Development of thermomechanical treatment of coil rolled products made of steel C86D micro-alloyed with boron

Parusov E. V.

PhD in Technical Sciences
Institute of ferrous metallurgy NASU
Dnipro, Ukraine

Parusov V. V.

D.Sc. in engineering
Institute of ferrous metallurgy NASU
Dnipro, Ukraine

Sagura L. V.

PhD in Technical Sciences
Institute of ferrous metallurgy NASU
Dnipro, Ukraine

Sivak A. I.

Institute of ferrous metallurgy NASU
Dnipro, Ukraine

Klimenko A. P.

PhD in Technical Sciences
Ukrainian State University of Chemical Technology
Dnipro, Ukraine

Sychkov A. B.

D.Sc. in engineering
Nosov Magnitogorsk State Technical University
Magnitogorsk, Russia

Abstract
Thermokinetic transformation diagram of austenite of steel C86D (EN ISO 16120-2: 2011, analogue of steel 85 according to DSTU 3683-98) was built using the method of differential thermal analysis. The influence of speed when continuous cooling on the peculiarities of structure formation and degree of perlite dispersion was determined. On the results of research the science-based technology of thermomechanical treatment of coil rolled products made of steel C86D in the running of continuous light-section wire mill 320/150 was developed and industrially implemented.
Keywords: AUSTENITE TRANSFORMATIONS KINETICS, STRUCTURE FORMATION, HIGH-CARBON STEEL, MICROALLOYING, BORON, COIL ROLLED PRODUCTS, COOLING MODE

State-of-the-art and objectives of the study

The compliance of rolled products microstructure in a state as received to the requirements of the reference documentation (EN ISO 16120-4: 2011 DSTU 3683-98) is one of the main quality indicators of high-carbon coil rolled products (wire rod), which provides a direct drawing (without the use of both the original and intermediate patenting) to the high-strength wire. Thus, in accordance with the requirements of EN ISO 16120-4: 2011 the limit value of invisible (indiscernible) perlite in rolled products microstructure when increasing by × 500 should be at least 75%, and according to DSTU 3683-98 – the amount of 1 point perlite (indiscernible) when increasing by × 1,000 should be less than 50% [1].

The degree of pearlite dispersion in the rolled products structure depends on temperature and cooling rate at which the decomposition of austenite takes place. We can distinguish the following methods of achieving the required degree of perlite dispersion:

- improving the stability of supercooled austenite due to input of additional alloying (chromium, vanadium) or micro-alloying (boron) of chemical elements;
- an increase of the accelerated air cooling rate of rolled products on Stelmor line;

High-carbon coil rolled products with additional input of alloying elements is generally used in the production of high strength wire for the manufacture of steel prestressing strands of 1770 MPa and 1860 MPa strength grades.

In production of high-strength prestressing strands it is possible to use high-carbon coil rolled products without addition of expensive alloying elements by development of new approaches to the modes of thermomechanical treatment, which include scientifically based parameters of rolling and subsequent air cooling predetermining the obtaining of desired degree of perlite dispersion.

In order to develop a science-based mode of thermomechanical treatment it is necessary to study the kinetics of austenite decomposition of steel C86D micro-alloyed with boron.

Materials and methods of research.

As an object of research the coil rolled products of JSC "MSW" with a diameter of 11.0 mm of steel C86D micro-alloyed with boron were used. The steel had following chemical composition, %: C – 0.88; Mn – 0.68; Si – 0.18; P – 0.01; S – 0.003; Cr – 0.03; Ni – 0.06; Cu – 0.12; Al – 0.003; N_{sv} – 0.004.

The processes of phase transformations were studied by differential thermal analysis (DTA) using a chromel-alumel thermocouple [2].

The continuous cooling transformation diagram (CCTD) of austenite transformations in the steel C86D is shown in Fig. 1.

Critical points A_1 and A_{cm} of studied steel are defined as the average of three dimensions – 727 ºC and 835 ºC respectively.

The austenitizing temperature of the samples was 1000 ºC and it was close to layer coiling of the rolled products under production conditions on Stelmor line (1020…1030 ºC).

