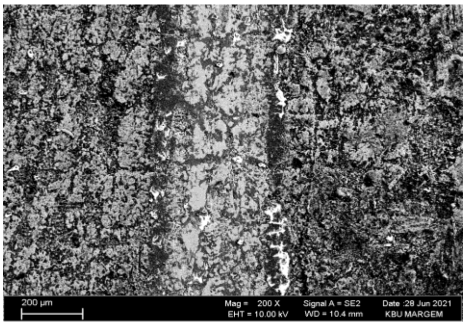

Fig. 23. SEM wear image 930 °C 10 hours 10N weight

As a result, the cementation time applied to the sample is inversely proportional to the wear loss. Likewise, the cementation temperature value is inversely proportional to the wear loss. However, the applied load is directly proportional to the wear loss. The SEM images of the wear tested samples are given in the figures below.

In the examined SEM images, it is seen that the most wear is in sample a in Figure 18.

RESULTS

In this study, the hardness and wear behavior of St37 steel, which is a general structural steel, after surface hardening with cementation was investigated. In the experiments, the sample that did not undergo cementation and the samples that underwent surface hardening at 800 and 930 °C in three different time intervals were used. Hardness tests were made with vickers type hardness test. As seen as a result of the hardness tests, it has been observed that the hardness values decrease as you go from the carburized surface to the inside of the sample. The maximum hardness value on the surface of the cemented specimen is 912 HV.

Considering the temperature parameters, the hardness value of the sample that was cemented for 3 hours at 800 °C is 377 HV, while the hardness value of the sample that was kept at 930 °C at the same time is 887 HV. Based on this result, it was seen that the increase in the furnace temperature value increased the hardness value of the material.

When we look at the time parameters, the hardness values of the sample, which underwent 3,5 and 10 hours of cementation at 800 °C, are 377 HV, 421 HV, and 474 HV, respectively. These results show us that the increase in the cementation time increases the hardness value of the material. the material.

Wear tests were performed on 6 different samples in a linear fashion. Accordingly, if the load applied to the samples increases while the temperature is the same, it has been observed that the amount of wear increases in a direct proportion. It was observed that the wear areas on the surface decreased as the hardness values of the samples increased with the increase of cementation time.

In the microstructure examinations, considering the coating thickness of the samples, it was observed that the maximum carbon diffusion rate was in the sample that was cemented for 10 hours at 930 °C.

In general, the following results emerged.

• It has been revealed that the temperature and time parameters affect the hardness values in a direct proportion.

• It is the sample that was cemented for 10 hours at 930 °C with the maximum coating thickness. For this reason, time and temperature directly affect the carbon emission rate.

• The amount of wear increased in direct proportion with the load applied to the sample.

• It was observed that the wear areas on the surface decreased as the hardness values improved in the samples with increased residence time in the oven.

• The volume losses in the sample cemented at 930 °C for 5 and 10 hours were lower compared to all other samples.

• The highest volume loss occurred in the sample that was cemented for 3 hours at 800 °C.

• The change in hardness of the samples caused the wear values to differ.

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