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# Investigation the Mechanical Properties of Carburized Low Carbon Steel

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**ABSTRACT**
This study presents the examination of reducing the carburizing for surface of low carbon steel in solution of oil. The variable parameter was the temperature (850 ˚C, 900 ˚C, and 950 ˚C) and the constant parameter was the carburizing process duration (2 hour). The research covers the analysis of the microstructure and mechanical properties such as hardness and wear resistance. The results of the experimental investigation showed that hardness increased from the inside to the outside of the specimens, as follows: from (102 HV to (250 HV) at (850 ˚C) carburizing temperature, from (105 HV) to (272 HV) at (900 ˚C) carburizing temperature and from (115 HV to 192 HV) at (950 ˚C) carburizing temperature. A wear resistance test was also conducted for the hardest sample (carburized at 950̊C). This test was applied for different durations and the results were the following: for 2 hours duration, the value of wear rate was ($9.99*10^{-6}$ g/m), for 4 hours duration, the value of wear rate was ($12.7*10^{-6}$ g/m) and for 6 hours duration the value of wear rate was ($15.13*10^{-6}$ g/m)
**Keywords:** Low carbon steel, carburization, microstructure examination, hardness, wear test.

## I. INTRODUCTION

The most popular techniques of surface hardening for steel are carburizing. This technique provides efficient mixtures of mechanical properties. The carburizing process consists of heating up low carbon steel containing (0.10-0.25 % C) in a carbon-rich environment at temperatures up to (900-1100 ˚C). At temperatures higher than (910 ˚C), when the iron is in FCC (γ) form, carbon atoms from the environment diffuse into the iron and form a carbon-enriched coat of adequate thickness after holding the iron at that temperature. It is possible to harden the carbon-enriched layer formed by reheating and quenching or by quenching straight from the temperature of carburizing. The carburizing process can take place in different media (solid, liquid or gaseous) according to the scope and type of process involved. During carburizing, the medium has a role in interstitially absorbance into the steel of the carbon atoms released at the carburizing temperature [1-6].

The process of carburizing or carburization is a heat treatment process during which the iron is heated up to certain temperatures alongside material containing carbon (charcoal or carbon monoxide). Carbon is then absorbed into the iron or steel, increasing the hardness of the final material. The duration of the process and the temperature impact the carbon content of the material. As a rule, the longer the time and the higher the temperature during processing, the thicker the carbon layer becomes. Abrupt lowering of the temperature (through quenching) causes the outer carbon layer to transform from austenite to martensite and to harden. At the same time, the inner material maintains a softer and tougher consistency with ferritic and /or pearlite microstructure [7, 8].

The case generated during carburizing, which is usually used as a surface-hardening procedure, is up to (6.4 mm) deep. The carburizing process implies that low carbon content steel is heated up in carbon-rich medium, such as high-carbon gas, liquid or solid with the purpose of diffusing carbon into the surface of the metal. The resulting high carbon steel displays superior hardness characteristics, as opposed to the core of the material, which has lower carbon concentration. The medium for the carburizing process is obtained through several methods implying the use of Carbon-rich materials (charcoal or cook) loaded into a tight container with the steel or iron material. The result of applying this technique, named packed carburizing, are thick layers on the surface of the material, from (0.6 up to 4 mm). [9-12].

The purpose of applying carburizing treatment is to improve wear resistance, surface strength, crush resistance, impact resistance, fatigue life and generate appropriate residual and compressive stresses. Through surface hardening, the hardness of the surface is increased, while the core is soft and tough. Toughness loss occurs with the hardening process. Thus, it is challenging to obtain recommended surface hardness for large surfaces through quenching to reduce the section size effect. It is also difficult to obtain residual stresses that reduce crack initiation. The carburizing process is widely employed in the production of various parts, such as camshafts, boiler mountings, universal joints, components for cranes, brackets for tractors, flywheel, axles, connection components, etc. It is possible to expand the applications of mild steel [13-15].

