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EXPERIMENTAL STUDIES OF THE FORMATION OF DUAL PHASE STRUCTURE WITH COOLING ON THE RUN-OUT TABLE AT NLMK 2000 CONTINUOUS HOT ROLLING MILL

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ABSTRACT

Using a joint analysis of the results of physical and mathematical modeling and preliminary industrial rolling on the continuous wide-strip rolling mill 2000 an alloying program has been developed for the production of hot-rolled dual-phase steel. Further approbation and an adjustment of the proposed alloying program, as well as development and improvement of technological parameters of single-stage cooling scheme in relation to the conditions of run out table on the continuous wide-strip rolling mill 2000, produced on semi-industrial hot rolling mill 140 TU Bergakademie Freiberg.

Keywords: automobile sheet steel, dual phase structure, alloying program, hot-rolling mill, run-out table, cooling parameters, single stage cooling, CCT-diagram.

INTRODUCTION

Relevance

Modern automobile manufacturing switches to high-strength steel, it reduces the weight of the automobile, the cost of gasoline, the exhaust gases, the burden on the environment and so on, and extends the gamma of grades. Fig. 1 shows the different types of steel which are used in the automobile industry, first of all they differ in structure [1]. The steel with widest current application on volume is located in the middle of the diagram. This is a dual phase steel, which is capable of receiving strength level of 500 to 900 MPa, while the flexibility is not significantly changed, which determines the steel's versatility and wide applicability. The microstructure of the DP-steels consists of two main phases: a soft ferrite, which provides high flexibility, but the low yield of strength, and solid martensite, which gives the necessary high level of safety for this steel. The structure of hot-rolled dual phase steels also can have a bainite component, traces of residual austenite with TRIP effect and traces of ferrite with higher carbon content providing BH-effects [2].

The increased use of dual phase refined quality automobile sheet steels in the global automobile industry is one of the major trends in the development of modern metallurgy [3]. Russian steel-making manufacturers are working at a new production technology of rugged steels that would meet the world standards. This approach is also conditioned by the increased need for domestic auto products as a substitute for imported goods.

There are two basic technological process schemes of the dual phase steels manufacturing. The first involves the cold rolling and the heat treatment on the continuous annealing unit (Fig. 2a) and the second involves getting rolled products into a hot-rolled condition using

* *The work was supervised by Rudolf Kawalla.*

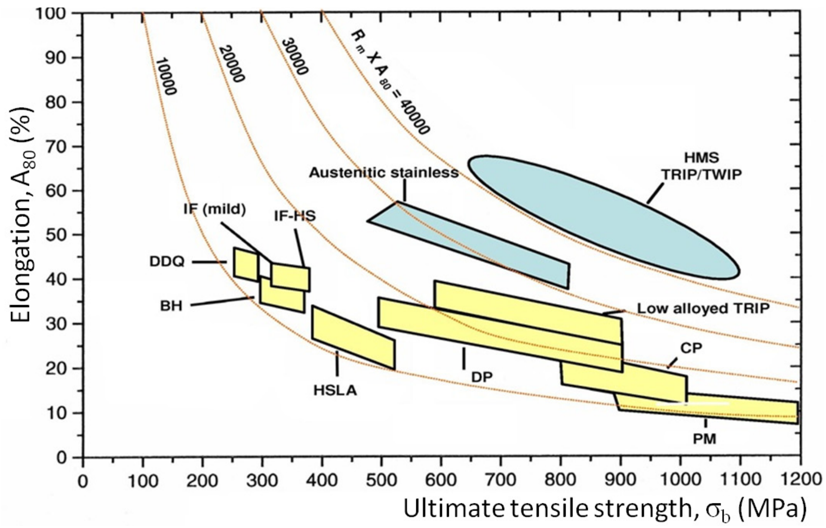

Fig. 1. Modern steels in automobile manufacturing [1].

a stepwise cooling on the run-out table of a continuous wide-strip hot rolling mill (Fig. 2b). However, in terms of expanding the assortment to upwards of 3 mm thickness the second scheme of the technology offers great possibilities for all metallurgical complexes.

