APPLICATION OF NONLINEAR CONTROLLED COOLING REGIMES FOR STRUCTURE FORMATION MANAGEMENT IN EUTECTOID STEEL

ПРИМЕНЕНИЕ РЕЖИМОВ НЕЛИНЕЙНОГО КОНТРОЛИРУЕМОГО ОХЛАЖДЕНИЯ ДЛЯ УПРАВЛЕНИЯ СТРУКТУРООБРАЗОВАНИЕМ В ЭВТЕКТОИДНОЙ СТАЛИ

Ph.D. Kaverinsky V., Prof., Dr.Sc. Trotsan A., eng. Sukhenko Z. , Prof., Dr.Sc. Bagliuk G.
Institute for Problems in Material Science, Ukraine

Abstract: *Using computer modelling with originally developed semi empirical physical grounded models study of structure formation when austenite transformation during cooling by certain regime in eutectoid steel was carried out. The model allowed us to predict final structure. Cooling curves leading to fine pearlite (almost without bainite) and lower bainite (with a small part of fine pearlite) structures were find out. The results obtained could be useful for high carbon ordinary instrumental and constructional steels with higher manganese production and processing (rails, cord and rope wire, springs, low stressed instruments). Realization of the fine pearlite obtaining regime needs equipment that could provide cooling rates from 0.04 deg./sec. to 6.6 deg./sec. with average value of 1.1 deg./sec.. For bainitic structure obtaining the range of cooling rates provided shoud be from 0.14 deg./sec. to 14.0 deg./sec. with average value of 2.2 deg./sec. The cooling intensivity must have an ability to arbitrary and controlled changing during process.*
***KEYWORDS**: STEEL, STRUCTURE FORMATION, AUSTENITE TRANSFORMATION, HEAT PROCESSING*

1. Introduction

The *objective* of the research is to define cooling two regimes one of which leads to formation of a fine pearlite structure without or almost without bainite and martensite, and another that provides a lower bainite structure with less content of pearlite (only fine one) and higher bainite, martensite also is not wished.

Ordinary high carbon eutectoid steels have quite wide area of usage. They have their application in cases where high hardness or resiliency or ware resistant is needed. They do not have so much hardness and ability to rapid cutting (which needs from material ability to save hardness at higher temperatures) as some high alloyed instrumental steels. But they are rather useful for hand tools, or wood and plastic machining cutting tools. As a constructional material they are known as steel for springs, steel for cord and metal rope wire, and very important area of their application is material for rails [1, 2].

Normal equilibrium structure of this type of steels is pearlite – eutectoid which consists of ferrite and carbide (cementite) plates. The smaller thickness of this plates the finer pearlite is the higher its mechanical properties. Finer pearlite is forming at lower temperatures. Along with pearlite in some conditions at lower temperatures bainitic structures also could be obtained in these steels. Bainite could be present in this steels mixed with pearlite or the structure could be almost fully bainitic. High carbon steels have also good ability to quenching during which martensite is forming [1].

There is no one certain opinion whether lower bainite or fine pearlite is better. The most wide spared and useful now are steels with pearlitic structure. Bainitic structure for construction materials was studied [3, 4], but the properties obtained in steel with bainite were not much better, sometimes even worse then in the same steel but with fine pearlitic structure [4]. But in work [3] it was shown that changing chemical composition of the steel it is possible to obtain much better complex of properties (especially ware resistance) in bainitic steels. These steels have much less content of carbon, more Mn and some amount of Mo and Cr [3]. But bainitic structure sometimes is helpful in instrumental steels instead of martensite. It is because lower bainite is less brittle and more elastic than martensite.

Detailed description of the mathematic model of austenite transformation is given in our works [5, 6] and detailed model examples with experimental verifications are presented in [5, 7]. It allows calculation of nucleation and grows of different phases that could occur in steels. Thermodynamics of phase transformation is also calculated by the model. But the main objective of it is calculation of kinetics. One of the most important essences of the model is that it allows to predict the material structure which could form in the certain conditions of temperature regime during transformation process.

2.1. Studied material

Chemical composition of the studied steel in this work is given in table 1.

Table 1

Chemical composition of the studied steel

Fe	C	Mn	Si	Cr	Ni	Mo	Cu
base	0.75	0.95	0.35	0.03	0.05	0.02	0.06

It's seen that the steel is near to eutectoid and has higher amount of Mn and normal concentration of Si. Content of other elements is small, but they were also taken into account in simulation. It is a typical rail or spring steel.