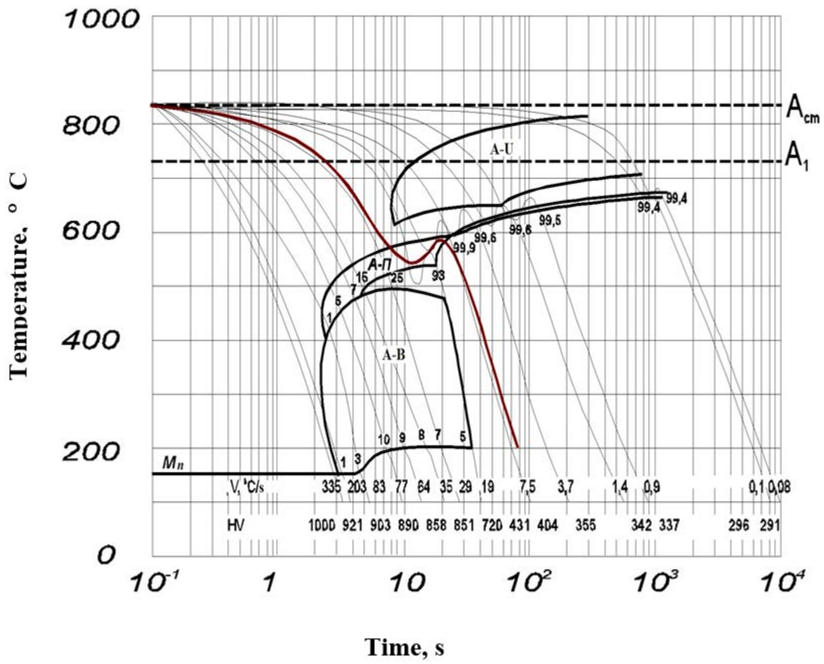

Figure 1. Continuous cooling transformation diagram of steel C86D micro-alloyed with boron with designed cooling mode (red line)

Results and their discussion

When cooling rates are 19 ºC/s and below the supercooled austenite decomposes by the diffusion mechanism on perlite of varying dispersion degrees.

At the minimum studied cooling rate – 0.08 ºC/s transformation begins with the separation of the secondary cementite on austenite grain boundaries in the temperature range of 817…706 ºC. The formation of pearlite structure starts at 667 ºC, and ends by the heat of phase transformation (recalescence heat) at a higher temperature – 680 ºC. The microstructure of steel after cooling at the rate of 0.08 ºC/s consists of 78 % of 1 point perlite (pearlite with interlamellar spacing less than 0.2 microns), 22 % of 2-6 points perlite according to standard scale of GOST 8233-56 and less than 1 % of the secondary cementite (Fig. 2, a).

