INFLUENCE OF AUSTENITIZING PARAMETERS IN ATMOSPHERIC AIR ON CHEMICAL COMPOSITION OF DECARBURIZED ZONE OF NC11LV STEEL

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Abstract
The paper aims at investigation of decarburization process carried out on NC11LV steel annealed in atmospheric air at 900 °C, 1000 °C, and 1100 °C during 10 to 60 minutes. Basic studies covered determination of changes of percentage carbon content as the function of distance from the steel sample surface performed by means of an emission optical spectroscope. The curves of changes of carbon content as the function of distance from the sample surface for samples annealed at higher mentioned temperatures in times of 10, 20, 30, and 60 minutes were determined. In the course of studies it could be noticed that during annealing at 900 °C, and 1000 °C the carbon content in the close-to-surface zone has decreased the most intensively in time until 30 minutes whereas at 1100 °C in time until 10 minutes. After 10-minute annealing of NC11LV steel at 1100 °C the carbon content in the zone directly exposed to decarburization, that is in the depth of 0.05 mm equals 0.269%. During revealing the structure of zone directly exposed to decarburization the sites of increased resistance to the action of etching reagent were noticed. In the course of investigation we could reveal that the thicknesses of decarburized layer after annealing of NC11LV steel in atmospheric air throughout the period of 60 minutes at 900 °C was about 0.2 mm, and at 1000 °C, and 1100 °C they were 0.55 mm and 1.05 mm, respectively. In turn the thicknesses of decarburized layer after annealing at 1000 °C throughout the period of 10 to 20 minutes were from 0.25 to 0.35 mm, respectively.

1. INTRODUCTION
It is well known that annealing of steel in the range/scope of austenite under atmospheric air results in formation of the oxide layer on its surface and change in chemical composition of the adjacent steel close-to-surface layer. During high-temperature annealing of carbon steels the ferrous oxide layer is formed with FeO oxide as the main component of the scale [1, 2, 3]. In the chromium steels at the initial period of oxidation Cr₂O₃ oxide is formed with a small amount of iron ions. In case of lower contents of chromium in steel a spinel type of oxide Fe₃⁻ₓCrₓO₄ is formed [3]. Sedricks [4] in turn states that lower-chromium stainless steel, e.g. type 304, may form the same spinel oxide with x approximating the value of 2 to form FeCr₂O₄ which, under certain conditions, may also be relatively protective. Oxide layer formation in tool steels leads in turn to decreasing the chromium content in the steel surface layer [5]. It was stated that with the increase of annealing time due to occurrence the diffusion processes in the oxide layer the pores are formed inside the layer with CO+CO₂ gaseous mixture effecting in decarburization of steel [1, 5]. Formation of cracks in scale gives rise for change in atmosphere acting on steel.
Extensive research of decarburization of type 12% Cr high-carbon tool steel annealed in atmospheric air were carried out by M. Hajduga and J. Fidler [1]. The subject of their studies was NC10 tool steel. The same authors [1], apart from experimental establishment of decarburization process of the steel during annealing at 1223 K, 1323 K, and 1423 K and times of 1 h to 3 h, also determined course of the calculated curves for carbon arrangement and other parameters concerning decarburization kinetics of higher mentioned steel.
The authors of this work are to present a part of the studies carried out concerning decarburization process of NC11LV steel annealed in atmospheric air. Basic aim of the work is to present carbon distribution in the decarburized layer of the steel after annealing at 900 °C, 1000 °C, and 1100 °C during the time span of 10 to 60 minutes.

2. MATERIAL AND STUDY METHOD
Chemical composition of steel being subject of the studies was determined by means of the SPECTROLAB emission optical spectrometer of LAB 05S/N 45/263 type, and presented in Table 1.

<table>
<thead>
<tr>
<th>Name</th>
<th>Feature</th>
<th>C</th>
<th>Cr</th>
<th>W</th>
<th>Mo</th>
<th>V</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC11LV</td>
<td>AISI D2</td>
<td>1.53</td>
<td>11.65</td>
<td>0.01</td>
<td>0.81</td>
<td>0.68</td>
<td>0.38</td>
<td>0.25</td>
<td>0.006</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Heat treatment of the specimens to study the processes of decarburization and oxidation was performed in the KO14 electric silicate furnace. The accuracy of temperature control was ±5 °C. Specimens after annealing at 900 °C, 1000 °C and 1100 °C during the periods of 10, 20, 30, and 60 minutes were cooled down in the quenching oil. Percentage content of carbon and alloying elements as the function of distance from the surface directly exposed to decarburization and oxidation was determined using method of removal by grinding of consecutive layers of about 0.05 mm thick each and then performing chemical analysis in four sites of such prepared specimen surfaces by means of the SPECTROLAB spectrocope. Scheme of the sample with sites of analysis carried out for chemical composition on each steel layer is presented in Fig. 1, covering cross-section A-A with the scheme of arc penetration.

Fig. 1. Scheme the sample for chemical analyses carried out in surface layer with four sites of arc penetration

Metallographic microscopic studies of structure of the zone directly exposed to decarburization and oxidation situated in depth down to about 0.05 mm, were carried out for specimens annealed at 1000 °C during the periods of 10 and 20 minutes. Metallographic
Microsections of the samples were performed mechanically using abrasive papers of the grit size from 100 to 2500 and then by polishing of the surfaces with Al₂O₃ water suspension. Such prepared microsections were etched by reagent of the following composition: 1 g picric acid, 5 ml HCl, 100 ml C₂H₅OH. Metallographic photographs of structure of the close-to-surface steel layer were made by means of the Epityp 2 microscope.

