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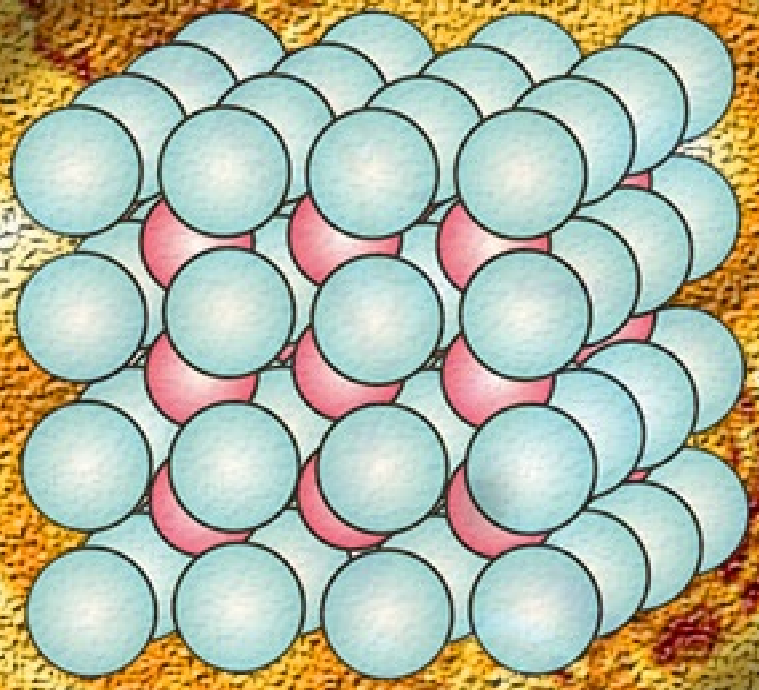

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C O N T E N T S

INFLUENCE OF THERMAL-CYCLIC DEFORMATION AND HEAT TREATMENT ON THE STRUCTURE AND PHYSICAL PROPERTIES OF STEEL 10

ВЛИЯНИЕ ТЕРМОЦИКЛИЧЕСКОЙ ДЕФОРМАЦИИ И ТЕРМИЧЕСКОЙ ОБРАБОТКИ НА СТРУКТУРУ И ФИЗИЧЕСКИЕ СВОЙСТВА СТАЛИ 10

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Abstract: *The results of the influence of preliminary thermal-cyclic deformation and subsequent annealing in the range of 100÷900 ℃ with a step of 100 ℃ on the microstructure, coercive force and linear expansion of hot-rolled sheet steel 10 are presented. It was found that the use of preliminary thermal-cyclic deformation results in increase in coercive force no more than by 8% in comparison with the steel sheet produced by an industrial technology. Decreasing feasibility in coercive force of the sheet steel produced with the use of thermal-cyclic forging almost by 3 times in comparison with the initial raw condition due to the subsequent annealing at 900℃ during 10 h. is shown. In addition, annealing in accordance with this mode reduces a temperature coefficient of linear expansion of a sheet steel on average by 6 % within the range of the test temperatures 50-450 ℃.*

***KEYWORDS**: STRUCTURE, STEEL, DEFORMATION, ANNEALING, PHYSICAL PROPERTIES, THERMAL-CYCLING DEFORMATION, COERCIVE FORCE, LINEAR EXPANSION.*

1. Introduction

Vast majority of half-finished goods, details and structural elements of products from various materials is used in industry after the strengthening technologies – deformation, thermal or superficial chemical heat treatments. However, increasingly restrictive requirements to the modern equipment brought in to existence the complex technologies including combined use of various techniques for both structure formation and management and, therefore, properties of materials. The thermo-mechanical, mechanical-thermal and more difficult – deformation thermal cyclic treatment (DTCT) belong to such technologies. The technological modes of these types of processings combine different types of cold and hot deformation with heats, holding at the fixed temperatures and cooling in the wide range of speeds (in water, on air or in furnace). DTCT is distinguished by repeatability of processing cycles. At that, the number of processing cycles and their parameters (temperature of heating and cooling; temperature interval of deformation; a type and deformation ratio in the cycle; overall deformation ratio, etc.) are subject to vary over a wide range. DTCT is widely covered in the literature as a technology applied for hardening of ferrous and non-ferrous metals and alloys, including steels, cast iron and aluminum alloys [1-9]. Much lesser attention is given to a problem of improvement electric, magnetic, thermal and other physical properties of various materials. It is possible to refer works of authors [1, 10-12] to such publications. One of the perspective directions of the use of DTCT is giving to structural low-carbon steel the properties being near to properties of some groups of the magnetically soft materials, in particular, technically pure iron and electrical steel which are combined with advanced mechanical and technological properties. Besides, an additional reserve for improvement properties of low-carbon steel can serve the subsequent heat treatment having impact on its structure and the most important properties, such as electric, magnetic and thermal (specific electric resistance, electric conductivity, losses on magnetic reversal, the coercive force, coefficient of thermal expansion, etc.) for the magnetically soft materials. Therefore, the aim of this work was to study the effect of the preliminary thermal - cyclic forging and the subsequent annealing on the coercive force and linear expansion of sheet hot-rolled steel 10.