The research of Tarakci *et al.* (2005) involved using an aqueous solution containing water, glycerin, and NH4Cl in the carburizing process of pure iron applied for a very short time. The XRD analysis performed after the process established that a carbon-rich was formed on the iron surface, confirmed by the SEM analysis with EDS. The average thickness of the carbon rich layer varied according to exposure time to carbon [16]. The experiment conducted by Fatai *et al.* (2010) had the following parameters: packed carburizing process with pulverized bone as carburizer was applied to mild steel at carburizing temperatures of (850°C and 900°C) and (950°C) for (15 minutes and 30 minutes). The mechanical properties of the resulting material were then analyzed and the conclusions indicated that process of carburization, temperature of carburizing and time of soaking at temperature of carburizing have a significant impact on mild steel mechanical properties [17]. Chatdanai *et al* (2012) used AISI 1020 steels together with 1.8 cm diameter and 1.8 cm height. The treatment applied included heating at (950°C), quenching and then do the tempering process at (650°C) for (60 min). The parts obtained were then grinded and polished with 1000 grid SiC paper and 0.3 mm alumina paste, respectively. For the carburizing process, the current heating technique was used with (40-240 W) electrical powers for (20 min). The results showed that higher electrical power leads to increased steel hardness [18].

## II. EXPERIMENTAL WORK

For the present study, low carbon steel (AISI 1008) was used. The chemical properties of the material are presented in table (1). The geometry of the parts, based on ASTM G99 was cylindrical, with (10 mm) diameter and (50 mm length), as shown in figure (1).

**Table (1) Chemical composition of specimen used in research**

| **Element** | **C** | **Si** | **S** | **P** | **Mn** |
|---|---|---|---|---|---|
| **%** | 0.073 | 0.150 | 0.016 | 0.005 | 0.487 |
| **Element** | **Ni** | **Cr** | **Mo** | **Al** | **Cu** |
| **%** | 0.085 | 0.056 | 0.002 | 0.016 | 0.222 |
| **Element** | **Fe** | | | | |
| **%** | remain | | | | |

For the pack carburizing technique used in this research, the samples were packed in a tight carburizing steel container, in a carbon rich medium with enclosed granules of carbon powder of cook +CaCO3. The temperatures were of (850 ˚C, 900 ˚C, and 950 ˚C), maintained for (2 hr) in an electric furnace. Carbon monoxide was produced as a reducing agent. The carbon released diffuses into the steel surface, where reduction develops at high temperatures. The hardness of the samples increased as the carbon was absorbed in the part.

The parts were afterwards prepared for the microstructure analysis through grinding with (No. 800, 1000 and 2000) grinding paper and polishing using alumina etched with (5%) ethanol nitric acid. The section of the parts was made using a diamond saw perpendicularly on the immersion direction. From microhardness analysis, the samples were polished. The INNOVA microhardness tester with a Vickers diamond indenter that have a (1 kg-load) was used to measure the microhardness for layer of carbon-rich appeared on the surface of low carbon steel and the modification in the cross-sectional hardness from the surface of the carbon-rich layer to the interior of the part.

The wear test was applied with a Pin-on-disk compliant to ASTM G99 standard. In this test, the specimen with a pin/ball geometry is placed on a revolving flat disk and then a particular load is applied through pressing the specimen against the flat disk. The results for the wear test are reported separately as volume losses for the pin/ball specimen and for the disk.