According to thermodynamic calculations equilibrium critical points of this steel are A_1 = 729 °C and A_3 = 733 °C.

2.2. Calculation and its results

Different shapes of cooling curves were used in the simulations. It was predicted that the structure which almost totally consists of fine pearlite could be formed when the cooling regime is responding to one that is shown on figure 1.

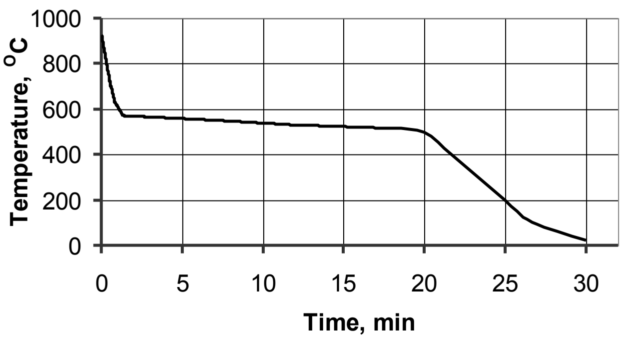

Figure 1 – Cooling regime for fine pearlite bainiteless structure obtaining in the eutectoid steel

Results of austenite transformation simulation (kinetic curve) in the investigated steel when temperature changes according to the cooling curve from figure 1 is shown on figure 2. From this illustration we can see that the transformations are almost completely end at about 514 °C. This moment comes after 1094 s from the beginning of the process and after 1063 s after the pearlite transformation starts (about 18 min) according to computer simulation. The pearlite transformation starts below 727 °C, but goes very slowly at the beginning. Because we don’t need rough pearlite the cooling rate in this period should be competently fast: from 5.0 to 6.6 deg./sec.

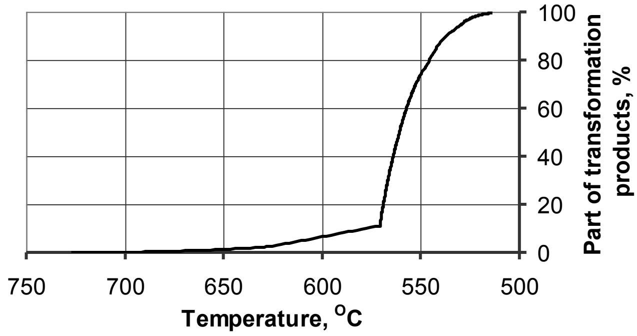

Figure 2 – Kinetic curve of austenite transformation in the regime of fine pearlite structure obtaining

Especially fast cooling rate is necessary lower 650 °C when the transformation process becomes quite swift. In this research it was considered that the fine pearlite structure should be obtained without quenching or cooling in liquid metal melts but by fast air cooling. This process has its limits, so that we obtain about 10 % of pearlite formed higher 575 °C. But fortunately amount of the pearlite formed higher 630 °C is very small. The bent of the kinetic curve near 570 °C is caused by slowing of the cooling rate (see figure 1). This deliberately decrease of the cooling rate to 0.4…0.7 deg./sec is needed to make pearlite transformation completely performed in a limited temperature range. This range is from 570 to 515 °C and its duration is about 19 minutes. This is enough to make pearlite transformation completely finished. Lower 515 °C according to calculations there is a possibility of higher bainite formation which is not wished in this case.

Another regime is aimed to a bainite structure obtaining. Its cooling curve is shown on Figure 3.

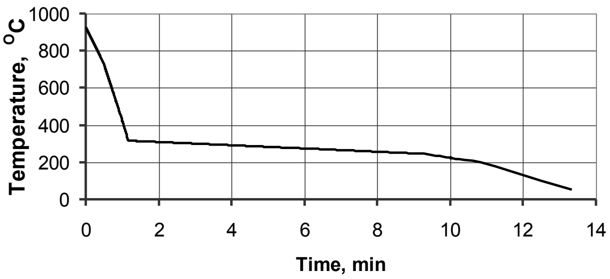

Figure 3 – Cooling regime for lower bainite structure obtaining in the eutectoid steel

This technique needs faster cooling rate at the beginning of the process. During first 80 seconds it should be 7…14 deg./sec. After this time metal should have temperature 325 °C. According to simulation it is the temperature when lower bainite becomes forming, but significantly higher than temperature of martensite transformation start which is 228 °C. Thus for lower bainite structure obtaining it is necessary to decrease the cooling rate to value 0.14…0.15 deg./sec. After about 7 minutes the bainite transformation is complete. The temperature at the end of the transformation is about 250 °C which is higher than temperature of martensite transformation start. Thus there is no martensite in the structure. A kinetic curve of the process is given on figure 4.

