# TECHNICAL SCIENCES

## THERMAL TREATMENT OF LOW-CARBON THIN-SHEET COLD-ROLLED STEEL BLANKS TO IMPROVE TECHNOLOGICAL PLASTICITY, PREVENTING THE POSSIBILITY OF DEFORMATION AGING AND REDUCING DEFECTS IN THE MANUFACTURE OF PRODUCTS

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**Abstract**

Temperature and time parameters have been developed for high-speed recrystallisation annealing and subsequent ageing of thin-gauge cold-rolled steel 08 kp to achieve increased technological plasticity while maintaining strength and preventing natural ageing in order to reduce the number of rejects in blanks intended for cold deep drawing.

**Keywords:** thin cold-rolled steel 08kp, rapid heating and cooling, recrystallization annealing, overaging, strength, technological plasticity, aging, cold stamping

**State of the problem.**One of the most sought-after types of metal products in manufacturing is cold-rolled thin sheet metal, which is widely used in all sectors of the economy [1,2]. Due to the increasing complexity of product design and operating conditions, as well as the expansion of consumption in various important sectors of modern industry, it is very important to meet the needs of machine builders for cold-rolled thin sheet metal with increased technological plasticity and deep drawing capability, while maintaining its sufficient strength. At the same time, it is necessary to achieve an increase in labor productivity, a reduction in metal consumption, and savings in electricity and natural gas, which is very important in our time.

Cold-rolled thin sheet (0.5-0.8 mm thick) low-carbon steel grades 08kp, 08ps (the equivalent in is steel 1008 or 1010 according to the American standard AISI (ASTM) is an important structural material widely used in various fields of machine building, household appliances, building structures, etc. Parts made from this sheet metal are manufactured with minimal energy consumption due to significant cold plastic deformation with very deep drawing (category VG).

The ability of cold-rolled steel to deform well in a cold state is determined by the structure formed as a result of stress-relieving heat treatment of rolled products, the purpose of which is to reduce the yield strength and significantly increase the plastic properties –relative elongation with a sheet thickness of 0.5 to 1.5 mm is not less than 28%. [2,3]. For boiling steels, the best plasticity, and therefore stampability, is achieved with an equilibrium ferrite structure with a grain size of 6 to 8 points [4-6]. A high-quality smooth sheet surface is achieved with a uniform ferrite grain size of no more than 7 points [7]. Large grains lead to very rough surface roughness and product breakage after deep stamping. Eliminating this defect requires complex surface treatment operations on finished stamped products. The uniformity of grain size is also very important for successful deep and complex stamping. Mixed grains of varying sizes lead to uneven deformation and defects due to cracks [8].

To achieve high-quality cold forming processes, especially for complex shapes, the structure and properties of cold-rolled steel at metallurgical plants are most often achieved by prolonged recrystallization annealing of densely packed metal coils in batch-type bell-type furnaces [4,6,9]. The purpose of annealing is to reduce the yield strength and increase the ductility of the metal. According to [10], the recrystallization annealing temperature is set depending on the steel grade in the range from 680 to 740 ºC (below the critical point AC1). A homogeneous structure with equiaxed grains of 7-8 points is formed in the metal, which, according to [6, 9], ensures the best cold plastic deformation capacity of steel in the manufacture of products. With an increase in the annealing temperature, the plastic properties increase, but the strength characteristics decrease.However, annealing steel in bell-type furnaces has a number of specific disadvantages: uneven heating of steel sheet coils and heterogeneity of structure and properties along the length and width of the sheet, unsatisfactory surface quality [11,12], and a very long and energy-intensive process [4,6]. In addition, annealed steel undergoes natural aging after a certain period of aging. All these factors deteriorate the quality of steel and its ability to be deformed without defects during the manufacture of products by cold pressure processing methods.

High-speed continuous heat treatment in continuous mills is an effective and productive technology that combines recrystallization annealing and aging in a single process to soften cold-rolled steel, ensure stability of properties, and prevent natural aging. The main and undeniable advantage of high-speed processing is the irreversible reduction in time—from several days to several tens of minutes [13-14]. At the same time, significant temperature differences are eliminated, which allows for a uniform structure and properties of the sheet in the roll, as well as better shape and surface quality. The short processing time provides a significant increase in productivity. However, continuous high-speed annealing has its own requirements: each steel grade requires a certain thickness of rolled stock and degree of preliminary deformation, the use of low-carbon steels (0.05-0.06% C) that are well purified of harmful elements of penetration, which will be less susceptible to deformation aging after accelerated heating and cooling during annealing [14 -16]. All this requires additional technological operations and significant financial costs.