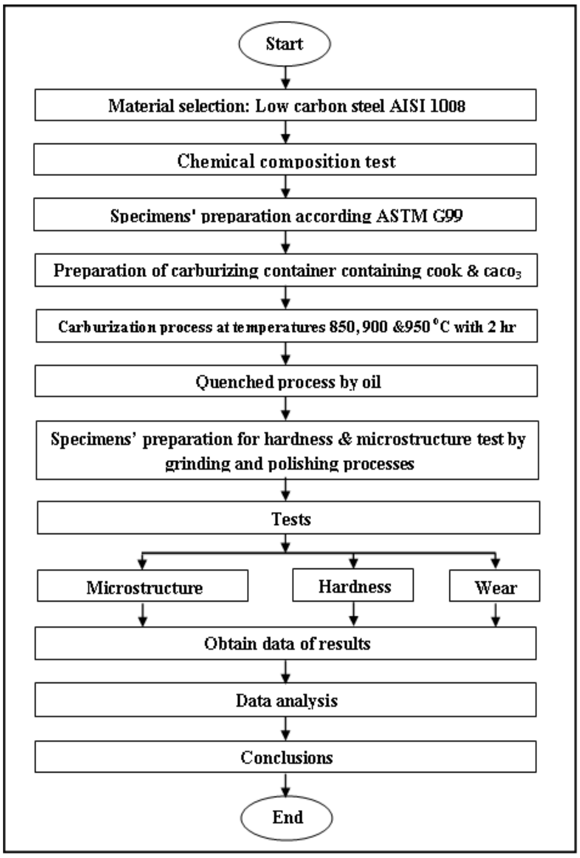



**Fig. (1) Flowchart for experimental procedure of research**

## III. RESULTS AND DISCUSSION

The microscopic views of the specimens obtained at three different temperatures exposed for the same duration (2 hr) are presented in figures (2, 3 and 4), respectively. Compared to the original microstructure shown in figure (5), there are no noticeable differences, except for the grain size, which is bigger for the samples obtained at (850 ˚C) and smaller for the samples obtained at (950 ˚C). In figure 6, the cross section differences are presented and in figure (7), the microstructure differences after carburizing and quenching from the low carbon steel surface to the core. The dark color and needle shapes indicate martensite case, while martensite and ferrite are present between the case and the core. Figure (7) shows case hardness values between (12 μm and 36 μm) as a consequence of variable temperatures, which indicates a dissimilar carburizing layer.

This phenomenon can be justified by the presence of martensite in some regions and of pearlite and martensite in other regions. However, the crystal structure of the core is not affected; indicating ferrite and pearlite structure, thus the differences in hardness values are less. Distinct areas of the core (points D, E and F) show very small differences as a result of maintaining the original microstructure (pearlite and ferrite).

The results after conducting the Vickers method hardness test are included in table (2). Figure 8 shows the relations between carburized samples and Vickers hardness No. The values for the Vickers No. hardness test from the outer layer to the core are included in table (3). Figures (9, 10 and 11) illustrate the influence of the part radius on the Vickers No. hardness test results from the outer layer to the core for samples obtained at (850˚C then 900˚C and 920˚C) temperatures. The compared observation of the Vickers No. hardness test results for the samples obtained at (850 ˚C, 900 ˚C and 920˚C) are presented in figure (12). The results indicate lower values for the sample hardness towards the center, while maintaining its toughness. The samples obtained through the carburizing process are harder at the exterior, making their surface scratch resistant.

The wear test results are presented in table (4) and the correlations between wear time and weight difference for the samples obtained at (950 ˚C) carburizing temperature are illustrated in figure (13).

The higher the carburizing temperature and longer the duration, the deeper the case becomes. At (950˚C) carburizing temperature, the carbon is absorbed faster into the surface for the steel and diffused more rapidly, the case becoming super saturated which may lead to cracking when quenched.

Long time distinguishes carbonization process, Controlling the exact depth of the case is problematic in pack carburizing as there are many aspects that impact it, such as packing amount density, air content of the container, duration of the process, heating of the container and of the carburizing material, carbon surface management and carbon gradient control. Other difficulties which occur in the pack carburizing process are quenching of the carburized products and the fact that the overall process is dirty and dusty.

