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RESEARCH OF SPECIAL LIMITS DURING HEAT TREATMENT OF MATERIALS IN THE TWO-PHASE REGION UNDER SUPERCRITICAL TEMPERATURE INFLUENCE

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The results of the research on establishing the dependence of the coercive force (Hs) on special boundaries in a low-carbon alloy are given. Annealing at a temperature of 900 ºC with a holding time of 1 to 3 h leads to an increase in the number of special boundaries from 22.7 to 37.17% and to an increase in magnetic permeability and, accordingly, a decrease in the coercive force from 1.60 to 1.24 A/cm. When the load is axially stretched, the coercive force changes. The initial stage of plastic deformation is most sensitive to the growth of coercive force, which allows us to identify areas in which local plastic deformation has occurred, which indicates a significant decrease in the operational characteristics of parts.

INTRODUCTION

The magnetic properties of armco iron, mainly the values of magnetic permeability in weak and field fields and the coercive force, can vary widely depending on the amount and composition of impurities, grain size, deformation, nature of heat treatment, etc. other reasons. The magnetic properties of armco iron are improved by growing large grains or by repeated remelting in a vacuum. Internal stresses in parts are removed by annealing. Therefore, to obtain iron with high magnetic properties, it is necessary to make efforts not only to remove impurities, but also to grow large grains, which is mainly achieved through appropriate heat treatment (annealing). Analysis of literature sources shows that there is a certain interest in the study of special boundaries in alloys, two-phase materials and widely used steels. However, special boundaries and their influence on the properties of metals with a single-phase (ferritic) structure have not been studied. Therefore, studies aimed at studying special boundaries and their properties in armco-gland are relevant.

The purpose of this work is to show the effect of different annealing modes on the formation of special boundaries, a change in the grain size in ferrite, and the magnetic properties (coercive force Hc) of armco iron.

MATERIAL AND EXPERIMENTAL PROCEDURES

Special boundaries were identified according to the features described in [1]. The relative number of special boundaries was determined by the secant method [2, 3]. The measurements were carried out in the fields of five secant lines and the average value was determined. At present, the main features are known, the presence of which directly indicates that grain boundaries belong to special (low-energy) ones [4–6].

1. If the border is divided into 2–3 unidirectional sections (facets), then such a border is special.
2. If both ends of the border enter into triple joints with opposite angles exceeding 170º, then this border belongs to special ones.
3. A border is special if it enters with one end into a quadruple or quintuple joint, and with the other end into a triple joint with an opposite angle of more than 170°.

Investigated samples cut from hot rolled steel Ǿ 42 mm. The samples were numbered according to the following scheme: sample No. 0 – sample witness; samples No. 1–4.

Laboratory processing scheme: samples No. 1–4 are heated to 900 °C, and kept in an oven for 1 h for samples No. 1 and 2, followed by cooling of sample No. 1 in water and No. 2 in air, sample No. 3 is held in the oven for 2 h and No. 4 – 3 h, followed by cooling in air. The coercive force was determined with a KRM-Ts-K2M semiautomatic coercimeter. Hardness measurements were made with a dynamic hardness tester TDM-2. To carry out metallographic studies of the structure, a 20×20×4 mm metal was sampled using an IA 32 automatic structure analyzer. Metallographic sections were prepared according to the standard procedure [7, 8].

EXPERIMENTAL RESULTS AND DISCUSSION

It is known that grain size affects most properties of materials, and this is not only related to the number and distribution of grain boundaries. Early models of boundaries considered them as a strong amorphous cement that holds the “bricks” together – the grain and atomic configurations within the boundaries were considered chaotic and random. Until now, it has become obvious that intergranular interfaces with different patterns of regular atomic packing (special boundaries are a very important component of the grain structure). Due to differences in the atomic structure of the grain boundaries, differing significantly in terms of specific surface energy, different properties are revealed. The practical use of the special properties of special boundaries became possible thanks to the development in recent years of the concept of lattices of coincident nodes, as well as the study of the fine structure and crystallographic parameters of special grain boundaries [9–11]. The concept of grain-boundary construction of materials arose, which, in order to improve the general properties of the material, involves the creation of a large number of certain low-energy boundaries at the expense of other, high-energy ones. The essence of grain boundary design is the management of temperature-turn-deformation processes in the manufacture of metal products to create a microstructure with the maximum number of special low-energy grain boundaries Σ3 and their derivatives Σ3n.