3. EXPERIMENTAL STUDY RESULTS

It results from the chemical composition analysis that NC11LV steel (Table 1) which is the subject of research contains 1.53% C and 11.65% Cr, and beside chromium other alloying elements like molybdenum and vanadium occur with the amount of 0.81% and 0.68%, respectively. The studies carried out on NC11LV steel were concerned with the effect of annealing temperature and time on the change course of carbon content as the function of distance from the sample surface. It was found that carbon content decreases with the increase of the annealing temperature and time. In the zone directly subject to decarburization and oxidation, that is in depth down to about 0.05 mm during annealing at 900 °C and 1000 °C, the carbon content has decreased the most intensively during the periods of 30 and 20 minutes, respectively.

<table>
<thead>
<tr>
<th>Annealing time, min</th>
<th>Annealing temperature, °C</th>
<th>Carbon content, wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>900</td>
<td>1000</td>
</tr>
<tr>
<td>10</td>
<td>1.47</td>
<td>1.12</td>
</tr>
<tr>
<td>20</td>
<td>1.37</td>
<td>0.895</td>
</tr>
<tr>
<td>30</td>
<td>1.29</td>
<td>0.853</td>
</tr>
<tr>
<td>60</td>
<td>1.25</td>
<td>0.635</td>
</tr>
</tbody>
</table>

Table 2. Results of determination of carbon content in zone directly exposed to decarburization of NC11LV steel after annealing in atmospheric air

![Graph](image-url)

Fig. 2. Effect of annealing temperature and time in atmospheric air on carbon content in zone directly exposed to decarburization and oxidation, about 0.05 mm in-depth of NC11LV steel sample surface
A very intensive decarburization occurs while annealing at 1100 °C during which just after 10 minutes the carbon content in the studied zone decreases down to 0.27% whereas a characteristic feature is that prolongation of annealing time at that temperature until 60 minutes provides for further but only a slight decrease in carbon content. The examples of the near-to-surface zone structure of significantly decarburized NC11LV steel quenched after annealing at 1000 °C is presented in Fig. 3.

Fig. 3. Structure of NC11LV steel quenched after annealing at 1000 °C in atmospheric air, transverse cross-sections, middle area of sampling: (a) zone in depth of about 0.03 mm after annealing during 10 minutes, (b) zone in depth of about 0.04 mm after annealing during 20 minutes

It was found that during revealing structure of samples surface directly exposed to oxidation and decarburization, it was much more difficult to carry out etching in the middle area of sample surface to reveal structure than in the areas lying on the edge. One may predict then that in the middle zone of sample accelerated decarburization and oxidation occur. The possibility of accelerated and more distinct oxidation in different areas of sample surface and different time was indicated also by D. Caplan and M. Cohen [after 5] in their studies on oxidation phenomenon for Cr24 steel.

One cannot exclude that higher mentioned phenomenon is the effect of arisen during the samples annealing the gradient of carbon content between their surface and middle zones what in turn affects the structure of these zones, the value and stress distribution in the sample transverse cross-section.

Decarburization during annealing steel in atmospheric air is affected by temperature, time and sort of steel. Temperature affects the most intensively resulting in atoms mobility and acceleration of their diffusion. At constant temperature the time influences the course of diffusion resulting in increasing the thickness of decarburized layer. In Figures 5, 6, and 7 the
carbon contents in decarburized layer of NC11LV steel is given for different distances from the sample surface dependent on annealing temperature and time.

It results from the diagrams 5, 6, 7 that increasing of temperature leads to greater thickness of decarburized layer, and thus, e.g. at the longest time assumed for the studies, equalling 60 minutes, the decarburized layer thickness after annealing at 900 °C is 0.2 mm whereas at 1100 °C...
°C it reaches value of 1.05 mm. Very similar is the effect of annealing time with the result that the longer time the thicker decarburized layer is obtained. Taking into account the practice the most important meaning is assigned to the annealing of NC11LV steel at 1000 °C during about 15 minutes because with these parameters the austenitizing of tools made of this steel during quenching operation is performed. It results from Fig. 6 that after 10-minite annealing of NC11LV steel at 1000 °C the thickness of decarburized layer is 0.25 mm and increases up to 0.35 mm after annealing during the time of 20 minutes.

4. CONCLUSIONS

Based on the studies carried out the following conclusions may be formulated:

1. During annealing of NC11LV steel in the atmospheric air at 900 °C, 1000 °C, and 1100 °C the carbon content in the close-to-surface zone, that is in depth of 0.05 mm has decreased the most intensively for annealing times until 30, 20, and 10 minutes, respectively.

2. Thicknesses of decarburized layer after annealing steel during the period of 60 minutes at temperatures of 900 °C, 1000 °C, and 1100 °C equal 0.2 mm, 0.55 mm, and 1.05 mm, respectively; the increase in carbon content during annealing at 1000 °C, and 1100 °C as the function of distance to sample surface with regard to the carbon content occurring under decarburized layer takes approximately the shape of parabola.

3. Thicknesses of decarburized layer after annealing steel at 1000 °C during 10 to 20 minutes equal 0.25 mm and 0.35 mm, respectively.

Acknowledgement

The Authors of the paper would wish to express words of acknowledgement to Mr Leszek Lemiesiewicz from Fabryka Maszyn Rolniczych in Slupsk, Przemyslowa 100, for his assistance in performing chemical analysis.

REFERENCES