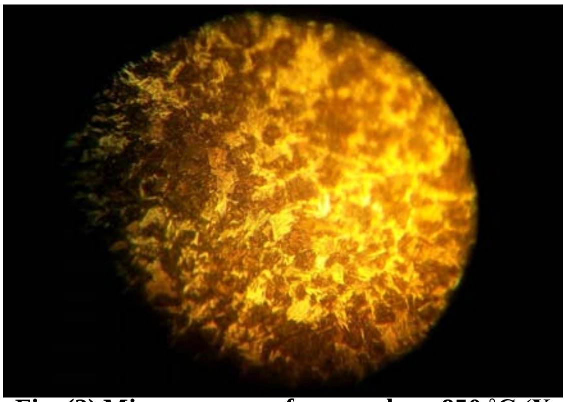


**Fig. (2) Microstructure for sample at 850 ˚C (X = 500)**

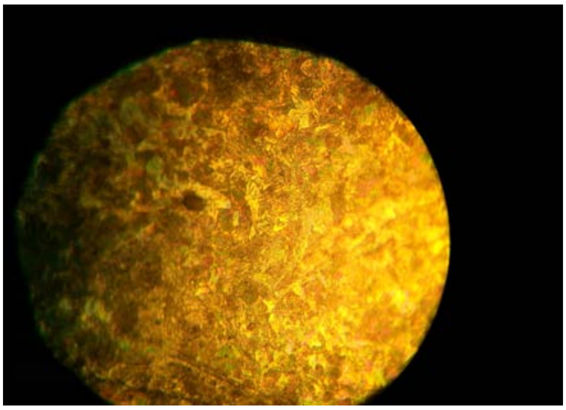


**Fig. (3) Microstructure for sample at 900 ˚C (X = 500)**

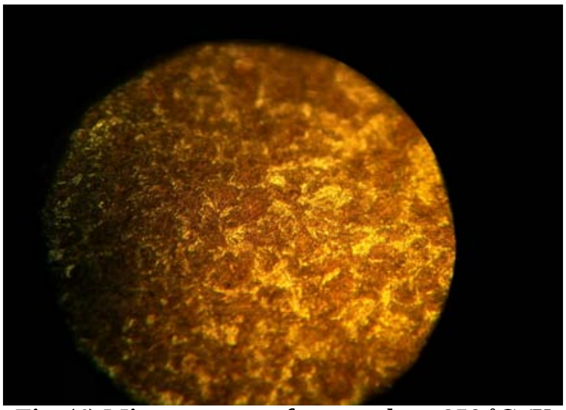


**Fig. (4) Microstructure for sample at 950 ˚C (X = 500)**

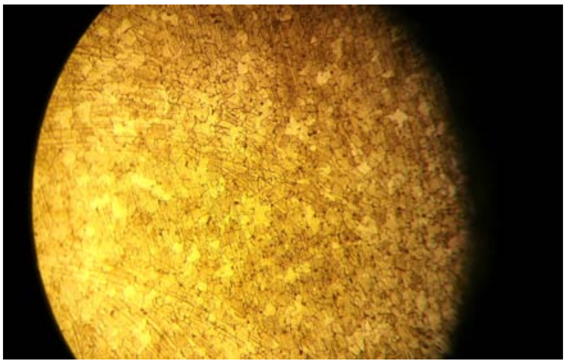


**Fig. (5) Microstructure for sample without carburizing (X = 500)**

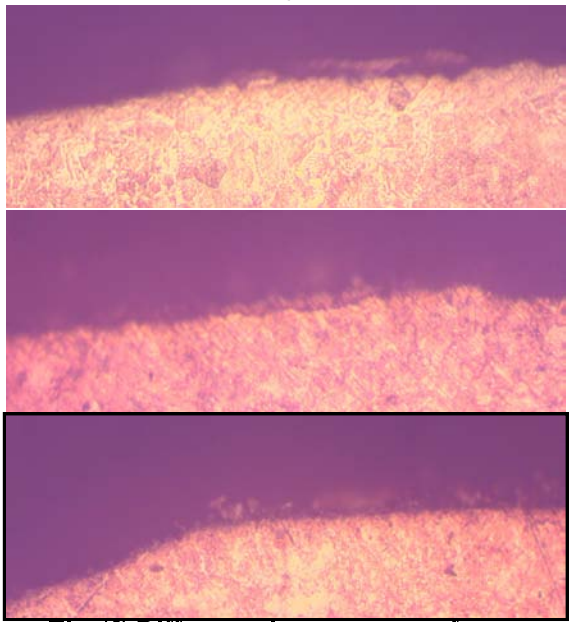


**Fig. (6) Different microstructures of cross section area for carburized specimen (X= 2000)**

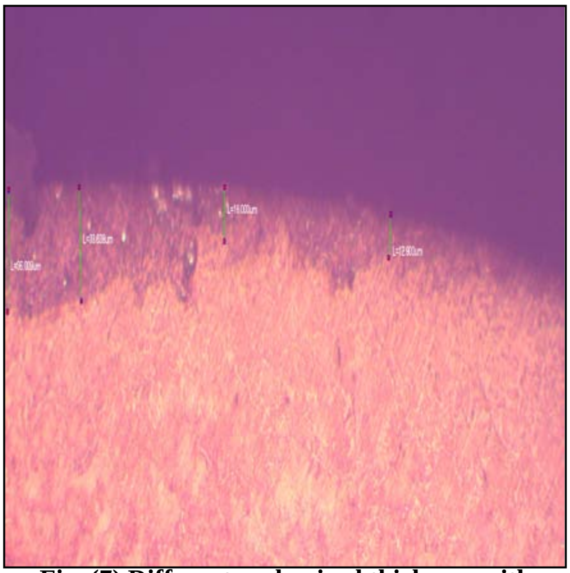


**Fig. (7) Different carburized thickness with surface of specimen after carburizing and quenching operation. (X= 2000)**

**Table (2) Vickers Hardness of carburized samples**

| Carburized samples No. | Carburization temperature (ºC) | Average of Vickers hardness for surface (HV) | Average of Vickers hardness for core (HV) |
|---|---|---|---|
| **1** | Without | 103 | 103 |
| **2** | 850 | 250 | 102 |
| **3** | 900 | 272 | 105 |
| **4** | 950 | 292 | 115 |