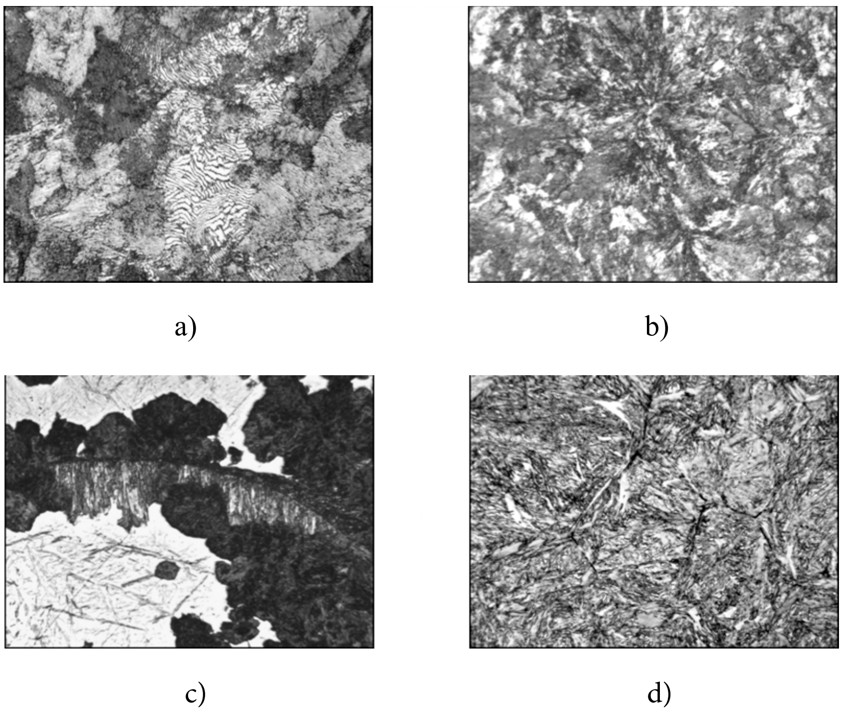

Figure 2. The microstructure of rolled products (× 500) of steel C86D after heating to 1000 ºC and cooling at different rates, ºC/s: a – 0.08; b – 25; c – 29; d – 335

The effect of heat of phase transformations, due to which the end line of pearlite transformation exceeds the pearlite start line is present in the range of cooling rates 0.1…7.5 ºC/s. In this velocity range separation of secondary cementite starts at the temperature 683…810 ºC, and ends at 627…703 ºC. The formation of pearlite structure starts at 583…667 ºC, and ends at the temperature 600…679 ºC. The microstructure of steel after cooling at 0.9 ºC/s consists of 85 % of 1 point perlite, 15 % of 2-6 point perlite and less than 1 % of secondary cementite.

Transition across the boundary value of the cooling rate 19 ºC/s is accompanied by fundamental change in the decay kinetics of supercooled austenite: the temperature range 657…617 ºC the percentage share of secondary cementite separates at temperature 580 ºC and pearlite transformation begins, the heat of phase transformations continues to release, but the heat eliminating at the cooling exceeds the recalescence heat and pearlite transformation ends at 539 ºC. At the temperature 477 ºC the remaining austenite transforms according to intermediate mechanism to bainite. At 200 ºC bainite transformation ends and the remaining austenite transforms to martensite. Final steel structure consists of a fraction of a percent of excess secondary cementite, 93 % of 1 point perlite, 5 % of bainite and rest – martensite.

In the range of cooling rates 29…203 ºC/s decomposition of austenite takes place by various mechanisms: to temperatures 400…524 ºC pearlitic structures are formed (without prior separation of the secondary cementite), and below these temperatures – bainite-martensite.

In mention range of cooling rates with increasing the cooling rate amount of decomposition products by the diffusion mechanism decreases, by the mixed – increases (up to speed 77 ºC/s), and then decreases. Thus, by cooling at a rate of 29 ºC/s microstructure consists of 25 % of 1 point perlite, 7 % bainite, rest is martensite (Fig 2 in.); when cooling at the rate 35 ºC/s – from 15 % perlite, 8 % bainite, and rest is martensite; when cooling at the rate 64 ºC/s – from 7 % perlite, 9 % bainite, rest is martensite; when cooling at the rate 77 ºC/s – from 5 % perlite, 10 % bainite, rest is martensite; when cooling at the rate 83 ºC/s – from 1 % perlite, 3 % bainite, rest is martensite.

Decomposition of austenite to martensite and bainite without prior pearlite transformation occurs in the following range of cooling rates 83…203 ºC/s. In this case, the microstructure consists of 1 % bainite, and rest structure is martensite. The characteristic feature of bainite transformation is the circumstance that it takes place in the temperature range where there is almost no diffusion of iron but carbon diffusion proceeds rapidly.

The minimum cooling rate at which all austenite subcools to the point M_s and transforms to martensite (critical cooling rate) is equal to 228 ºC/s. Colling at the rate of 335 ºC/s leads to the transformation of austenite into needle-type martensite of 6-8 points (Fig. 2, d). The martensite formation starts at 154 ºC and proceeds down to room temperature. However, since the end temperature of the martensitic transformation lies at the range of negative temperatures, so in the samples at normal temperature 2…4 % of retained austenite is remained.

