PECULIARITIES OF AUSTENITIZATION OF THE LOW-CARBON STEELS DURING HEAT TREATMENT OF PLATES IN-LINE OF THE ROLLING MILLS

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Peculiarities of austenitization process of low-alloyed plate steels in line of rolling mill are studied taking into account preliminary cooling of them ant their initial structure. Oriented formation of austenite on the boundaries of ferrite grains and its growth along certain crystallographic planes is found in steels with ferritic-pearlitic structures. It is the evidence of widmannstatten nature of this polymorphous \( \alpha \rightarrow \gamma \) transformation. At heating of steel with initial ferritic-pearlitic structure, formed in result of preliminary cooling of plates after hot rolling to temperature of intercritical region, process of austenite formation during following heat treatment with phase transformation is not accompanied by expected grain refinement. It this case heat treatment does not provide increasing of complex of mechanical properties of rolled plates in comparison with hot rolled state. The decreasing of them may take place in some cases.

Plate rolled products from low-carbon and low-alloyed steels to provide the necessary complex of mechanical and technological properties is subjected to different types of heat treatment. Austenitization is the obligatory part of such treatments.

Effectiveness of austenitization in many respects depends on initial structure of steel. At heat treatment in line of rolling mill, based on hot loading of plates in continuos rolling furnaces [1], low-carbon low alloyed steels have ferritic-pearlitic structure and at hot loading in intercritical range of temperatures they may have austenitic-ferritic structure.

Process of austenitization of steels with ferritic-pearlitic structures was studied by numerous investigatirs [2-4]. But despite of this fact, many questions, connected with mechanism of \( \alpha \rightarrow \gamma \) transformation in low-alloyed steels in real conditions of their heat treatment remain the subject of discussion yet. It is necessary to fulfill the special investigation of influence of austenitic-pearlitic structure, formed in result of preliminary cooling of plates after hot rolling to temperature of intercritical region, on character of grain size changing in result of following heat treatment with phase transformation

In this work the austenitization of low-alloyed steels of 10HSND and 09G2s1 grades was investigated. These steels are widely used for producing of plate rolled products for general applications. Structure and phase transformation at heating of steels in dual phase \( \alpha \,+\,\gamma \)-region were evaluated by metallographics analysis, based on light and electron microscopy. Samples 20x30 mm, were cut out from hot rolled plates with sickness 14 mm.

They have the ferritic-pearlitic structure and they were heated to temperatures in the range 700-900 °C with step 20 °C. After that they were cooled on air. Duration of heating was 2 minutes for every 1 mm of plate cross-section. It corresponds to existing conditions of austenitization of plate rolled products during heat treatment in industrial conditions. Volume of austenite decomposition products, formed after cooling of steel was calculated by the method of secants. The error of evaluation was less than 3%. Kinetic of austenite formation was studied by magnetothermal method with using of specially designed unit in accordance with techniques, described in [5].

Process of structure recrystallization of previously overheated steels at repeated heating was studied by high-temperature metallography. It permits to make direct observation of changes as in old existing grains as in new-formed austenitic grains. To do this, samples with size 3x12x72 mm were heated in vacuum chamber of IMASH-5S unit (p=2*10^{-5} mm Hg.) to the temperature 1050°C. They were soaked at this temperature 10 minutes and cooled with the
cooling rate 0.5 °C/s to 600 and 750°C. It provides the correspondent formation of ferritic-pearlitic and austenitic-ferritic structure. After that they were subjected to repeated heating to temperature 930°C with exposition time 3-5 minutes.

The microstructure of plate steels after cooling on air from different temperatures of intercritical range is shown on figure 1.