The prospective development of the automotive industry requires another major step in the production of automobile sheet steels at metallurgical plants with high production capabilities, such as NLMK (Novolipetsk steel), where it is possible to develop and introduce the production technology of hot-rolled dual phase automobile sheet steels with nearly incompatible characteristics of strength and plasticity, operational reliability and qualitative characteristics.

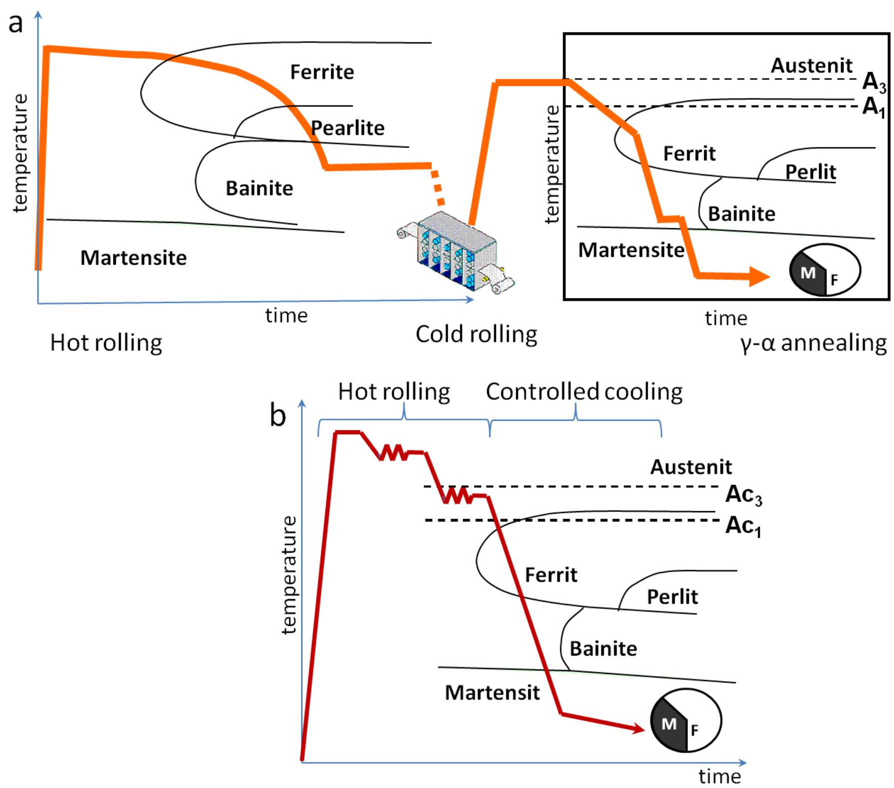

Fig. 2. Schematics of producing cold-(a) and hot-rolling (b) dual-phase steels.

Generally, the increase in steel strength results in a considerable decrease in steel plasticity, which makes it hard or even impossible to use the methods of cold stamping with deep drawing to produce parts required for new automotive materiel. At the same time a high-plastic auto sheet may lack enough strength to solve the constructive problems of modern automotive industry. An effective method of solving the formulated problem is the commercial production development of the HDT580X strip hot-rolled dual-phase steel (meeting the European prEn 10338 standard) at NLMK 2000 hot rolling mill, which can provide a complex of stable characteristics of strength (ultimate strength above 580 MPa), plasticity (tensile strain above 19 %), and other auxiliary properties required for the production of vehicle components and other automotive material.

The development of the hot-rolled dual phase auto sheet steel production will allow to reduce the weight of certain automobile parts made of cold-rolled stamped sheet due to the simultaneous increase in metal strength and plasticity. Reduced automobile weight will provide reduced fuel consumption, i.e. reduced power inputs, and increased economic efficiency of vehicles operation. At the same time, there will be a reduction of environmental pressure and an increase in ecological safety. The manufacture of this product will contribute to a competitive domestic automotive industry.