The consequence of the increase in the number of such limits is an increase in the complex of physico-mechanical and corrosion properties of products, including parts that work under conditions of high-temperature heating in the conditions of metallurgical production. The analysis of changes in the properties of steels after heat treatment allows us to determine that the best strength is steel 3ps aged at a temperature of 750 °C for 1 h. Attention is drawn to the fact that when the technological parameters of heat treatment are varied, the strength and coercive force of the samples change dramatically.

As for the effect of heat treatment on the structure of steels, on the example of 3ps steel (Fig. 1), the initial microstructure of the studied sample, which is a ferrite-pearlite mixture with a ferrite/pearlite ratio of ~ 80/20% at a temperature of 750 °C, changes the ratio of ferrite–pearlite to ~ 75/15%, respectively (see Fig. 1), that is, it increases from 4 to 5.

This ratio is observed both after exposure for one and three hours. However, in the latter case, the coercive force is slightly reduced due to the spheroidization of pearlite. In this case, new pearlite colonies begin to form from the boundary of the ferrite grains with extensive germination into ferrite grains.

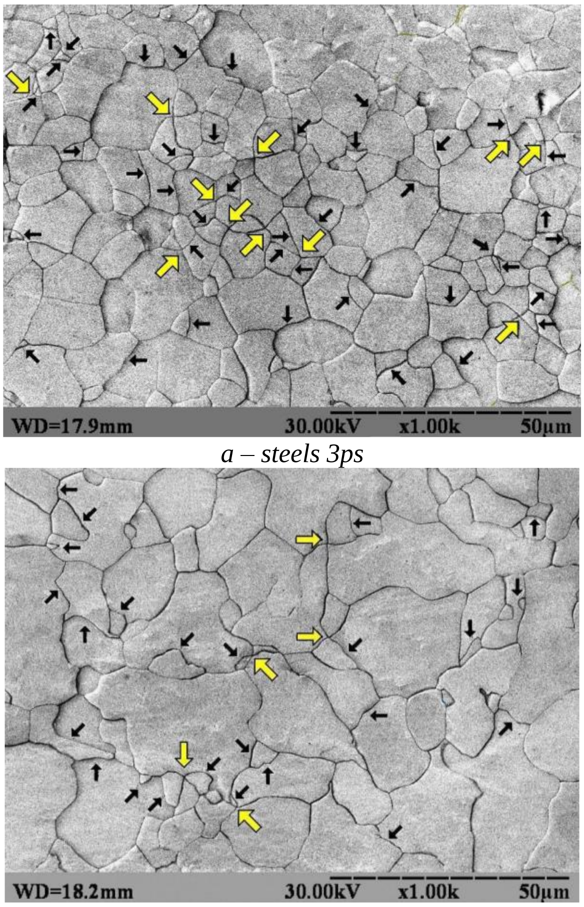
Determination of structural changes in the grain size, hardness, and magnitude of the coercive force suggests that the use of the coercive force as a control tool will make it possible to evaluate the structure of steels under various thermal treatment regimes. Studies of the magnetic and mechanical properties of steels A516-55, St37, 3ps in comparison with metallographic samples showed that the strength properties of Gt, Gv and the hardness of these steels can be determined by the following values

The value of the coercive force Hc. The magnitude of the coercive force Hc decreases with increasing temperature exposure time.

The main features are known, the presence of which directly indicates that the grain boundaries (see Fig. 1,a) belong to special (low-energy) grain boundaries.

On the basis of these features, the microstructures of 3ps steel were analyzed after a three-hour exposure at a temperature of 750 °C and grain boundaries were identified, where special boundaries are marked with black arrows (see Fig. 1,a), and four joints are marked with light three-dimensional arrows. The average relative value of the number of special borders of this processing mode is 32%.

The study of the microstructure of steel 09G2S (see Fig. 1,b) after a three-hour exposure at a temperature of 750 °C in an unprotected atmosphere made it possible to determine the average relative value of the number of special boundaries, equal to 36%.



a – steels 3ps

b – steels 09G2S

Fig. 1. Microstructure of steels after 3 years of vitrification at a temperature of 750 °C, x1000

The specific content of special tetrahedrons in the structure was not calculated, since they are relatively rare, which prevents the collection of a sufficient amount of statistical data, but even a small amount indicates a higher probability of the presence of special boundaries in the structure of the studied material.