Figure 1 – Microstructure of 10HSND (a, b, d) and 10G2S1 (c) after cooling on air from temperatures:
- a, c – 740°C, x400
- b – 780°C, x400
- d – 780°C + tempering 650°C duration 4 hours., x4200

Formation of austenite intermediate decomposition products with spherical and needle shape on boundaries of ferrite grains is the typical feature of structure of steel after such treatment. Ratio of structure components, their appearance, shape and location depend on temperature of heating. Thus, at cooling from lower part of intercritical range in structure of steel along with ferrite and pearlite the bainite appears. It has the shape of chain of separate grains around the α-phase. X-ray analysis shows the presence of retained austenite in amount to 15% in these areas. With increasing of heating temperature in the range \( A_{	ext{c}1} - A_{	ext{c}3} \), the amount of bainite component increases and reaches the maximum at 780-820°C (figure 2). In this case the bainite areas have the shape of plates (needles) extended from boundaries to body of ferrite grain. They decompose rather easy during the tempering at 650°C with formation of fine-dyspersated carbides (figure 1d). At following increasing of heating temperature with their approaching to \( A_{	ext{c}3} \) point
the amount of bainite component decreases and pearlite and pearlite-bainite complexes appear in steel

![Graph showing the amount of structure components in 10HSND steel after cooling on air from different temperatures in intercritical range: 1 - ferrite, 2 - bainite, 3 - pearlite]

Uncovered peculiarities of structure transformation in low-alloyed steels after their heating in two-phase \( \delta + \gamma \) region may be explained by redistribution of carbon and alloying elements (manganese and silicon in particular) between austenite and ferrite due to simultaneous existence of these phases at given temperatures. Investigations with using of X-ray microanalyzer MAR-1 shows that ferrite of 10HSND steel after heating at 800°C and cooling on air contains 2 times higher concentration of silicon that bainite regions and consequently austenite, formed during heating.

Obtained data about changes in structure of low alloyed plate steels permit to define more exactly our conception about mechanism of austenitization during heat treatment.

Formation of austenite at heating of steel take place not only in pearlite, but widely on ferrite grains boundaries. At first pearlite areas subjected to austenitization. Ends of cementite plates in place where they go out on boundaries of pearlite colonies are the preferable places for austenite nucleation. More rare case is the nucleation on the contact surface between ferrite and cementite. In this case formation of austenite easier occurs along the ferrite lamina in pearlite. Cementite plates play role of barrier for \( \alpha \rightarrow \gamma \) transformation. In separate regions, where continuity of cementite is broken, and austenite is formed in adjacent ferrite laminas. Austenite regions in this case are rather isometric. It is the evidence of approximately equal austenite growth rate along and crosswise pearlite plates. Absence of strict oriented connection between ferrite and pearlite permits to make the conclusion about normal nature of transformation mechanism of crystal lattice during austenitization of pearlite despite of more expected oriented shift character of transformation, taking into account similarity of crystal lattices of austenite and cementite.

The fact of austenite nucleation directly on boundaries of ferrite grains. This tendency becomes clear at short-term expositions. At heating of steel above the \( A_{c1} \) point on 10-20°C the
austenite case forms on ferrite grain boundary at first step. Next, with increasing of temperature austenite is formed as set of parallel plates, located on one side of ferrite grain boundary, more rarely – on both sides of it. As a rule, austenite plates connected by common basis and have the similar orientation inside of ferrite grain. Angle between parallel sets of plates usually equal to 60 or 120° (figure 3).

Figure 3 – Oriented formation of austenite in normalized steel 10HSND at 780°C: a – x1000, b – x4200

At heating above certain threshold temperature that corresponds to 760-780°C for investigated steels, the activation of oriented nucleation of austenite is observed inside of ferritic grain. Shape of austenite regions is pronounced needle-like. They nucleate directly at austenite massifs or on ferrite grain boundaries and are growing along certain crystallographic planes.

Oriented formation of austenite and existence of crystallographic relationship with structure-free ferrite gives the arguments to consider the mechanism of polymorphous transformation on this stage of austenitization as Widmanstätten, characterized by shift nature of lattice transformation.

Considerable interest has the fact that many of nucleated in ferrite austenite grains have not the contacts with pearlite and massifs of austenite, formed earlier. It points out on the fact that grain boundaries and another structure imperfections of the α-phase are rather benefit places for nucleation of austenite form the energetic point of view, but in the course of further development of austenite transformation transfer of carbon is possible not only in direction “cementite-austenite-ferrite” but in direction “cementite-ferrite-austenite” too. Refinement of ferritic-pearlitic structure substantially accelerates α→γ transformation in comparison with coarse-grain state at practically equal dispersity of cementite laminas in pearlite. It confirms the substantial role of surfaces of separation of ferritic phase and pearlitic colonies in formation of austenite (figure 4).

