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Соболенко М.О., Романова Н.С.

Структуроутворення за безперервного охолодження деформованого аустеніту борвмісної сталі

Український державний університет науки і технологій, м. Дніпро, Україна

Sobolenko M.A., Romanova N.S.

Structure formation during continuous cooling of deformed austenite of boron-containing steel

Ukrainian State University of Science and Technologies, Dnipro, Ukraine

Анотація. *Мета. Встановити закономірності формування структури сталі 30Г1Р за охолодження з різними швидкостями від температури нагрівання 1030 -1040 ℃. Проаналізувати кінетику розпаду деформованого аустеніту низьковуглецевої борвмісної сталі. Методика. Дослідження структурно-фазових перетворень і кінетики розпаду деформованого аустеніту проводили із застосуванням метода диференційно-термічного аналізу на зразках борвмісної сталі з дослідженнями мікроструктури та твердості.Результати. Вивчено кінетику перетворень структурних складових і побудовано термокінетичну діаграму розпаду деформованого аустеніту борвмісної сталі з урахуванням впливу гарячої пластичної деформації. Виявлено особливості впливу швидкості охолодження деформованого аустеніту на об'ємну частку структурних складових досліджуваної сталі. Наукова новизна. Показано вплив температуро - деформаційних умов і режимів охолодження з підстуджуванням після деформації на особливості структуроутворення борвмісної сталі. Виявлено вплив швидкості охолодження на характер перетворень деформованого аустеніту та механічні властивості досліджуваної сталі. Практична значимість. Проведені дослідження розпаду гарячедеформованого аустеніту сталі 30Г1Р дозволяють обґрунтовано підійти до розробки режимів і технології виробництва підкату під холодну висадку з формуванням оптимальних мікроструктур і властивостей у гарячекатаному стані. Встановлено інтервали швидкостей охолодження, які забезпечують формування необхідної структури, що складається переважно з високодисперсного квазіевтектоїду та самовідпущеного бейніту, що є основою для реалізації прогресивних видів сфероїдизуючих обробок сталі.*
Ключові слова: *швидкість охолодження, термокінетична діаграма (ТКД), структура, кінетика перетворень аустеніту, борвмісна сталь.*

Abstract. *Purpose. To establish the regularities of the formation of the structure of 30G1R steel during cooling at different rates from the heating temperature of 1030 -1040 ℃. To analyze the kinetics of the decomposition of deformed austenite of low-carbon boron-containing steel. Methodology. Studies of structural-phase transformations and the kinetics of the decomposition of deformed austenite were carried out using the method of differential thermal analysis on samples of boron-containing steel with studies of microstructure and hardness. Findings. The kinetics of transformations of structural components was studied and a thermokinetic diagram of the decomposition of deformed austenite of boron-containing steel was constructed, taking into account the influence of hot plastic deformation. The peculiarities of the influence of the cooling rate of deformed austenite on the volume fraction of structural components of the studied steel were revealed. Originality. The influence of temperature-deformation conditions and cooling regimes after deformation on the features of the structure formation of boron-containing steel is shown. The influence of the cooling rate on the nature of the transformations of deformed austenite and the mechanical properties of the studied steel is revealed. Practical value. The conducted studies of the decomposition of hot-deformed austenite of 30G1R steel allow us to reasonably approach the development of modes and production technology for cold-rolling with the formation of optimal properties in the hot-rolled state. Cooling rate intervals have been established that ensure the formation of the required structure, consisting mainly of highly dispersed quasi-eutectoid and self-tempered bainite, which is the basis for the implementation of progressive types of spheroidizing treatments of steel.*
Keywords: *cooling rate, thermokinetic diagram (TKD), structure, kinetics of austenite transformations, boron-containing steel.*

Introduction

A promising area of research aimed at improving the mechanical characteristics of metal for cold volumetric stamping (CVS) is the formation of a controlled structure of the hot-deformed undercut, through the targeted formation of the decomposition structure of hot-deformed austenite and its subsequent controlled cooling. This is achieved by optimal microalloying of steel with elements capable of significantly increasing the stability of austenite with a shift to the right of the ferrite and pearlite transformation regions on the thermokinetic diagram (TKD) of austenite decomposition. One of these elements that effectively affects the degree of increase in the resistance of austenite to decomposition is boron.