Recent developments in the production of hot-rolled dual phase auto sheet steels are primarily based on the use of the existing equipment [3 - 6]. In order to obtain the required properties many alloying programs have been currently developed, some of them presented in the work [7]. However, any suggested chemical composition, especially those developed at foreign industrial

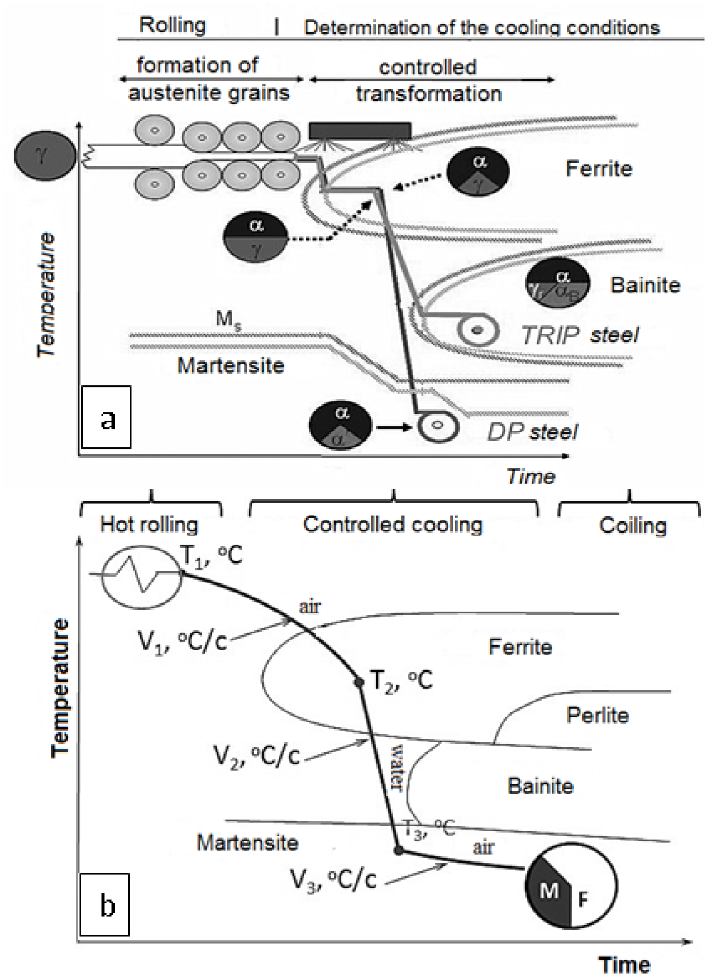

Fig. 3. Cooling strategy on the run-out table of the continuous wide-strip rolling mill: a - two-stage, b - single-stage.

complexes, must be adjusted to specific technological and design features of domestic continuous wide-strip rolling mills. Therefore, the basic chemical composition was chosen from those developed at NLMK.

Research sequence

Most works [1, 5, 8, 9] suggest a two-stage cooling on the run-out table of continuous wide-strip rolling mills, including an additional pause in air supply in the ferrite transformation area (Fig. 1a). The design features of the run-out table of NLMK 2000 continuous wide-strip rolling mill cannot provide the two-stage cooling conditions; therefore we suggest for research a single-stage cooling scheme in the production of hot-rolled dual phase steels (Fig. 3b).

Thus, the present work was carried out in two directions: 1 - the development of an alloying program for the production of the hot-rolled dual phase steel with the basic chemical composition; 2 - the development and improvement of process-dependent cooling parameters on the run-out table of NLMK 2000 continuous wide-strip hot rolling mill. The main used chemical compositions and types of basic research carried out in the work and planned for implementation are shown in Fig. 4.

EXPERIMENTAL

During hot rolling in line NLMK 2000 mill base chemical composition probes were taken by drum-type shears before the task of roll in the finishing train. Cylindrical samples from selected probes were fabricated in sizes 5h10mm (DIL 805A-D) and 15h20mm (Gleeble 3800). Three experimental chemical compositions were smelted in a laboratory furnace for 1 kg each. To conduct the pilot experiment on hot rolling 140 TU Bergakademie Freiberg Germany mill ingot total weight of 25 kg was melted in the semi induction furnace and before rolling was cut into 5 pieces.

