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Formation of Dual-Phase Structure during Cooling on the Exit Conveyer of the 2000 Broad-Strip Rolling Mill at OAO NLMK

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Abstract—The step-by-step development in the production of HDT580X hot-rolled dual-phase steel (according to the EN 10338 standard) by means of the 2000 broad-strip hot-rolling mill at OAO Novolipetskii Metallurgicheskii Kombinat is considered. The analysis is based on theoretical and experimental results regarding topics such as the influence of alloying elements and the cooling parameters on structural and phase transformations in dual-phase steel for the auto industry. Physical modeling of the deformational parameters and the rolling and cooling temperatures and speeds on the broad-strip mill also proves helpful. Rolling and cooling rates are proposed for the 140 FGA semicontinuous hot-rolling mill.

Keywords: hot rolling, auto industry sheet, dual-phase steel, cooling strategy, mechanical properties, structure formation

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Current improvements in the production of high-strength dual-phase steel sheet for the auto industry do not depend on the modification of existing equipment. Appropriate alloying is used to obtain the required steel properties. However, any chemical composition proposed in the literature—especially those developed by foreign corporations—must be corrected for use on Russian broad-strip hot-rolling mills. Therefore, the chemical composition of steel produced at OAO Novolipetskii Metallurgicheskii Kombinat (NLMK) is adopted as the baseline.

Two-stage cooling on the exit roller conveyer of broad-strip mills is assumed in most studies [3–5]; the procedure includes an additional interval in air within the range of ferrite transformation. At OAO NLMK, the design of the exit conveyer at the 2000 broad-strip hot-rolling mill does not permit two-step cooling. Therefore, in the present work, we consider the potential for single-step cooling (Fig. 1) [3].

Two goals are adopted here:

(1) the development of an alloying program for the production of hot-rolled dual-phase steel;

(2) the improvement of cooling on the exit conveyer of the 2000 broad-strip hot-rolling mill.

INFLUENCE OF COOLING PARAMETERS ON THE STRUCTURAL AND PHASE TRANSFORMATIONS

To investigate the role of cooling, we plot experimental thermokinetic diagrams for the baseline chemical composition and three experimental alloying programs. The thermokinetic diagrams for the structural

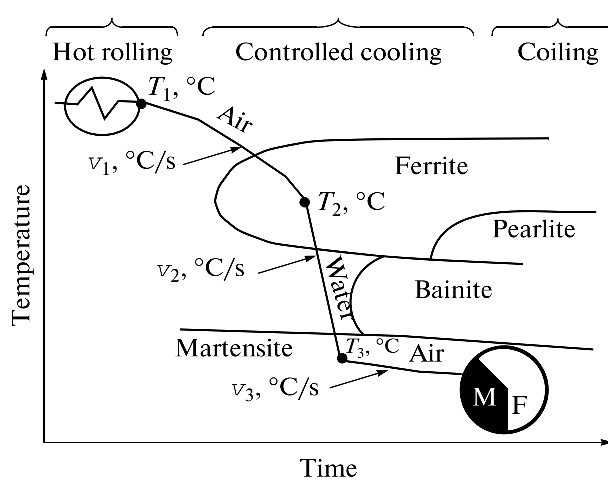

Fig. 1. Production of hot-rolled dual-phase steel in one-stage cooling.

and phase transformations in steel with four different chemical compositions are plotted by analysis of the dilatometric curves, metallographic structural data, and measurements of the microhardness of each of the tested samples.

For the baseline chemical composition, the thermokinetic diagrams reveal excess formation of bainitic structure (45%), even at low cooling rates (5°C/s). Adding Mn, Cr, and Al to the baseline chemical composition in specific quantities eliminates the excess formation of bainite–martensite structure over a broad range of cooling rates. In addition, at cooling rates of 5–30°C/s, the soft ferrite matrix (65–85% of the total) is hardened by bainite–martensite packets at the grain boundaries. The addition of aluminum (increase in its content by a factor of 5–10) plays a key role in the formation of such structure. Aluminum permits considerable increase in the influence of ferritic and martensitic transformation on the formation of the final dual-phase microstructure over a broad range of cooling rates. Such behavior is also observed for the second experimental composition (Fig. 2).

The results are significantly different in the third experimental composition, where the chromium content is increased by a factor of 1.5 and the aluminum content by a factor of five with respect to the baseline. We analyze the parameters of one-stage cooling with the baseline composition on the DIL 805 A-D deformational module. Two versions of single-stage strip cooling on the exit conveyer of the 2000 broad-strip hot-rolling mill at OAO NLMK are considered.

The research shows that the main controllable parameters in cooling are the time τ_b in air before accelerated cooling; and the rate v_{fc} of forced cooling. If τ_b is increased, ferritic transformation is more complete, and subsequent accelerated cooling at the optimal rate should ensure the necessary quantity of martensite in place of bainite. The test conditions on the Gleeble 3800 physical modeling system and the influence of the final rolling temperature t_{fr} and τ_b on the ratio of structural components in the baseline steel may be found in [3]. The results show that varying t_{fr} determines the variation in τ_b and permits additional modification of the quantity of ferrite formed. Laboratory data yield recommendations for attaining the required ratio of ferrite and bainite structures (80 : 20) for the proposed alloying program with single-stage strip cooling on the exit conveyer of the 2000 broad-strip hot-rolling mill.