The increased content of special boundaries in the decarburized layers compared to the base metal can be explained by the absence of pearlitic or other immobile elements of the structure. The perspective of this phenomenon lies in its application as a surface layer, which increases the resistance of products against atmospheric and some other types of corrosion. Previous studies show that such processing, which increases the content of low-energy boundaries, also leads to changes in the activity of the coercive force of the entire material. Thus, isothermal heat treatment of low-alloy and low-carbon steels at a supercritical temperature of 750 °C for 3 h leads to the formation of special boundaries in ferrite. The work proved for the first time that during the stay of steels at a temperature of 750 °C, the number of special boundaries reaches the value of 32% for steel A414 and 36% for steel A516-55. The increased content of special boundaries in the decarburized layer has a favorable effect on the corrosion resistance of steels that are used in conditions that do not require high strength properties. Heat treatment of low-alloy and low-carbon steels in the two-phase region, at a supercritical temperature effect of 750 °C, leads to a decrease in the hardness, strength and magnetic properties of steels and an increase in special limits. Such a dependence allows to control the structure of metal in responsible objects of metallurgy: cranes and other objects that transport liquid metal.

It was found that laboratory processing (annealing) of samples No. 1–4 caused a change in the coercive force Hc. The results of measuring the coercive force Hc and hardness HB are shown in Table.

Value of coercive force ns
and hardness in each model

Sample	Hc, A/cm	HB
0	0.94	98
1	1.60	150
2	1.45	120
3	1.25	110
4	1.24	116

On the basis of the features indicated in [7, 8], images of the microstructure of armco iron were analyzed after one hour, two hours, and three hours of exposure at a temperature of 900 °C and grain boundaries identified.

Annealing of ultra-low-carbon alloys such as armco iron leads to an increased content of special boundaries in ferrite, which can be explained by the absence of pearlite or other slow-moving elements of the structure. Materials with an increased content of low energy boundaries can successfully compete with traditional metals and alloys in the field of electrical engineering and magnetism.

In Fig. 1, black arrows indicate special boundaries, and quadruple joints – light volumetric arrows.

Sample No. 0 – witness sample – is characterized by a low value of the coercive force Hc = 0.94 A/cm, reduced mechanical properties, hardness is 98 HB.

Sample No. 1 – cooling in water leads to a certain decrease in the grain size D = 53 μm and an increase in the coercive force up to Hc = 1.6 A/cm and, accordingly, an increase in hardness up to 150 HB.

Sample No. 2 – holding in the furnace for 1 h and cooling in air leads to a decrease in internal stresses, a decrease in the value of the coercive force Hc = 1.45 A/cm, a hardness of 120 HB and a slight increase in grain to 64 μm.

Sample No. 3 – holding in the oven for 2 h and cooling in air causes an increase in magnetic permeability, a decrease in the coercive force Hc = 1.25 A/cm and residual induction, hardness 110 HB and leads to an increase in the grain size to 78 μm.

Sample No. 4 – an increase in holding in the furnace up to 3 h and air cooling leads to a further increase in the grain size to 81 μm and an already insignificant decrease in the value of the coercive force Hc = 1.24 A/cm, and the hardness practically did not change 116 HB.

The specific content of special quadruple junctions in the structures was not calculated, since they are relatively rare, which prevents the collection of a sufficient number of statistical data, however, even small amounts of them indicate a relatively high probability of the presence of special boundaries in the studied material, which are reflected in the work.