From the curve a certain separation of pearlite and bainite transformation is seen. Some pearlite which seems to be a fine one appear between 630 and 455 °C. Its amount in the structure is astimated to be 25.3 % from which 22.8 is a fine disperse pearlite and 2.3 is ordinary pearlite. The fastest cooling rate should be set in the temperature range from 450 °C to 325 °C. Austenite is less stable in this period and is able to transform to brittle higher bainite, which is not a wished structure. Thus the cooling rate should be raised up to 14 deg./sec. Lower 325 °C austenite transforms to lower bainite. In the final structure by our computer model presence of 74.1 % of lower bainite was estimated.

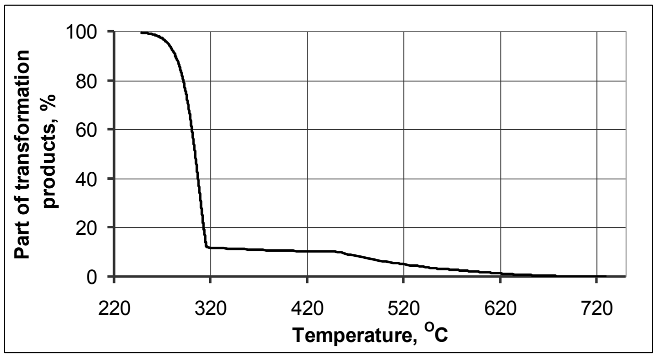

Figure 4 – Kinetic curve of austenite transformation in the regime of bainite structure obtaining

3. Conclusions

Using self developed computer model regimes for fine pearlite and bainite structure in eutectoid steel with higher manganese obtaining were developed. The regimes provide turning of higher cooling rate to slower ones at certain temperatures. Pearlite forming needs cooling rate 5.0…6.6 deg./sec. before 575 °C and than slowing it to 0.04…0.7 deg./sec. for 19 minutes. Regime for bainite structure obtaining is some faster. It needs cooling with rate 7…14 deg./sec. higher 325 °C (especially intensive at 450… 325 °C) and than slowing it to 0.14…0.15 deg./sec. for 7…8 minutes.

The obtained results present in the paper are useful for high carbon ordinary instrumental and constructional steels with higher manganese thermal processing regimes developing.

3. References

1. Houdremont E. Special steels / E. Houdremont - M: "Metallurgy", V.1 - 1966. - 736 p., V.2 - 1966. - 538 p. (Rus.)

2. Perfection of an assortment and the production technology of railway rails / [D. V.Stalinsky, A. S. Ruduk, I. V.Ganoshenko, etc.]// Metallurgical and mining industry. - №6. - 2010. - P. 66 - 68. (Rus.)

3. Bhadeshia H.K.D.H. Bainite in steels / H.K.D.H. Bhadeshia // The Institute of Materials: London, UK. – 1992. – 468 p.

4. Clayton P. wear Behavior of bainitic steels / P. Clayton, K. J. Sawlay, P. J. Bolton, G. M. Pell // wear – 1987. – vol. 120. – is. 2. – p. 199 – 200.

5. V. V. Kaverinskiy, A. I. Trotsan, Z. P. Sukhenko, V. S. Synuk XV Vseukrains'ka naukovo-praktichna konferencija «Special'na metalurgija: vchora, s'ogodni, zavtra – 2017» (XV National Scientific Conference "Special Metals: Yesterday, Today and Tomorrow – 2017") (Kiev: “KPI”: 2017), p. 1158. (in Russian).

6. A. I. Trotsan, V. V. Kaverinskiy, I. L. Brodetskiy, Z. P. Sukhenko, Sbornik materialov konferentsii “Stroitel'stvo, materialovedenie, mashinostroenie: Starodubovskie chteniya – 2016” (The collection of materials of the conference "Construction, materials science, mechanical engineering: Starodubov reading – 2016”) (Dnepropetrovsk: PGSA: 2016), vol. 89, p. 177. (in Russian).

7. Kaverinsky V. V. About computer simulation of austenite transformation in bulk [Text] / V. V. Kaverinsky // Journal of materials science and applications. – 2017. – Vol. 3. – P. 46 – 52.