It should also be noted that enterprises that consume sheet products do not have effective methods for improving the quality of finished sheets (blanks) to correct and reduce defects. In this regard, the development of new methods for improving the quality of thin-gauge rolled steel 08kp, as well as the reprocessing of finished sheets (blanks) in order to increase technological plasticity while simultaneously increasing strength and preventing aging, is a pressing issue and has unconditional practical significance.

**Material and methods of research**. The study used cold-rolled 08 kp steel sheet with a thickness of 0.6 mm. In its initial state after rolling with 60% reduction, the steel had a textured structure with an average ferrite grain size of 60-70 μm and the following properties: $\sigma_B$ = 810 MPa, $\sigma_{0.2}$ = 640 MPa, δ ~ 2%.

Cold-rolled sheets were subjected to high-speed recrystallisation annealing at temperatures in the range of 680 -720 °C with a holding time of 5, 10 and 15 seconds. The sheet in a roll was heated on a heat exchanger drum unit, and the sheet blanks were processed on a heat exchanger flat plate unit. The sheet from the roll enters the furnace, where it successively wraps around two heated drums and is annealed as a result of contact with their surfaces. The blanks are annealed upon contact with the heated plates. Upon exiting the furnace, the sheet metal is cooled on water-cooled rollers. The heating and cooling rates were 100 and 80 °C/s, respectively.

After recrystallisation annealing, the steel was subjected to ageing at a temperature of 400 °C with a holding time of 5 seconds to 2 minutes. The natural ageing of the steel during its storage after heat treatment lasted 30 days.The effectiveness of annealing and overaging was evaluated based on the microstructure of the steel and its mechanical properties both immediately after heat treatment and after natural ageing.

The mechanical properties were determined by tensile testing using a standard method. The drawability of the steel was evaluated on 50 × 50 × 0.5 mm samples based on the results of tests using the Erichsen method.

Grain size and size distribution were evaluated using a special computer program.

**Results and discussions**. The size of the recrystallized grain of cold-worked metal depends on the heating temperature and the holding time, due to which the recrystallization processes are completed. The heating rate also has an effect: the lower it is, the larger the grain in the steel will be and the worse its properties will be. High-speed recrystallisation annealing at 680 °C with a holding time of 5 seconds completely eliminates the texture of deformed steel, but the ferrite grain remains large – average size 50–45 microns (5 on the grain size assessment scale) (Fig. 1, a). After a 10-second hold, small grains appear alongside grains measuring 30–35 μm, which is a result of the onset of recrystallisation processes (Fig. 1, b). When the hold time is increased to 15 seconds, a noticeable grain refinement to 23 μm is observed. However, grain size variability persists, with grains up to 10-12 μm in size being recorded (Fig. 1, c). Mixed grains of varying sizes lead to uneven deformation and defects due to breaks.

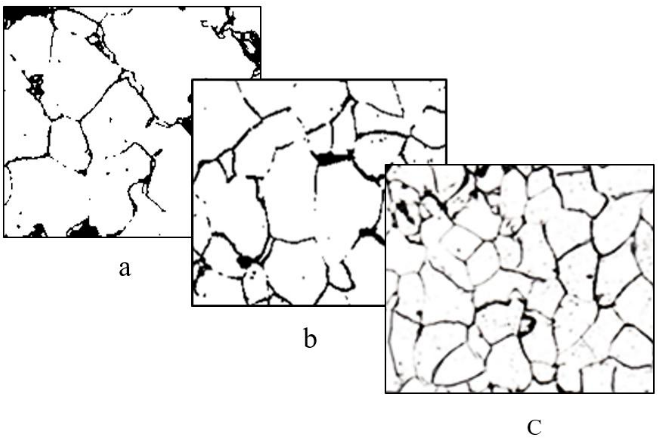


*Figure 1. Microstructure of 08kp steel after rapid annealing at 680 °C with holding times: a – 5 s ; b – 10 s; c – 15 s; ×500*

Annealing at a temperature of 700 °C with a holding time of 15 seconds ensures the formation of a structure with fairly uniform grains of a predominant size of 18-20 μm, which corresponds to number 8 of the evaluation scale (Fig. 2, a).When the temperature is increased to 720 °C and a holding time of 15 seconds, most of the grains have a size of 12-13 μm (number 10) (Fig. 2, b). It should be noted that such small ferrite grains contribute to the strengthening of the steel and complicate its processing by pressure methods in the cold state.