Tests were implemented by the deformation dilatometer to construct continuous-cooling transformation diagrams (CCT-diagrams), schematically shown in Fig. 5. Heating of the cylindrical sample size 5h10mm was

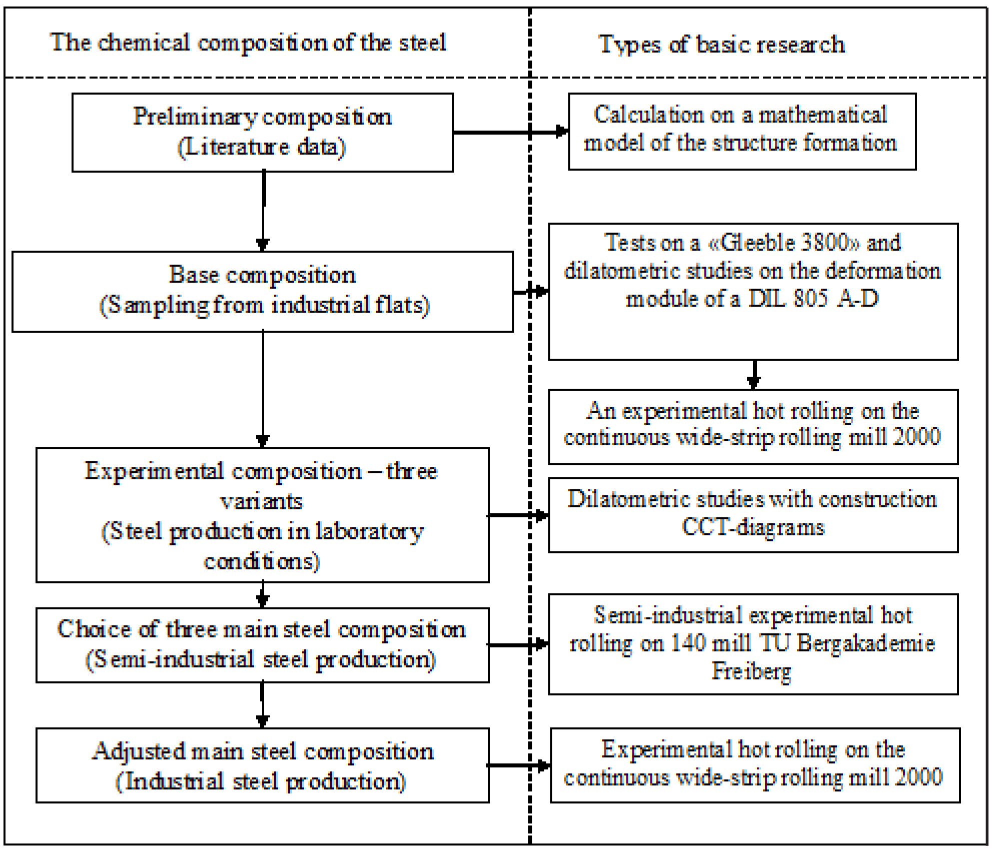

Fig. 4. Used chemical composition and basic research types.

administered at a rate of 5 - 10°C s^{-1} to a temperature of 1150°C, holding it at this temperature for 1 - 5 minutes and then cooling it to a predetermined temperature; it underwent single or multiple deformation with desired compressions and speeds and subsequent continuous cooling with predetermined rates.

RESULTS AND DISCUSSION

Research based on the basic chemical composition

The test conditions of the experiment carried out at the Gleeble 3800 physical modeling complex and the identified regularities of the combined influence of final rolling temperature (t_{fr}) and the air supply pause before the forced cooling (t_p) on the ratio of structural components in the basic chemical composition steel are presented in the work [7]. The research results have shown that variations in t_{fr} actually determine changes in the air pause t_p and allow additional changes in the amount of formed ferrite. The laboratory research results have enabled us to make recommendations on how to achieve the desired ratio of ferrite (80 %) and bainitic-martensitic (20 %) structures for the suggested alloying program using the single-stage cooling strategy on the run-out table of the NLMK 2000 rolling mill.