Comparison CCTD of steel C86D micro-alloyed with boron with steel C80D2 alloyed with vanadium and micro-alloyed with boron (chemical composition, %: C – 0.87; Mn – 0.64; Si – 0.20; V – 0.083; P – 0.012; S – 0.005; Mo – 0.007; Cr – 0.05; Ni – 0.08; Cu – 0.17; Ca – 0.001; N – 0.004; B – 0.0025) [3] has shown the following: the steel studied has the selection area of secondary cementite from austenite (~19…0.08 ºC/s), which precedes the transformation of austenite to pearlite. Steel C86D has higher upper and lower critical cooling rates than steel C80D2 (228; 19 °C /s and 120; 12.3 ^{0}C/c respectively). The lower critical cooling rates in the steel C80D2 are due to alloying of steel with vanadium.

From the analysis of built CCTD follows that when increasing the cooling rate amount of 1 point perlite rises and reaches a maximum at V_{cool} = 7.5 ºC/s, and then passing through the boundary cooling rate (~ 19 ºC/s) begins to decrease and reaches the zero value at V_{cool} ~ 203 ºC/s. Increasing the cooling rate of the austenite decreasing A_{r1} line, thereby increasing the degree of perlite dispersion.

Considering of the results obtained for carbon steels sorbitizing in the flow of continuous wire mills it is expedient to use intercritical range of cooling rates, where perlite of greatest dispersibility is formed. At the same time rapid cooling should be stopped in the temperature range 540…580 °C /s and further cooling should be implemented in still air allowing decay of untransrormed austenite to dispersed perlite in quasi-isothermal conditions [4].

Considering the peculiarities of structure formation the thermomechanical technology of coil rolled products treatment was developed on Steelmor line, according to which the rolled products come out of the wire mill at the temperature ~1050 °C , expend on the revolutions at 1030…1020 °C and then rapidly cooled by air jets providing temperature drop at the open insulating covers up to 580…540 ° C at an average rate up to 20 ° C/s. Then cooling is continued under the closed insulating covers to the temperature ~100 ° C (red cooling line in Fig. 1).

Metallographic analysis showed that coil rolled products cooled in accordance with established technology contained about 85 ... 90% of 1point perlite and 15 ... 10% 2-3 points perlite (Fig. 2, b). The evaluation of the cementite network presence in the wire rod was performed by comparison with the references microphotographs of template III of standard NFA 04-114. Cementite network corresponded to class B (traces of cementite). Coil rolled products made of steel C86D micro-alloyed with boron with a diameter 8.0; 10.0 and 11.0 mm were produced in accordance with the established technology of thermomechanical treatment. It showed a high technological plasticity when the production method of direct drawing of high-tensile wire designed for laying into high strength stabilized prestressing strands in accordance with the requirements EN 10138-3:2005 [5].

Conclusion

1. CCTD of steel C86D micro-alloyed with boron (analogue to steel 85 according to DSTU 3683-98) was built and the peculiarities of structure formation in continuous cooling at different rates were established.

2. Lowering the start line of pearlite transformation A_{r1} while increasing the austenite cooling rate shows a corresponding increase in degree of perlite dispersion, which is typical for the entire austenite→ perlite transformation area including the intercritical range of cooling rates.

3. Increasing the degree of perlite dispersion in the structure of coil rolled products made of steel C86D micro-alloyed with boron is advisable to carry out by the accelerated air from the temperatures of wap formation 1030…1020 ºC to the temperatures 580…540 ºC, further in quasi-isothermal conditions. At the same time stage of rapid air cooling is performed in the intercritical rate range.

4. The technology of thermomechanical treatment of coil rolled products micro-alloyed with boron made of steel C86D was developed and implemented, according to which, after laying coiler coil rolled products laid out on the roller hearth of Stelmor line, the first stage was cooled at open insulating covers with intense jets of air to temperatures 580…540 ºC at an average rate in the range 18…25 ºC/s, and subsequent cooling was performed under closed covers in the quasi-isothermal conditions.

5. The coil rolled products made of micro-alloyed with boron steel C86D with a diameter 8.0; 10.0 and 11.0 mm have been produced in accordance with the developed modes of thermomechanical treatment. They can be subjected to direct drawing into the high-tensile wire, which is used for production of high-strength prestressing stabilized strands (EN 10138-3:2005) and reinforcing wires (EN 10138-2:2005).

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