DISPLACEMENT OF CARBON AND ALLOYING AND ADMIXTURE ELEMENTS IN DECARBURIZED LAYER OF NC11LV (160 H12MF) STEEL ANNEALED AT 1150 °C IN ATMOSPHERE OF AIR

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Abstract

In the course of the investigation it was found that annealing of NC11LV (160 H12MF) steel at 1150 °C in the atmosphere of air during 10, 20, 30, and 60 minutes leads to decarburization on the depth of about: 0.6, 0.8, 1.0, and 1.2 mm, respectively, with the most intensive decarburization appearing during first 10 minutes of annealing.

Chromium content in zone of 0.1 mm in-depth from the surface is slightly higher than its content in annealed steel, then after increasing time of annealing the chromium content in decarbonized layer decreases, that is during 10, 20, 30, and 60 minutes on the depth of about 0.45, 0.60, 0.65, and 1.2 mm, respectively. In zones lying deeper the chromium content rises to the initial value (in annealed steel). The contents of molybdenum and vanadium in decarbonized layer is slightly lower from their average contents in annealed steel. On the other hand, the contents of admixture elements, such as W, Mn, Si, Cu, Ni, Al, Ti, and P in the subsurface layer is insignificantly higher.

Keywords: NC11LV (160 H12MF) steel, decarburization, decarburized layer, carbon displacement, alloying and admixture elements

1. INTRODUCTION

Under industrial conditions, annealing of parts of machines and tools made of carbon and alloyed steels in the atmosphere of air leads to decarburization and forming of oxide layer on the metal surface. As the consequence of decarburization, other structure of parts is obtained on surface than in the bulk after cooling to the environment temperature. Oxidation causes macro- and micro-changes of the part, with unevennesses and pits formed on its surface. It is known that under industrial conditions, annealing in salt and vacuum stoves with protecting atmospheres is carried out in avoidance of decarburization and oxidation of machine parts and tools. Knowledge of the problems covering decarburization and oxidation of particular grades of steels may have considerable meaning for small industrial shops which have no possibility to finance purchase of expensive vacuum stoves and/or those with protective atmosphere.

The investigations of decarburization and oxidation of steels containing of about 2% C and 12% Cr were carried out, among others, by Hajduga and Fidler [1], and Hajduga [2]. In [1], the results of decarburization process of NC10 (165H12) steel after annealing at 1223-1423 K and times of 1-3 hrs, are given. The curves of carbon displacement (calculated) and coefficients of carbon diffusion and reaction of environment dependent on temperature were determined. In [3], experimental curves of carbon displacement in NC11LV steel samples annealed at 900, 1000, and 1100 °C in the atmosphere of air during 10, 20, 30, and 60 minutes, are given. It was stated, that the steel decarburization process occurs the most intensively during first 10 minutes, and after 60 min the thickness of decarburized layer equaled: 0.2 mm at 900 °C, 0.55 mm at 1000 °C, 1.05 mm at 1100 °C.

According to Morawec and Werber [4], the state of concentration of the reaction products has a decisive influence on the metal oxidation, e.g. the iron oxidation course at 100
and 200 °C occurs in agreement with logarithmic law, whereas at 900, and 1100 °C, according to parabolic law. The process of external oxidation and changes in the metallic phase caused by selective oxidation have been presented in Weber’s work [5]. It was found in [5] that during oxidation of Fe-Cr alloys the chromium concentration decreased in the subsurface layer on the border with scale. According to Wood and Melford [6] in Fe-Cr alloy containing 14.4% Cr after 10-30 min of oxidation at 1000 °C in the atmosphere of water vapour, the thickness of layer with the chromium gradient equals 5 μm with minimum chromium concentration in this layer being 11.5%. The phenomenon of decreasing chromium content at the subsurface zone of alloy containing 5.82% Cr oxidized in the air at 980 °C was confirmed also by Ipatiev and Orlova [7].

The aim of the investigation, with the results given in this work, was to establish changes in contents of carbon and alloy and admixture elements in the decarburized layer of NC11LV steel annealed at 1150 °C in the atmosphere of air during 10, 20, 30, and 60 minutes.

2. MATERIAL AND STUDY METHOD
The studies have been carried out for NC11LV steel of the composition given in Table 1.

Table 1. Chemical composition of the investigated NC11LV steel, in wt%

<table>
<thead>
<tr>
<th>Element</th>
<th>C = 1.500</th>
<th>V = 0.625</th>
<th>Si = 0.325</th>
<th>S ≤ 0.03</th>
<th>Cr = 11.690</th>
<th>W = 0.016</th>
<th>Ni = 0.0238</th>
<th>Cu = 0.080</th>
<th>Mo = 0.833</th>
<th>Mn = 0.399</th>
<th>P = 0.016</th>
<th>Co = 0.031</th>
<th>results of 6 analyses</th>
</tr>
</thead>
</table>

In the Table 1, percentage contribution of elements determined on the basis of 6 analyses of samples derived from different rods and sites, is presented. The chemical composition of steel was determined by means of emission optic spectroscope SPECTROLAB of type LAB 05S/N45/263. Samples for the studies were taken of rods of diameter of about 14 mm, forged and soft annealed, coming from the same melt/heat. Heat treatment, relying on annealing samples at 1150 °C in the atmosphere of air during 10, 20, 30, and 60 minutes, was performed in an electric chamber oven. The accuracy of temperature control was ±5 °C. After annealing the samples were cooled down in hardening oil.