The issue of providing steel billets with the appropriate structure during heat treatment is directly related to improving the properties of metal products made of boron-containing steels intended for the manufacture of high-strength fasteners [1]. Microalloyed boron-containing steel of the 30G1R brand currently serves as a promising material for the production of fasteners manufactured by cold volume stamping (CVS).

Formulation of the research problem. In the real production process of manufacturing a roll for metal products by hot deformation, the cooling of the roll occurs with a continuous decrease in the temperature of the processed metal, and not under isothermal conditions. That is, in real technological processes, hot plastic deformation (rolling process) violates the equilibrium state of austenite and has a significant impact on the structure and properties of steel [2, 3]. It is known [4] that the properties of steel products are determined by the final structure, which in turn depends on the structures formed at the previous stages of the technology. In particular, it depends on the structural state of austenite formed in hot rolling, depending on the parameters of deformation and subsequent cooling.

The studies conducted in [5, 6] on the kinetics of decomposition of supercooled austenite during continuous cooling concern the regularities of decomposition of austenite, which was in a relatively equilibrium state, since the studied samples of 30G1R steel were subjected to austenization by separate heating. It should be noted that the majority of TKDs for steels listed in the literature are constructed without taking into account the influence of plastic deformation on the transformation of supercooled austenite. This circumstance allows us to assert that such TKDs only approximately reflect the features of the structure formation process in deformed metal. When using such TKD, it is impossible to accurately predict the parameters of heat treatment modes in relation to the technology of production of hot-rolled coiled steel.

In the works [7, 8] it is stated that currently the technology for manufacturing high-strength fasteners is developing in the direction of increasing the degree of compression during cold plastic deformation of hot-rolled (rebellious) billets with a significant complication of the shape of metal products. In this case, the structure and properties of the steel used for the CVS are subject to requirements related to increasing the ductility life and uniformity of the roll structure.

Therefore, to optimize existing technologies for the production of undercuts for high-strength steel, as well as to develop new heat treatment modes in the rolling mill flow, it is most advisable to use TKDs built taking into account temperature-deformation effects on the metal, as close as possible to production conditions.

In view of the above, studying the features of the kinetics of the decomposition of deformed austenite, establishing patterns and determining the conditions for the formation of the hot-rolled structure of 30G1R steel during accelerated cooling at different rates is a relevant task.

Research material and methodology. To determine the conditions for the formation of the hot-rolled structure of 30G1R steel, laboratory studies were conducted on the influence of conditions after deformation cooling of the roll on the kinetics of the transformation of supercooled austenite of the specified steel. Chemical composition of steel, % by mass: C – 0,30; Si – 0,31; Mn – 1,02; S – 0,007; P – 0,024; Cr – 0,20; Al – 0,02;Ti – 0,017; B – 0,0007.

Phase transformations were studied using the differential thermal analysis method [9] on samples of wire rod with a diameter of 6.5 mm made of 30G1R steel with studies of microstructure and hardness. The recording of heating and cooling curves, changes in thermo-EMF during phase transformations was carried out using an automatic potentiometer CTP4-011 and a two-coordinate recorder DDS-002. The study of the metal microstructure was carried out on a light metallographic microscope "Neophot – 21". The hardness of the samples was measured in laboratory conditions using the Vickers scale on a TP-7P1 type device.

The kinetics of phase transformations during the production of rolled products is determined based on the construction of diagrams that take into account the combined effect of deformation, accelerated cooling, and subsequent slowed cooling. In laboratory conditions, rolled steel samples with a diameter of 6.5 mm were subjected to heat treatment under conditions similar to industrial cooling conditions for a round profile. The sample processing modes included austenization at 1100 °C, which corresponds to the temperature of the billets before the first stand of the rolling mill. The deformation of the samples was carried out in one pass with a degree of 35%, which corresponds to the rolling modes in production conditions. The rolling temperature of the laboratory samples was 1030–1050 °C and corresponded to the temperature of the metal exit from the finishing stand of the rolling mill.