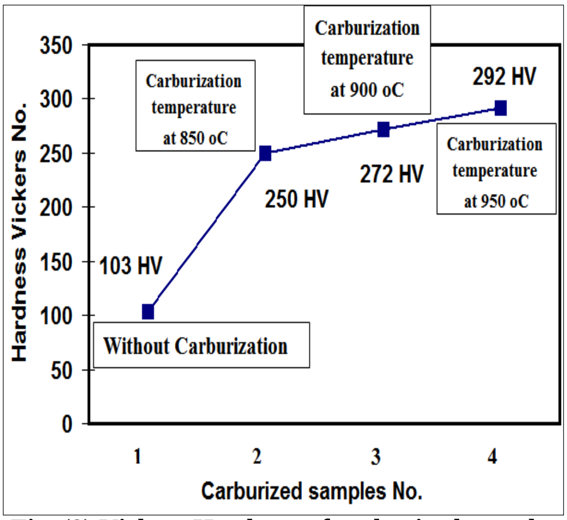
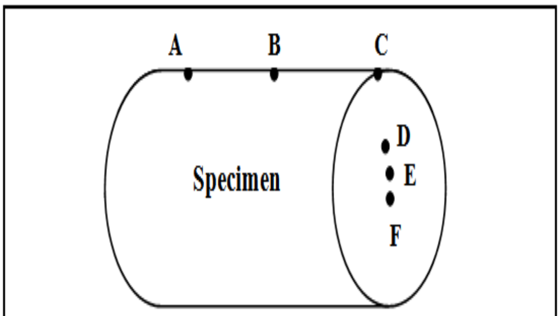



**Fig. (8) Vickers Hardness of carburized samples**

**Table (3) Vickers hardness from outer surface of specimen to core**




| Position | Vickers hardness of carburized specimen at 850 °C | Vickers hardness of carburized specimen at 900 °C | Vickers hardness of carburized specimen at 950 °C |
|---|---|---|---|
| A-surface | 255 | 277 | 291 |
| B-surface | 249 | 274 | 290 |
| C-surface | 246 | 265 | 295 |
| D-core | 106 | 107 | 115 |
| E-core | 100 | 102 | 112 |
| F- core | 100 | 106 | 118 |