The following studies have been performed on annealed and hardened samples:

**Chemical composition investigation.** Percentage contribution of carbon and other elements against the distance from surface was determined by means of spectrometer SPECTROLAB. The method relied on removal of consecutive of about 0.05 mm-thick layers by grinding and performing analyses on such obtained surfaces by means of the mentioned spectrometer.

3. RESULTS OF THE STUDY
Average percentage share of elements in each zone of decarburized layer was determined based on 4 analyses. The depth of penetration performed during the analyses is given in Figure 1.

It results from Figure 1 and Figure 2 that decarburization process occurs the most intensively during first 10 minutes. After annealing during that period, the carbon content in the subsurface zone (in the distance of 0.1 mm) equals 0.97% and after 60 minutes this diminishes down to 0.30%.
The percentage of Cr in the analyzed zone insignificantly rises with time up to 11.84% after 60 minutes of annealing, whereas the contents of Mo and V are slightly lesser than in annealed steel and in practice do not change with time up to 60 minutes.

It is known that during annealing of steel in such a high temperature, apart from intensive decarburization, the process of steel oxidation occurs leading to arising of the oxide layer. The investigation results concerning this problem will be presented elsewhere.

The studies of changes in contents of Cr, Mo, and V in the decarburized layer in function of time and distance from the surface (Figure 3) have revealed that Cr content decreases...
successively with the increase of distance above 0.1 mm. This effect occurs the most distinctly after 60-minute annealing. After that annealing the chromium content in the distance of 1.2 mm from the surface equals 11.30% that means it is lesser of 0.39% than the content in an annealed steel, whereas the contents of Mo and V in the decarburized layer are slightly lesser than those in annealed steel and their distribution in function of distance is heterogeneous.

During annealing of NC11LV steel at 1150 °C in the atmosphere of air the admixture elements in the surface direction occur. The percentage share of admixture elements in decarburized layer for the annealing time of 60 minutes in function of the distance from surface is given in Table 2 and Table 3.

Table 2. Selected results of determination of contents of W, Mn, Si, and Cu in decarburized layer of NC11LV steel annealed at 1150 °C in air atmosphere during 60 minutes

<table>
<thead>
<tr>
<th>Annealing time, min</th>
<th>Element</th>
<th>Contents in annealed steel, %</th>
<th>Distance from the surface, mm</th>
<th>Contents of elements, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>W</td>
<td>0.016</td>
<td>0.1 0.5 1.0 1.4</td>
<td>0.022 0.020 0.020 0.021</td>
</tr>
<tr>
<td></td>
<td>Mn</td>
<td>0.399</td>
<td></td>
<td>0.420 0.407 0.397 0.396</td>
</tr>
<tr>
<td></td>
<td>Si</td>
<td>0.325</td>
<td></td>
<td>0.336 0.335 0.340 0.338</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>0.08</td>
<td></td>
<td>0.095 0.08 0.088 0.088</td>
</tr>
</tbody>
</table>

Table 3. Results of determination of contents of Ni, Al, Co, Ti, and P in annealed NC11LV steel and in the subsurface zone (on depth of 0.1 mm) after sensitization of the steel at 1150 °C in air atmosphere during 60 minutes

<table>
<thead>
<tr>
<th>State of steel</th>
<th>Contents of admixture elements, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ni</td>
</tr>
<tr>
<td>Annealed</td>
<td>0.238</td>
</tr>
<tr>
<td>Zone of 0.1 mm</td>
<td>0.254</td>
</tr>
</tbody>
</table>
It results from data in Tables 2 and 3 that contents of W, Mn, Cu, Ni, Al, Co, and P in the subsurface zones of decarburized layer is slightly higher than their contents in annealed steel.

4. CONCLUSIONS

The following conclusions may be drawn based on the results of investigation carried out:

1. Annealing of NC11LV (16OH12MF) steel at 1150 °C in the atmosphere of air during 10, 20, 30, and 60 minutes results in decarburization on the depth of about: 0.6, 0.8, 1.0, and 1.2 mm, respectively. The decarburization proceeding is the most intensive during first 10 minutes of annealing.

2. The effect of time of annealing on the contents of elements in decarburized layer:
   (a) after annealing during 10 to 60 minutes the chromium content in the zone of 0.1 mm from the surface is slightly higher than the average content of this element in annealed steel; afterwards with annealing time increase the chromium content in decarburized layer decreases, that is after 10, 20, 30, and 60 minutes on the depths of about 0.45, 0.60, 0.65, and 1.2 mm, respectively. In deeper lying zones the chromium concentration rises to the initial content (in annealed steel),
   (b) concentrations of molybdenum and vanadium in decarburized layer is only slightly lesser than in annealed steel, whereas the distribution of these elements is clearly heterogeneous (see Fig. 3),
   (c) contents of admixture elements such as W, Mn, Si, Cu, Ni, Al, Co, Ti, and P in the subsurface zone is slightly higher than their average contents in the annealed zone (see Tables 2, 3).

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