Carburizing treatment of low alloy steels: Effect of technological parameters

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Abstract. The surface areas of the parts subjected to mechanical loads influence to a great extent the resistance to wear and fatigue. In majority of cases, producing of a hard superficial layer on a tough substrate is conducive to an increased resistance to mechanical wear and fatigue. Cementation treatment of low alloy steels which bonds superficial martensitic layer of high hardness and lateral compressive to a core of lower hardness and greater toughness is an example of a good solution of the problem. The high hardness of the martensitic layer is due to an increased concentration of interstitial carbon atoms in the austenite before quenching. The lower hardness of the core after quenching is due to the presence of ferrite and pearlite components which appear if the cooling rate after austenitization becomes lower than the critical one. The objective of the present study was to obtain a cemented surface layer on low alloy steel by means of pack carburizing treatment. Different steel grades, austenitization temperatures as well as different soaking times were used as parameters of the pack carburizing treatment. During this treatment, carbon atoms from the powder pack diffuse toward the steel surface and further on to the subsurface zone where they combine with the iron atoms to form the iron carbides. The effect of carburizing parameters on the transformation rate of low carbon surface layer of the low alloy steel to the cemented one was investigated by several analytical techniques.

1. Introduction

Carburizing treatment carried out at a temperature between 1143 °K and 1203 °K is used to increase the surface hardness of steel parts. The depth of carburization is a function of carburising time and the carbon potential at the surface [1-5]. High carbon potential is suitable for short carburising times [6-9]. The soaking step of carburizing treatment of low carbon steels is usually followed by quenching and tempering at low temperature [10, 11]. Carburization is the oldest heat treatment used for improving the wear and fatigue resistance of steel parts. For achieving this objective, it is necessary to know the type of steel in order to choose appropriate carburization parameters [12].

The steel grade, the soaking time and the temperature of the carburization were chosen as three technological parameters in this study. During this treatment, carbon atoms from the powder pack diffuse toward the steel surface and further on to the subsurface zone where they combine with the iron atoms to form the iron carbides. Effect of carburizing time and temperature on the transformation rate of low alloy steel to a cemented steel layer was investigated by means of different experimental techniques. The growth kinetics of carburized layer by diffusion-precipitation as a function of the soaking temperature, duration of the carburization and the steel grade are presented in the work.
2. Experimental details

Two low alloy steels (AFNOR 18CN4 and 22MC4) were used for carburization. The chemical compositions of the investigated steel grades are given in Table 1.

| Grade   | C  | Ni | Cr  | Mn  | Si  | Cu  | Mo |
|---------|----|----|-----|-----|-----|-----|----|
| 18CN4   | 0.18| 0.4| 1.02| 0.09| 0.028| 0.03| 0.05|
| 22MC4   | 0.22| 0.08| 0.32| 0.89| 0.05 | 0.02| 0.02|

Cylindrical samples 20 mm in diameter and 10 mm long were cut out of the steels. In order to reduce their roughness to Ra = 0.25 µm, the samples were mechanically polished with use of sandpaper. Both steel substrates were received a pack cementation treatment. A cement coke powder (as a source of carbon atoms) mixed with barium carbonate (as an activator) was used as carburizing medium. The specimens were carburized at different temperature (1143, 1173 and 1203°K) and different soaking time (2, 4 and 6 hours).

To provide optimal mechanical properties, all samples after carburization underwent a quenching in oil and tempering at temperature of 443°K for a length of time of 2 hours. After carburizing, transverse cross-sections were made of the samples and the section surface was polished. The samples were then etched in a solution containing 3% of nitric acid in ethyl alcohol. Olympus microscope type B O71 was used to investigate the microstructure and the thickness of the carburized zone of the samples. Three measure experiments were performed in order to obtain a representative thickness value. The phase composition of the cemented layer was investigated by X-ray diffraction using Phillips diffractometer. Cu Kα characteristic radiation with a wavelength of 0.154 nm was used over a 2θ range of 25°–95°. The hardness profile was measured the cross-sections along the direction normal to the surface of the cemented layer by a Leco microhardness tester equipped with a Vickers indenter. The hardness was obtained on specular surface of the samples by applying 0.25 N of indentation load.

3. Results and discussion

3.1. Structure

X-ray diffraction spectra of 22MC4 steel carburized at temperature of 1203°K for time of 2, 4 and 6 hours are shown in Fig. 1. X-ray diffraction pattern corresponding to sample treated for 2 hours shows that only small volume fraction of iron carbides, Fe₃C and Fe₇C₂ were formed in the cemented layer.
Two broad peaks from the tempered martensite phase of a low diffraction intensity appear in the diffraction spectra. The volume fraction of the iron carbides in the cemented layer increases progressively with carburizing temperature and the length of the soaking time. When the carburizing time increases, the volume fraction of the iron carbides increases as well. It follows from the X-ray diffraction spectra that a small amount of a new phase Fe₅C₂ appeared for carburizing time of 4 hours which however increased considerably for length of carburization time of 6 h. Contrary to this behaviour, it looks like that the volume fraction of the tempered martensite phase seems to decrease for the length of 6 hours of carburization.