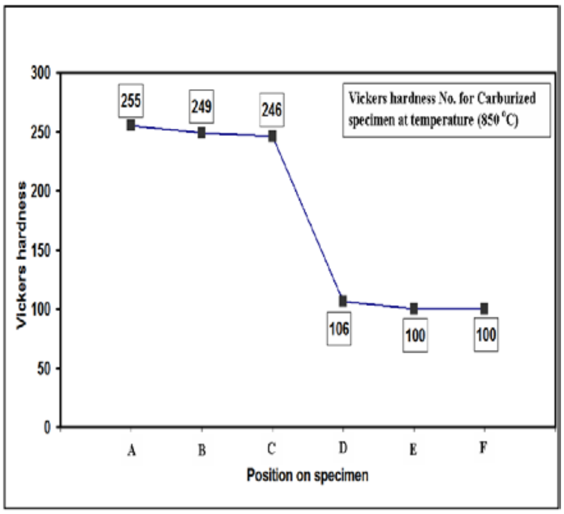



**Fig. (9) Hardness Vickers No. for Carburized specimen at temperature (850 °C)**

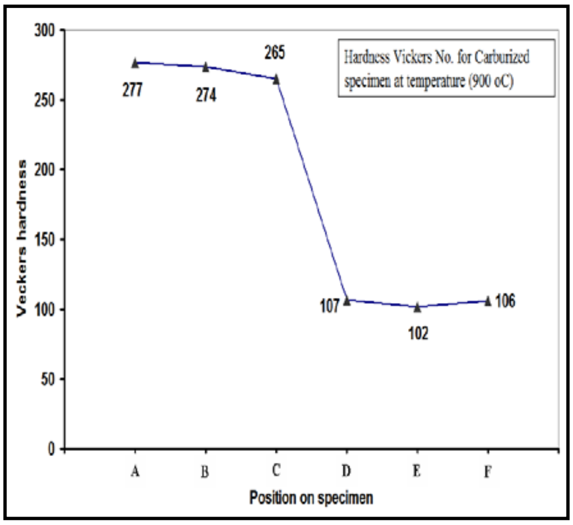



**Fig. (10) Hardness Vickers No. for Carburized specimen at temperature (900 °C)**

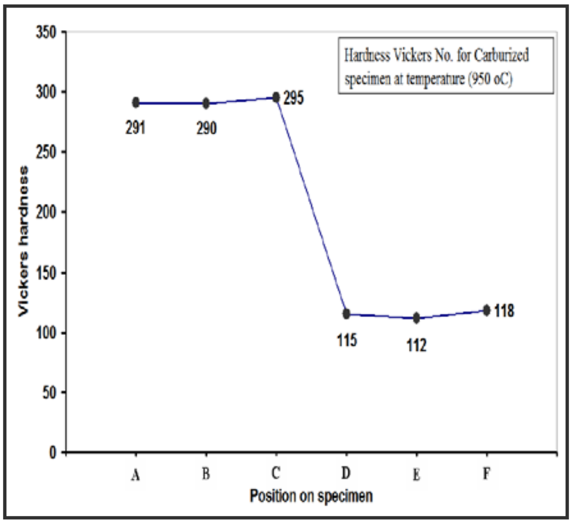



**Fig. (11) Hardness Vickers No. for Carburized specimen at temperature (950 °C)**

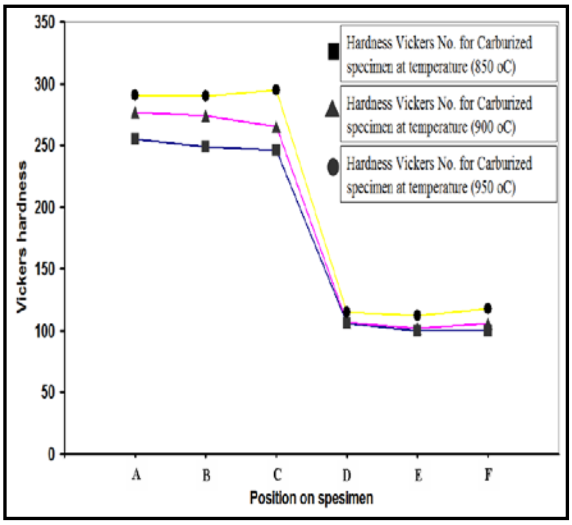



**Fig. (12) Comparison of Hardness Vickers No. for Carburized specimens at temperature (850, 900 and 950 °C)**

**Table (4) Results of wear test for Carburization temperature at (950 °C)**

| Time of wear (hour) | Difference in weight (g) | Wear rate (g/m) |
|---|---|---|
| **2** | 0.1928 | $9.99*10^{-6}$ |
| **4** | 07028 | $12.7*10^{-6}$ |
| **6** | 1.2513 | $15.13*10^{-6}$ |

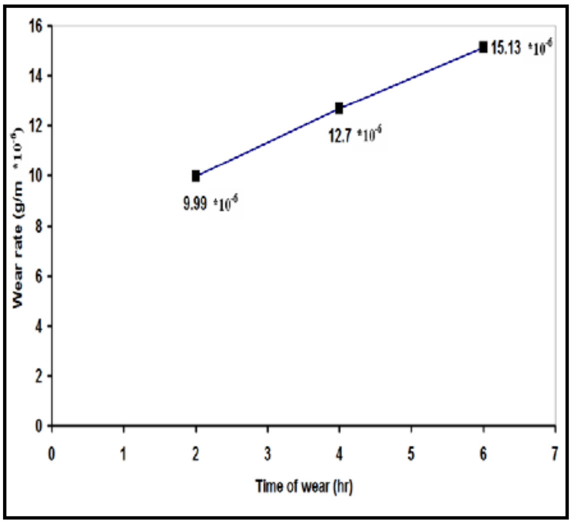



**Fig. (13) Time of wear Vs Wear rate for carburization temperature at (950 °C)**

## IV. CONCLUSIONS

After the analysis of the AISI 1008 low carbon steel rods submitted to pack carburizing treatment at 850˚C then 900 ˚C and 950 ˚C temperatures, the following conclusions can be drawn:

**1-** The carburizing process has a significant impact on low carbon steel mechanical properties, such as hardness and wear.

**2-** Higher carburizing temperatures produce parts with superior hardness and wear resistance.
**3-** Increasing time of wear leads to higher wear rates.
**4-** The highest hardness value was produced for the low carbon steel carburized at ˚C950 temperature, compared to the other temperatures values applied in the present study.
**5-** The higher the carburizing temperature, the harder the case becomes, while maintaining a tough core.
**6-** Carbon diffuse rate into the surface is improved when the carburizing temperature is higher.

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