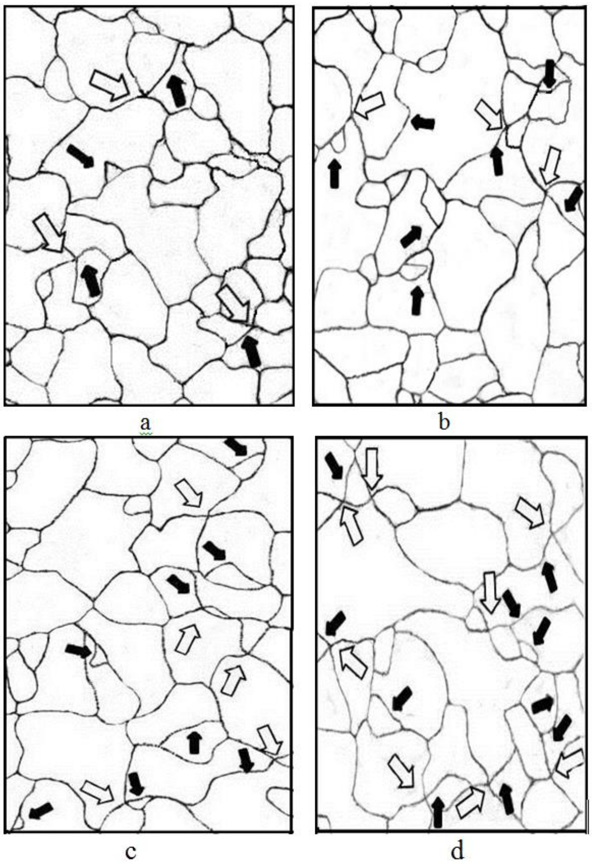


Fig. 2. Microstructure after endurance in the furnace with 900 °C:
a – the model of 1 – 1 h in the furnace, cooling – water;
b – the model of 2 – 1 h in the furnace, cooling – air;
c – the model of 3 – 2 h in the furnace, cooling – air;
d – the model of 4 – 3 h in the furnace, cooling – air

In this way, it was proved that exposure of armco iron at a temperature of 900 ºC for 3 h leads to an increase in grain sizes and the relative number of special boundaries in ferrite. It was established for the first time that the annealing of armco iron at a temperature of 900 ºC with a holding time of 1 to 3 h leads to an increase in the relative number of special boundaries in ferrite from 22.7 to 37.17%. It was established for the first time that an increase in the number of special boundaries from 22.7 to 37.17% leads to an increase in magnetic permeability and, accordingly, a decrease in the value of the coercive force from 1.60 to 1.24 A/cm. The use of the coercive force Hs as a control tool allows one to evaluate both the structural state of armco iron and the relative number of special boundaries under different annealing regimes.

Annealing of ultra-low-carbon alloys of the armco iron type leads to an increased content of special boundaries in ferrite and a decrease in the coercive force, which can be explained by the absence of pearlite or other inactive structural elements. Materials with a high content of special low-energy boundaries can successfully compete with traditional metals and alloys in the field of electrical engineering and magnetostrictive devices.

CONCLUSIONS

1. Holding armco iron at a temperature of 900 °C for 3 h leads to an increase in the grain size and relative amount special borders in ferrite.

2. It is shown for the first time that annealing of armco iron at a temperature of 900 °C with holding from 1 to 3 h leads to an increase in the relative number of special boundaries from 22.7 to 37.17%.

3. It was established for the first time that an increase in the number of special borders from 22.7 to 37.17% leads to an increase in magnetic permeability and, accordingly, a decrease in the magnitude of the coercive force from 1.60 to 1.24 A/cm.

4. The use of the coercive force Hc as a control tool makes it possible to evaluate both the structural state of armco iron and the relative number of special boundaries under different annealing modes.

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ДОСЛІДЖЕННЯ СПЕЦІАЛЬНИХ ГРАНИЦЬ ПРИ ТЕРМІЧНІЙ ОБРОБЦІ МАТЕРІАЛІВ У ДВОФАЗНІЙ ОБЛАСТІ ПРИ НАДКРИТИЧНОМУ ТЕМПЕРАТУРНОМУ ВПЛИВІ

Борис Середа, Ірина Кругляк, Дмитро Середа, Віталій Волох

Наведено результати дослідження по встановленню залежності величини коерцитивної сили (Hc) на спеціальні границі в низьковуглецевому сплаві. Відпал при температурі 900 ºС з витримкою від 1 до 3 год призводить до збільшення кількості спеціальних границь з 22,7 до 37,17% та до збільшення магнітної проникності й відповідно зниження величини коерцитивної сили з 1,60 до 1,24 А/см. При осьовому розтягуванні навантаження змінюється коерцитивна сила. Початкова стадія пластичної деформації найбільш чутлива до зростання коерцитивної сили, що дозволяє виявити ділянки, в яких сталася локальна пластична деформація, що свідчить про значне зниження експлуатаційних характеристик деталей.