Presentation of the main research material. In laboratory work, the continuous-sequential effect of hot plastic deformation and cooling regimes on the kinetics of phase transformations of 30G1R steel was investigated. The influence of the deformation temperature of 1030…1050 ºC on the position of the regions of formation of intermediate transformation products, the position of the boundaries of the decomposition regions in the case of a combination of plastic deformation and cooling conditions that correspond to the production technology of high-quality undercuts was determined.

To prevent partial decomposition of austenite after hot deformation in laboratory conditions, the samples were rapidly cooled from the end of rolling temperature at a rate of 230–250 °C/s to temperatures in the range of 835–390 °C with subsequent slow cooling to room temperature (the cooling rate was 0,06–0,09 °C/s).

The results of experimental studies are summarized in the form of a TKD, which is presented in fig. 1.

The conducted studies have established that the TKD of the decomposition of deformed austenite of

30G1R steel has the following transformation regions: ferritic, pearlitic, intermediate and martensitic.

Hot deformation under the specified temperature-deformation regimes and intensive cooling to temperatures of 390 ℃ and 450 ℃ with subsequent slow cooling ensure the decomposition of austenite mainly by an intermediate mechanism with the formation of 90 - 95% bainite and the rest - martensite. Such a structure is formed due to the preferential suppression of diffusion processes of austenite decomposition, (fig. 2 a). It is noteworthy that both structural components are in a self-tempered state due to the decomposition of austenite under semi-isothermal conditions, as evidenced by the rather low hardness value of the steel, which is 272 - 248 HV.

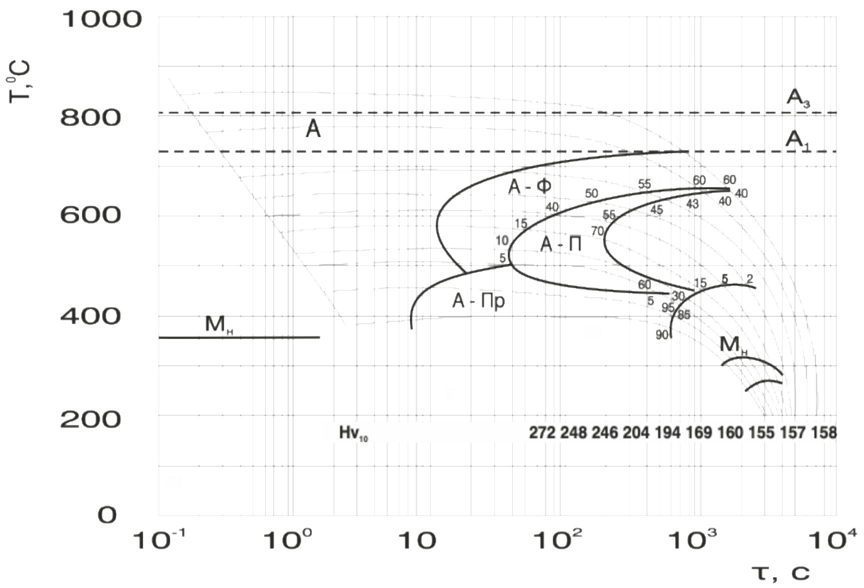


Fig. 1. Thermokinetic diagram of the decomposition of deformed austenite of 30G1R steel, rolled at 1030–1050 °C with a degree of deformation of 35%, with continuous cooling at different rates

When the temperature of the end of intensive cooling after deformation is increased to 500 ℃, the first products of purely diffusion decomposition of supercooled austenite are observed in the structure: 5% ferrite and 5% quasi-eutectoid (cane-sorbite-like pearlite, fig. 2 b) and the rest is bainite. At the same time, the hardness of the steel practically does not change and is 246 HV.