At temperature of heating higher than 820°C α→γ transformation realizes by the growing existing regions of γ-phase and practically full absence of new regions nucleation. Austenite plates become wider and growing inside the body of ferritic grain. Ferritic spaces, separated them, disappear. Well-developed substructure forms in austenitic grains.

Heating of previously overheated steel with ferritic-pearlitic structure causes the considerable refinement of initial austenite grain at phase transformation. In result of heating of steel with initial austenite-ferritic structure, that was formed by preliminary cooling of samples from 1050°C to intercritical range (750°C), the process of austenite formation does not correspond by grain refinement. Obtained grain does not differ in shape and size from initial (figure 5).
Figure 4 – Kinetic curves of austenite formation in 10HSND at 750°C in dependence on ferritic-pearlitic grain size:

1 – grain number 6-8, 2 – grain number 9-10

Figure 5. Change of austenite grain previously overheated (1050°C) 10HSND steel at repeated heating to 930°C after preliminary cooling to 750°C (a) and 600°C (b), x 400

This recovery of former austenitic grain at repeated heating explains by the influence of austenite regions that were not subjected to transformation in result of preliminary cooling in two-phase region on structure mechanism of α→γ- transformation. It is significant that disappearing of excessive ferrite formed at cooling to 750°C in the shape of net on boundaries of former austenitic grains occurs due to migration of austenite region boundaries in direction of absorbed ferrite. It provides complete recovering of initial austenite grain shape.
It is natural to assume that in this case the moving boundary is the effective diffusion way and therefore the mean of acceleration of transformation in new phase state.

Parallel with recovering of austenitic grain at repeated heating of steel with austenitic-ferritic structure, the formation of new grains is observed. They have practically the same size, but not coincide with the former grains in shape. It is important that separate regions with more coarse grains comparing with initial were found. It points out on possibility of some coarsening of former austenite grain at heating of steel with austenitic-ferritic structure. It is necessary to note that growth of separate coarse austenitic grains takes place in account of adjacent finer grains. This process is similar to secondary recrystallization except the fact that only certain austenitic grains are growing in this case.

It is possible to assume that one of reasons of abnormal growing of separate grains is the state of ferritic-austenitic matrix before $\alpha \rightarrow \gamma$-transformation start. Presence of recrystallized $\alpha$-phase regions causes the formation of austenite nucleus with different orientation. They stabilize the initial matrix, increase the difference in grain size and promote to selective growth of these austenitic grains that have the increased size to this moment or reach it due to migration of interphase boundary. Besides that, at formation of new austenitic grains in recrystallized matrix some of them may be separated by partially conjugated boundaries. In result they obtain the possibility of accelerated growth, but there is no any connection of them with former austenitic grain. One of possible reasons of abnormal growth of certain austenitic grains may be the nonuniformity of their chemical composition, intensified by the redistribution of carbon and alloying elements between $\alpha$ and $\gamma$-phases at exposure in intercritical range of temperatures.

Uncovered fact of recovering and coarsening of grain after heating of steel with initial austenitic-ferritic structure permits to conclude that heat treatment of plates with temperature of hot loading in intercritical range does not provide the increasing of complex of mechanical properties (cold-resistance in particular) comparing with hot rolled state and in some cases may cause their decreasing. This conclusion may be conformed by results of industrial testing, shown in table 1.

**Table 1 – Mechanical properties of plates after in-line normalization with hot loading**

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<tr>
<th>Temperature of hot loading °C</th>
<th>$\sigma_b$, N/mm²</th>
<th>$\sigma_t$, N/mm²</th>
<th>$\delta_5$, %</th>
<th>$\Psi$, %</th>
<th>KCU, J/cm² at temperature, °C</th>
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The complex nature of structure transformations that take place during heating of low-carbon, low-alloyed steels with different initial structure must be taken into account for selecting of optimal parameters of heat treatment of plates in-line of rolling mills. The development and realization of new intensive energy- and resource-saving technologies is impossible without this consideration.

REFERENCES