3.2. Morphology

Micrographs of polished and etched sections of 18NC4 and 22MC4 steel carburized for the length of time of 4 hours at temperature of 1203 °K are shown in Figure 2. Three distinct zones were identified in the cross sections of two steel grades. An outer zone consists of a martensite rich in carbon and of different iron carbides, an intermediate region consists a diffusion zone of a lower content of carbon atoms and an inner region characteristic for the investigated steel grades not influenced by diffusion of carbon atoms from the carburizing medium. As indicated in table 2, the thickness of carburizing layers of steels increases with increasing of temperature and time of treatment.
Table 2. Thickness of the cemented layers on 18CN4 steel and 22MC4 one for different temperature and the length of the carburizing time.

| T (°K) | 18CN4 | 22MC4 |
|--------|-------|-------|
|       | Time (h) |       |       |
|       | 2 | 4 | 6 | 2 | 4 | 6 |
| 1143  | 30 | 37 | 42 | 35 | 50 | 55 |
| 1173  | 35 | 45 | 50 | 40 | 55 | 70 |
| 1203  | 40 | 55 | 65 | 45 | 65 | 80 |

3.3. Kinetic growth

In the classical kinetic theory, the square of the cemented layer thickness as a function of the length of the carburizing time is described by [13-15].

\[ d^2 = Kt \]  

where \( d \) is the thickness of the cemented layer, \( K \) is the kinetic growth rate constant and \( t \) the length of the carburizing time.

Figure 3 presents a relationship between the square of the thickness of the cemented layers produced on 16CN6 and 22MC4 steels and the length of the carburizing time for different temperatures. One can notice that the square of the cemented layer thickness for the both steel grades increases linearly with increasing length of carburizing time.
From the slopes of the plots indicated in Fig. 3, the growth rate constants $K_T$ of the cemented layers on steels were calculated for each temperature. The values of the $K_T$ constant are given in Table 3.

Table 3. Values of the kinetic growth rate constants $K_T$ of the cemented layer on the surface of the investigated steels at different temperatures of the carburization

| Temperature (°K) | 1143  | 1173  | 1203  |
|-----------------|-------|-------|-------|
| $K_T \times 10^7$ (cm$^2$/s) |       |       |       |
| 18CN4           | 1.80  | 0.97  | 0.62  |
| 22MC4           | 2.84  | 2.01  | 1.25  |
The growth rate constant is related to the inverse of the treatment temperature according to the Arrhenius equation for thermally activated processes [13-15].

\[
\ln K = \ln K_0 - \frac{Q}{RT}
\]

(2)

where \( K_0 \) is a pre-exponential constant, \( Q \) is the activation energy (J/mol.), \( T \) is the absolute temperature (in °K) and \( R \) is the gas constant (J/mol.K).

Figure 4 shows the variation of the growth rate constant \( K_T \) of carburizing layers of steels as a function of the inverse temperature \( T^{-1} \). Activation energies are calculated from the slopes of the plots and their values are 155.11 and 199.54 kJ/mol. for 22MC4 and 18CN4 steels respectively.

One should notice that the 22MC4 steel has an ability to be carburized in a shorter time than that for the other steel. This effect is plausibly due to an increased content of manganese in the 22MC4 steel. Addition of this element promotes in general the hardness of the steel, however it reduces toughness of the steel [16].

![Fig. 4](image)

**Fig. 4** Growth rate constant \( K_T \) of the thickness of cemented layer versus inverse temperature of carburizing steels 18CN4 and 22MC4

### 3.4. Hardness

Figure 5 shows the hardness profiles obtained for 18CN4 and 22 MC4 steels carburized for the time of 6 hours at temperature of 1203 °K. It is shown that the hardness profile curves have a similar shape with three distinct regions. The first region, corresponding, to the outer layer, is characteristic of the highest hardness. This feature can be explained by an important diffusion rate of carbon atoms to the austenite during soaking period. As a result, the martensite originated from the saturated austenite phase has the highest hardness. The second region which is called the diffusion zone, shows the descending hardness values which can be explained by a decreasing diffusion flow of carbon atoms with an increasing depth from the steel surface. As a result the phase composition in this region is changing from martensitic to semi-martensitic and next to ferrito-perlitic one. For the third region, the hardness has almost stationary value which corresponds to the intact core of the steel. The hardness values for the 22MC4 steel are slightly higher than for the 18CN4 one due to greater carbon and manganese content in the steel.
Fig. 5  Hardness profiles for the both steels carburized for the length of time 4 h at 1203 °K

4. Conclusions
Powder pack carburizing treatment performed for two low alloy steel grades confirm possibility to optimize useful properties of the steels with use two experimental parameters as carburization temperature and the length of time of the soaking process.

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