Dilatometric studies using the DIL 805 A-D deformation dilatometer have shown that the main controlled cooling parameters are the air pause (t_p) before the start of accelerated cooling and the forced cooling rate (v_{fc}). Increase in t_p provides a more complete ferrite transformation, and the subsequent accelerated cooling at a proper rate should provide a required amount of

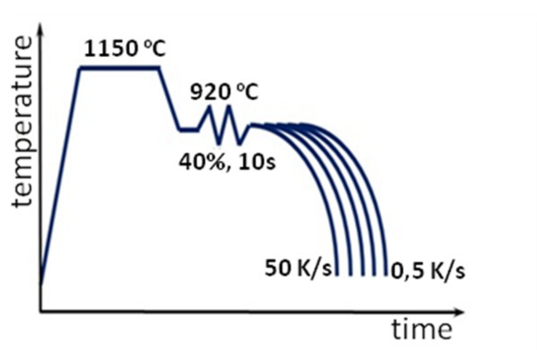

Fig. 5. Mode of thermomechanical processing and subsequent rapid cooling.

martensite instead of bainite.

The results of the pilot industrial experiment which are presented in detail in the work [7] have shown that it is reasonable to apply the single-stage cooling strategy to the production of the basic chemical composition hot-rolled dual-phase steel on the run-out table of the NLMK 2000 continuous hot rolling mill. Under certain temperature-rate conditions of hot rolling it is possible to obtain mechanical properties which comply with DP450 and DP600 strength standards. To obtain a dual phase structure with a basic chemical composition, it is necessary, first, to increase t_p in order to get a required amount of ferrite, secondly, to decrease coiling temperature (t_c), i.e. to increase the number of included sections in order to get a required amount of bainite-martensite structure. The problem is that the first and second recommendations contradict each other; i.e. the increased t_p reduces the number of included sections and therefore increases t_c.

Plotting the CCT-diagram of the researched steel compositions

The study of the influence of step-by-step cooling parameters on phase and structural transformations were conducted with the DIL 805 A-D deformation dilatometer by plotting the experimental CCT-diagram for basic chemical composition and making three pilot alloying programs. The CCT-diagrams of phase and structural transformations of four chemical compositions are plotted on the basis of the dilatometric curves analysis, metallographic structure studies and the measurement results of microhardness of each tested sample. Fig. 6 shows a general view of the basic chemical composition CCT-diagram.

The obtained CCT-diagrams have shown that an additional alloying of Mn, Cr and Al in a certain ratio in the basic chemical composition steel allowed to eliminate the formation of excessive bainite-martensite structure in a wide range of cooling rates. Furthermore, in the velocity range from 5 to 30°C/s with ferritic matrix of 85 – 65 % is hardened with bainite-martensite packages precipitated along the grain boundaries. The crucial part in the formation of such a ratio of structural components was played by the aluminum additive (its

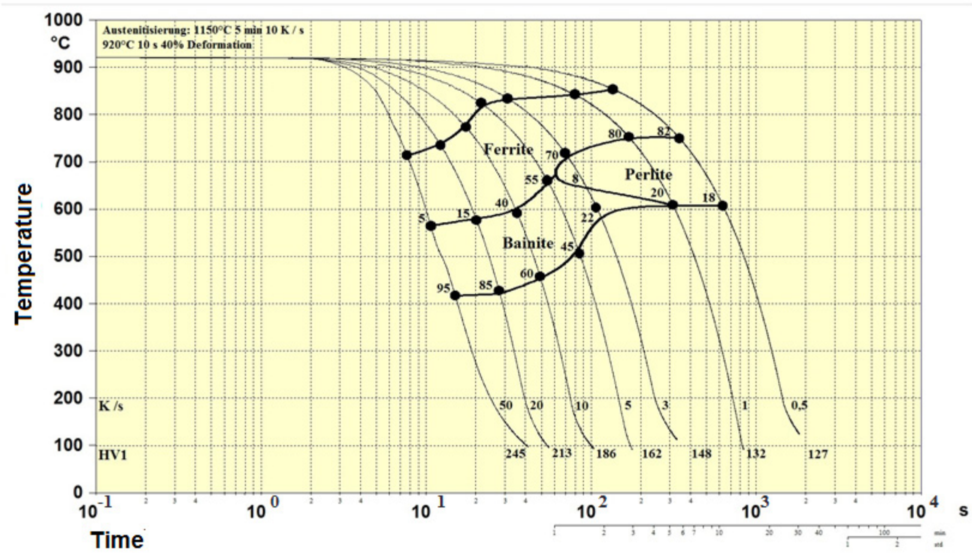

Fig. 6. Basic chemical composition CCT-diagram.

portion 5 - 10 times increased). It was aluminum that allowed a significant increase in the impact of ferritic and martensitic transformations on the formation of final dual phase microstructure in a wide range of cooling rates. This trend became fully apparent for the 2nd pilot composition (Fig. 7).

