INTRODUCTION

Ultralowcarbon IF (interstitial free) steels with microadditives of titanium and niobium introduced in order to bond the interstitial elements (carbon and nitrogen) are widely used nowadays in the automobile industry because of the favorable combination of ductile and strength properties.

In recent time this class of steel is created with specific properties. For example, body panels are forged successfully from steels possessing the effect of hardening upon drying of the paint-and-vanish coating, which are known as steels with a BH (bake hardening) effect. They possess a low yield point and a high ductility in the initial state, which makes it possible to forge composite body parts from them. When the paint-and-vanish coating on the body is dried at 150 - 200°C the steel hardens and its yield point increases by over 40 MPa, providing the requisite service properties.

The recrystallization parameters of cold-rolled steels are important for studying the interrelation between the microstructure and the mechanical properties. Knowing these parameters we can explain the mechanism of formation of the microstructure and properties of the heat treated steel and predict to a certain extent the possibility of formation of the requisite combination of properties in it.

In order to harden the steel in the drying process it should contain a specific content of carbon in ferrite in the original state. From the data of [1, 2] ferrite should bear at least 6 apm (0.0006 wt.%) carbon. At the same time an excess content of carbon, especially in semi-finished rolled stock, causes an undesirable decrease in the characteristics of ductility, the coefficient of normal plastic anisotropy in the first turn [1], and increases the susceptibility of the steel to natural aging [3].

It is also known [4, 5] that the reeling temperature after hot rolling can cause a marked change in the microstructure and the mechanical properties of the steel due to the differences in the degree of bonding of carbon in special carbides.

The aim of the present work consisted in quantitative and qualitative estimation of the effect of the chemical composition and the reeling temperature on the recrystallization parameters of cold-rolled ultralow-carbon steels.

METHODS OF STUDY

We studied steels with about 25 apm (0.0025%) carbon, about 120 apm (0.012%) titanium, and about 100 - 220 apm (0.010 - 0.022%) niobium from five heats with different Nb/C proportions.

The proportion of the atomic fractions of niobium and carbon in the steels was calculated by two methods. The first method allows for the formation of titanium compounds that do not bear carbon (TiN and TiS). In this case carbon is fully or partially bonded in niobium carbides depending on the niobium content; the carbides can dissolve at a quite high temperature upon short-term heating (about 60 - 150 sec) in the heat treatment process in devices for continuous annealing. For this reason, the carbon content in the solid solution (ferrite) and, consequently, the BH-effect increase. In an equilibrium state at an atomic proportion of Nb/C < 1 the solid solution should contain excess carbon, and at Nb/C > 1 the solid solution should contain excess niobium.

However, from the data of many researchers, for example, [3, 6], ultralow-carbon steels alloyed with titanium may form titanium carbosulfide \(\text{Ti}_4\text{C}_2\text{S}_2\). In this case carbon is partially bonded in the titanium carbosulfide that is practically insoluble at the annealing temperature (about 850°C). Therefore, the effective content of carbon (i.e., the carbon capable of entering the solid solution as a result of the dissolution of carbides) decreases.

The proportion of the total niobium content (in atomic fractions) to the total content of carbon Nb/C (in the case of
Fig. 1. Microstructure of cold rolled steel annealed at 720°C for 100 sec (x 400): a) c) rolled at $t_1 = 770^\circ$C; d) e) $t_1 = 650^\circ$C; a, d) Nb/C $\leq 0.5$; b, e) Nb/C $\geq 0.8$; c) Nb/C $\geq 1.3$; f) Nb/C $\geq 0.9$.

TABLE 1. Proportion of the Atomic Fractions of Niobium and Carbon in Steels

<table>
<thead>
<tr>
<th>Steel</th>
<th>Nb/C</th>
<th>Nb/C$_{cf}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>5</td>
<td>1.3</td>
<td>1.8</td>
</tr>
</tbody>
</table>

formation of titanium sulfide TiS) and the proportion of the total content of niobium to the effective content of titanium Nb/C$_{cf}$ (Ti$_4$C$_2$S$_2$) are presented in Table 1 (the data are averaged for two reeling temperatures).

It can be seen that under the condition of formation of titanium carbossulfide the composition of steel 3 corresponds to a stoichiometric one.

The steels were hot rolled in the austenitic temperature range ($t > 910^\circ$C) with subsequent reeling of the sheets at a