2. Material and methods

Low-carbon fine steel 10 was used as a material in the study. The steel was made at the Novokuznetsk Iron and Steel Plant JSC (Novokuznetsk, Russia). The chemical composition of experimental steel, in % (weight): C – 0,13; Si – 0,22; Mn – 0,42; P – 0,014; S – 0,018; Cr – 0,05; Ni – 0,04; Cu – 0,20; As – 0,06; Fe – the rest. A slab of steel 10 was subjected to hot cyclic forging through single-pass broaching by flat backups with blank turning at the forge-thermal shop of the West Siberian Metallurgical Plant (Novokuznetsk, Russia) using a hydraulic forging press with the load of 2000 ton-force. A hot cyclic forging technique is presented in this work [11], and its main characteristics and technique are given below. The heating temperature before forging was 1250 °C, the slab holding time in the furnace before forging was 2 hours. Forgings were cooling in the air to 200-300°C. There were 10 cycles of forging with a deformation ratio in each cycle 6 ÷ 8 %. Overall deformation ratio was 65÷68 % at the overall reduction ratio – 1.90.

Further the blanks were rolled to sheets 3 mm thick at the semi-continuous hot-rolling combination mill 810 according to the manufacturing process for hot-rolled sheet carbon steel 10. Before rolling the blanks were preheated in a gas furnace. The heating temperature of blanks for rolling was 1120÷1250 °C, and the holding time in the furnace was 2÷2,5 hours. The rolling finishing temperature for a sheet 3 mm thick was 800 - 860 °C. In further detail, technological mode of hot-rolled sheet carbon steel 10 is given in the work [2].

Annealing of the specimens cut from sheets was carried out in resistance furnaces SNOL 2.2, 5.2 / 12.5-I1. An optical microscope LaboMet-I1was was used to investigate the microstructure of the steel. High-temperature dilatometer DIL 402C with digital data processing and error of measurement of $0{,}1 \cdot 10^{-6}$ K^{-1} was used for determination the temperature coefficient of linear expansion (TCLE) of steel specimens at various temperatures. Determination the coercive force was carried out on KIFM-1 coercimeter with a probe-type magnetic-field sensor (demagnetization current of a magnetic conductor $8 \cdot 10^{-3}$ A) on rectangular sheet specimens 90×120 mm with a thickness of 3 mm. The measuring error was 4 A/m.

3. Results and discussion

One of the most important properties of the magnetically soft materials is the coercive force determining losses of energy on magnetization reversal of magnetic circuits elements. First of all, that belongs to cores of the magnetic conductors with difficult configuration, stators and rotors of high-frequency machines, throttles, transformers and other structural elements [13]. In this regard the size of coercive force has been determined for the hot-rolled steel 10 made by an industrial technology of rolling and with the use of preliminary DTCT. She was 214 A/m in the first case. If thermal-cyclic forging are used, she was 232 A/m. Such increase in coercive force due to the using modes of preliminary thermal-cyclic forging at production of sheet hot-rolled steel 10 can be explained with the changes occurring in its microstructure:

grains crushing of ferrite and pearlite colonies oriented along the rolling direction (first of all). This fact corresponds with results of the metallographic researches carried out in works [2, 6]. Such a fine crushing of structural components and, therefore, increase in extent of grain boundaries, where crystal structure imperfections (dislocations, vacancies, etc.) are gathered, is a reason for increasing in size of the coercive force in structure of the sheet steel 10 made with use of DTCT. Magnetic elements work often in the industry at the elevated and lowered temperatures, including widespread lamellar stacked cores with electrically insulated coating, the magnetically operated sealed switches (gerkon) and other products of this sort. Therefore, one of important characteristics for such products made from magnetically soft materials is a characteristic of thermal expansion – the temperature coefficient of linear expansion (TCLE). Performed impact studies of the mode of thermal-cyclic forging on linear expansion of steel 10 revealed that use of DTCT doesn't exert impact on true temperature coefficient of linear expansion. The size of its change after cyclic forging and rolling to a sheet doesn't exceed 5 % (fig. 1). However, it is possible to note a tendency of the coefficient increasing in the field of low test temperatures (to 300 °C) by 5 % in comparison with coefficient of hot-rolled steel made by an industrial technology and opposite change of TCLE values for more high test temperatures (300-450 °C).