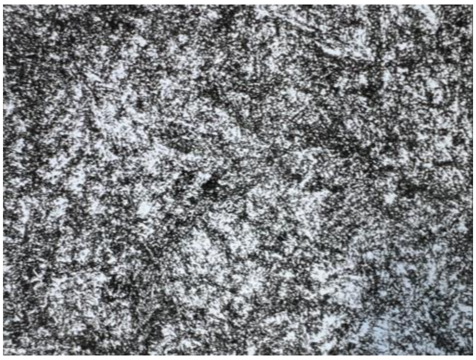
A sharp increase in the amount of these structural components, especially the quasi-eutectoid (up to 60%), is observed when the temperature at the end of intensive cooling increases to 530 - 575 ℃ (fig. 2 c). Analysis of the TKD of 30G1R steel shows that with a decrease in the temperature of the end of intensive cooling, the temperature of the eutectoid decomposition also decreases, as a result, the degree of pearlite dispersion increases. At the same time, it should be noted that quasi-eutectoid cementite has not only a high degree of dispersion (which is assessed according to scale 1 of DSTU 9074:2021 and is identified as pearlite of the 1st point) and a shape similar to spherical, but also a fairly uniform distribution of structures across the cross section of the section.

Such a structural state can positively influence the formation of optimal structures during subsequent heat treatments. The hardness of steel due to the specified structural changes is significantly reduced to a value of 194 HV.

Increasing the temperature of the end of intensive cooling to 610-700 ℃ leads to a sharp decrease in the steel structure of bainite and martensite (up to 2-5%) and the predominant formation of polyhedral or dendritic ferrite morphology (up to 55%), which is presented in fig. 2 d. The hardness of steel under the considered processing modes is 155 HV.

Intensive cooling in the supercritical and intercritical temperature range (760 – 835℃) with subsequent slow cooling in the temperature range 640 – 725℃, diffusion processes of formation of polyhedral ferrite or ferrite of dendritic morphological type (60%) and dispersed pearlite (40%) occur – fig. 2 f. At the same time, the hardness value of the steel increases slightly to 157 – 158 HV.

A decomposition diagram of hot-deformed austenite of 30G1R steel has been constructed, which allows a scientifically sound approach to the development of heat treatment regimes for cold-rolling with the formation of both optimal properties of the metal in the hot-rolled state and the formation of its optimal structure for subsequent heat treatment with separate heating.

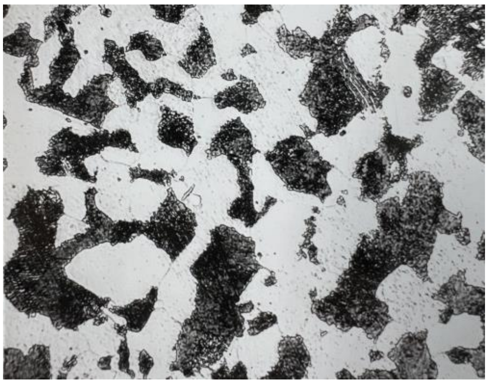


a

b

c

d



f

Fig. 2. Microstructure of hot-rolled samples of 30G1R steel, cooled in different modes, x500: temperature of the end of cooling of samples (cooling): a – 390 ℃;
b – 530 ℃; c – 575 ℃, d – 700 ℃; f – 760 ℃

Conclusions. The influence of temperature-deformation conditions of rolling and cooling modes after deformation on the features of the structure formation of 30G1R steel has been established. The temperature intervals and kinetics of the decomposition of deformed austenite and the regularities of the formation of the structure of boron-containing steel grade 30G1R during cooling at different rates were studied. The results of the research are presented in the form of a thermokinetic diagram of the decomposition of deformed austenite of 30G1R steel. The conducted research can be used to develop heat treatment regimes integrated into the production line of hot-rolled strip, which is used for CVS of high-strength fasteners.

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