The analysis results of the experimental CCT-diagrams allowed adjusting the content of Mn, Cr and Al in the basic chemical composition of the steel, thus increasing the volume fraction of ferrite and martensite by reducing the amount of bainite. These features of the phase and structural transformations for the three

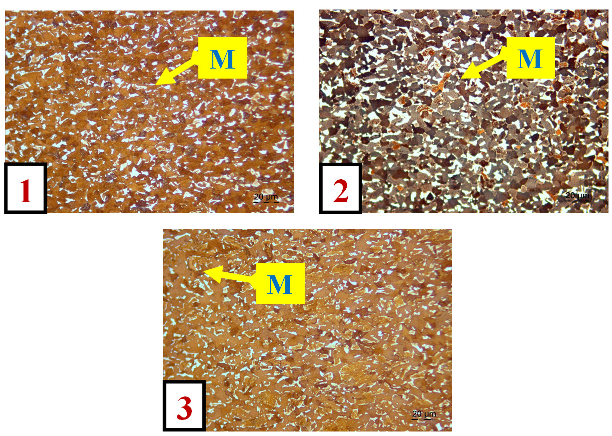

Fig. 7. The metallographic analysis results (martensitic color etching) for three experimental alloying programs (cooling rate 30°C s^{-1}); 1, 2, 3 - numbers of the experimental compositions.

considered experimental compositions give grounds for the need of a minimal five times increase in Al content in the basic chemical composition of the steel with the same Cr content. This addition will definitely lower t_{fr} by 30 - 40°C relative to the reference temperature and respectively reduce t_p to 6 - 7 s and increase t_c to the proper level, thus resolving the contradiction between the accelerated cooling parameters t_c and t_p.

Hot rolling on the 140 TU Bergakademie Freiberg Germany mill

In consideration of the results of the previous studies and the effect of alloying elements on the technological features of structure formation in the industrial rolling mill, an experimental chemical composition for a pilot experiment on the 140 TU Bergakademie Freiberg Germany mill have been suggested. The experimental distinctive feature is an increased aluminum and manganese content as compared with the basic alloying program. A hot rolling program on the 140 TU Bergakademie Freiberg Germany, which takes into account the temperature-rate and energy-power conditions of the NLMK 2000 hot rolling mill, has been made. The distinctive feature of each mode is the difference in forced cooling conditions (v_{fc}) and coiling temperature rate (t_c).

Three pilot experiments have been conducted. According to the structural analysis, the greatest amount of ferrite (80 %) is formed at a moderate cooling rate (minimal $v_{f.c.}$) and high coiling temperature $t_c = 400^oC$. The moderate rate has also given positive results in terms of the compliance of mechanical properties with the standard for steel HDT580X.

The research results on the hot rolling 140 TU Bergakademie Freiberg Germany mill have made it possible to determine the single-stage cooling parameters based on the experimental chemical composition, which allow obtaining the proper structure with 80 % ferrite and 20 % bainite-martensite constituents. This structure provides the strength/plasticity ratio required for DP600 strength steels.

CONCLUSIONS

The experimental studies have shown the possibility of adjusting the ratio of ferritic and martensitic structural components in a wide range during the single-stage cooling.

The basic regularities of the structure formation of dual phase steels during the single-stage cooling include the following features:

- air pause before the accelerated cooling is to provide the formation of a required ferrite amount;
- forced water cooling rate and coiling temperature provide the formation of a proper martensite amount;
- final rolling temperature is recommended to be decreased in order to increase the air pause efficiency for a longer ferrite area period;

The limiting possibility of controlling the basic cooling parameters - air pause, forced cooling rate, coiling temperature on the run-out table of the hot rolling 2000 NLMK mill can be compensated by adjusting the chemical composition and thus changing the CCT parameters.

To increase the ferrite amount and martensite transformation temperature it is necessary to increase the aluminum content.

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