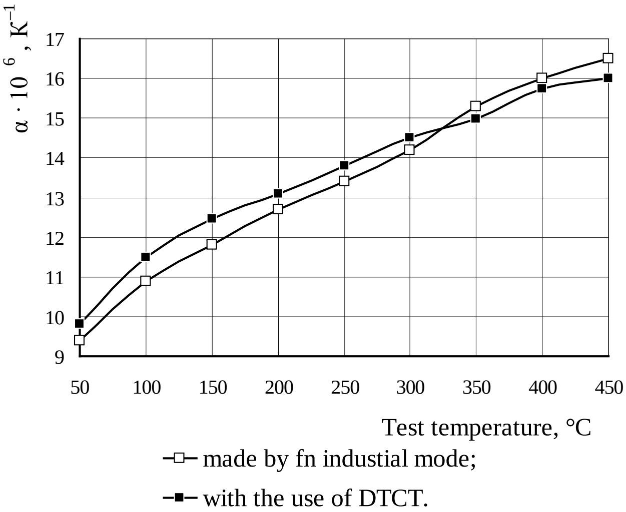

Fig.1 *– Influence of thermal -cycling forging on the linear expansion of hot- rolled sheet steel 10 (sheet thickness of 3mm)*

Further influence of the subsequent annealing during 10 h was investigated on physical properties of the sheet steel 10 (3 mm thick) subjected to DTCT. It is established that increase in annealing temperature from 100 to 900 °C with a step of 100 °C leads to a consecutive decrease in size of steel coercive force (fig. 2). Its intensive decreasing was noted at more high annealing temperatures, beginning from 600 °C. The minimum value of coercive force corresponds to annealing at temperature of 900 °C and is 83 A/m, that is nearly 3 times lower, than at specimens without heat treatment. Apparently, coercive force decrease of the sheet steel made with the use of DTCT can be attributed, with increase in annealing temperature, to general decreasing in stress level and defects of the crystal structure (vacancies, dislocations, etc.), which are formed in metal as a result of the used modes both of deformation and cooling and also significant growth in grain of ferrite and some reduction of a volume fraction of the pearlitic colonies.

Influence of the subsequent annealing temperature during 10 h on linear expansion of the sheet hot-rolled steel 10 subjected to DTCT is investigated in this work. Received curves of temperature dependence of true TCLE of the steel 10 made with thermal cyclic forging, after annealing at 600, 700, 800 and 900 °C are given in fig. 3.

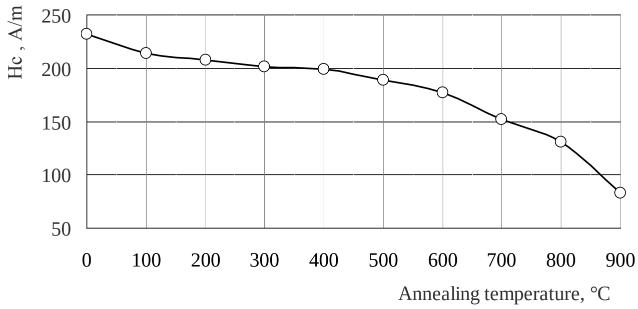

Fig. 2 *– Influence of heating temperature with cooling in the furnace on the coercive force of the steel 10 made with the use of DTCT*