INDUSTRIAL HOT-ROLLING TRIALS AT THE 2000 BROAD-STRIP HOT-ROLLING MILL

Single-stage strip cooling on the exit conveyer of the 2000 broad-strip hot-rolling mill at OAO NLMK is effective in the production of hot-rolled dual-phase steel with the baseline chemical composition, according to the results of industrial trials [3]. At certain hot-rolling temperatures and speeds, mechanical properties corresponding to strength classes DP450 and DP600 may be obtained. To obtain dual-phase structure with the baseline chemical composition, we need to increase τ_b (so as to form the required content of ferrite); and to reduce the coiling temperature t_{co} or, in other words, to increase the number of operational sections (so as to obtain the required volume of bainite–martensite structure). However, these two requirements conflict: increase in τ_b reduces the number of operational sections and so increases t_{co}.

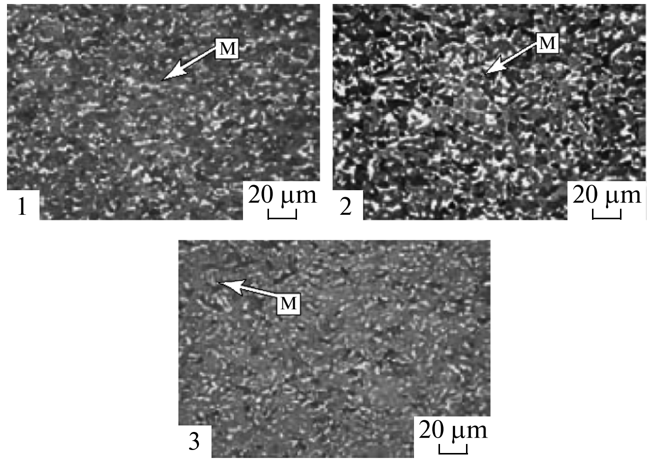

Fig. 2. Results of metallographic analysis (color etching on martensite) for experimental alloying programs 1–3: M, martensite. The cooling rate is 30°C/s.

Analysis of experimental thermokinetic diagrams permits correction of the Mn, Cr, and Al content in the steel, with corresponding increase in the content of ferrite and martensite at the expense of bainite. These structural and phase transformations for the three experimental compositions indicate the need to increase the Al content to at least five times its baseline value, without change in Cr. That permits 30–40°C decrease in t_{fr} relative to the baseline, with corresponding decrease in τ_b (by a factor of 6–7) and increase in t_{co} to the required value, thereby resolving the conflict between the required changes in t_{co} and τ_b.

SIMULATION OF ROLLING AND STEPWISE COOLING ON A SEMICONTINUOUS 140 MILL

On the basis of industrial data for the influence of the alloying elements on the structure of the rolled steel, we propose an experimental chemical composition for a semiindustrial experiment on the 140 FGA mill. In the experimental composition, the aluminum and manganese content is greater than in the baseline. We propose three stepwise-cooling programs on the exit conveyer of the 2000 broad-strip hot-rolling mill at OAO NLMK for simulation of the strip's thermal state [8]. In particular, we select the stepwise-cooling parameters for the 140 FGA mill. On the basis of the calculations, we plot cooling curves, which may be compared with the thermokinetic diagrams of the experimental composition.

Three industrial experiments are conducted. According to structural analysis, the greatest quantity of ferrite (80%) is formed in moderate cooling conditions. Such proportions of the structural components in dual-phase steel correspond to the mechanical properties of HDT580X, according to the prEN 10338 standard. In the two other cases considered, we observe intense cooling to the ferrite region, and coiling in the martensite region is simulated. Thus, the proportion of bainite–martensite structure increases to 39 and 27%, respectively, on average. Accordingly, the strength increases, while the plasticity declines. The results for the 140 FGA mill allow us to determine the parameters of single-step cooling such that optimal structure with 80% ferrite and 20% bainite–martensite component is obtained with the experimental chemical composition. This structure ensures the strength and plasticity required by the standard for steel of strength class DP600.

CONCLUSIONS

Experiments show the possibility of regulating the proportions of ferrite and martensite structure over a broad range in single-step cooling. The basic aspects of structure formation in dual-phase steel during single-step cooling are as follows.

(1) The time in air before accelerated cooling must ensure the formation of the required quantity of ferrite.

(2) The rate of accelerated cooling by water and the coiling temperature ensure the formation of the required quantity of martensite.

(3) Reduction in the final rolling temperature is recommended so as to increase the effectiveness of the interval in air before accelerated cooling; in terms of prolonged residence in the ferrite region.

(4) The limited scope for regulating the main cooling parameters—the interval in air before accelerated cooling, the forced-cooling rate, the coiling temperature—on the exit conveyer of the 2000 broad-strip hot-rolling mill at OAO NLMK may be compensated by adjusting the parameters of the thermokinetic diagrams, with correction of the chemical composition.

The aluminum content must be increased in order to increase the proportion of ferrite and temperature of martensitic transformation.

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