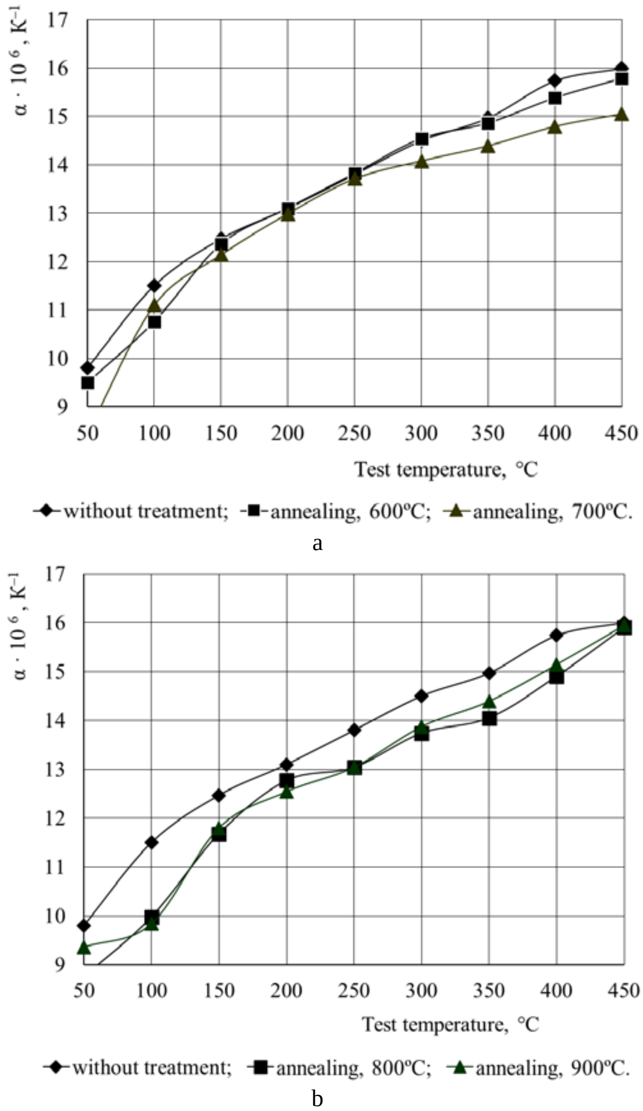

Fig. 3 *– Influence of annealing temperature at 600 and 700 ºC (a) and 800 and 900 ºC (b) (holding time 10 h) on linear expansion of the sheet hot-rolled steel 10 made with use of DTCT*

Graphic dependences of average coefficient according to test temperature intervals from annealing temperature (fig. 4) are constructed on the basis of the analysis of temperature dependence curves of true TCLE of the steel 10, made with use of thermal-cyclic forging after annealing during 10 h at 600, 700, 800 and 900 °C (fig. 4)

Obtained dependences allow to grains draw a conclusion about decrease in the steel 10 capability to thermal expansion after annealing at all studied temperatures; beside that, annealing of steel at 800 and 900 °C reduces TCLE more considerably.

This decrease averages are more than 6 % in all temperature interval of tests (to 450 °C). At that, annealing at 800 and 900 °C reduces most considerably the average value of TCLE in the field of low temperatures of 50-100 and 50-200 °C. So, this reduction makes 8 and 12 % after annealing at 800 °C, and 12 % respectively after annealing at 900 °C – 7 in comparison with thermally raw steel samples.

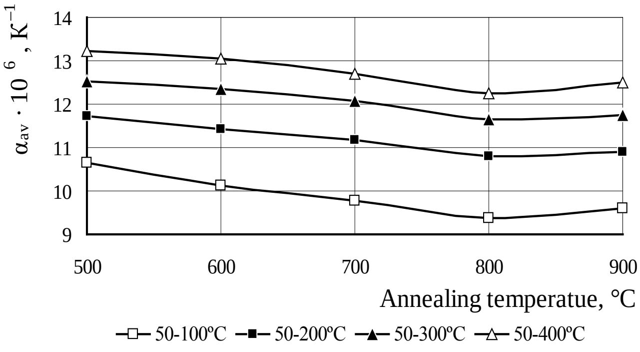

Fig. 4 *– Influence of annealing temperature on average TCLE in various intervals of test temperatures of the sheet hot-rolled steel 10 made with use of DTCT*

4. Conclusions

1. The use of thermal-cyclic forging for the production of sheet steel 10 (thickness of 3 mm) increases the size of its coercive force no more than by 8 % in comparison with the industrial mode and has no significant influence on its thermal expansion.

2. The subsequent high-temperature annealing (900 °C) during 10 h of the sheet steel 10 made with use of thermal-cyclic forging allows to reduce its coercive force by almost 3 times in comparison with stock material.

3. The most considerable decrease in TCLE for the steel 10 produced with use of DTCT is observed at the subsequent high-temperature annealing (800 and 900 °C) on average more than by 6 % in an interval up to 450 °C and average coefficient in low-temperature area (up to 100 and 200 °C) by 7-12 %.

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