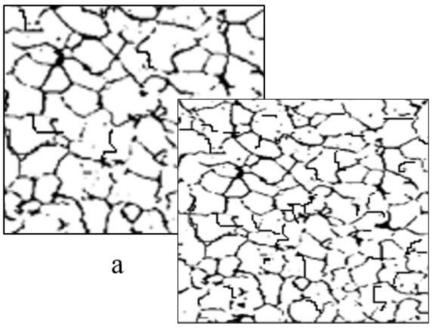


*Figure 2 – Microstructure of 08kp steel after rapid annealing at 700 °C with holding time: a –15 s ; b –after annealing at 720 °C with holding time 15 s; ×500*

Changes in the structure at different annealing temperatures with different holding times affected the mechanical properties of the steel, which, according to microstructural studies, indicate that the best mode of steel weakening is recrystallization annealing at 700 °C with a holding time of 15 s (Table 1). The obtained mechanical characteristics correspond to the category of very deep drawing for 08kp steel, which is achieved by long-term and low-performance recrystallization annealing in hood furnaces. Increasing the annealing temperature is not advisable both from the point of view of strength and technological plasticity of the steel.

Table 1.

Mechanical properties of cold-rolled steel after different recrystallization annealing regimes

| Annealing temperature, ºC | Exposure time, sec | $\sigma_в$, MPa | $\sigma_{0.2}$, MPa | δ, % |
|---|---|---|---|---|
| 680 | 15 | 363 | 310 | 27 |
| 700 | 15 | 350 | 293 | 30 |
| 720 | 15 | 370 | 320 | 28 |

However, sometimes during storage or transportation of a steel sheet to the consumer, its natural aging occurs - the relative elongation δ significantly decreases (from 30 to 15%), and the strength indicators, especially the yield strength, increase (from 293 to 340 MPa), which is explained by the release of excess brittle phases from the supersaturated metastable ferrite solution, which was formed as a result of high-speed recrystallization annealing. The consequence of deformation aging of steel is a deterioration in its ability to deform in the cold state during the formation of products, which will lead to the impossibility of obtaining high-quality products and a significant number of defective blanks

To prevent the ageing effect, the steel was subjected to overaging after recrystallisation annealing under optimal conditions. Studies have shown that after overaging at 400 °C with a holding time of 2 minutes, plasticity increases (δ = 31.7%) while maintaining sufficiently high strength. The mechanical properties of steel remained almost unchanged over the course of a month (Fig. 3). Such stabilisation of mechanical properties over time, when structure formation processes proceed slowly, can be explained by the complete purification of the solid solution (ferrite) from excess carbon and harmful impurities and the achievement of a balanced structural state.

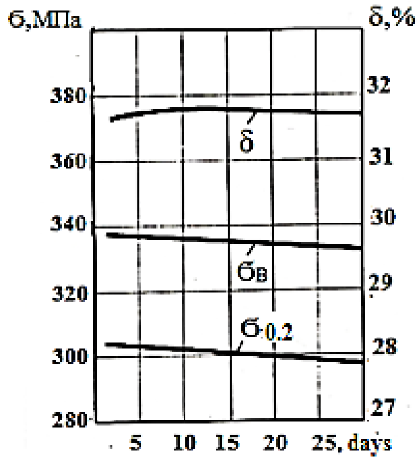


*Figure 3 – Mechanical properties of 08 kp steel after annealing (700 °C, 15 s), over-aging (400 °C, 2 min) and natural aging for one month.*

Considering that most parts made of thin-gauge cold-rolled steels are manufactured by cold stamping from drawn steel, the metal's ability to deform cannot be accurately assessed by strength and ductility indicators, which are determined by uniaxial tensile tests, while during stamping, the metal is subjected to biaxial tensile stress. Therefore, special technological tests are used to assess the stamping ability, when the same conditions are created as in the part manufacturing process. The simplest and most widespread method is the spherical indentation method, known as the Ericksen method, in which the diameter of the indentation is used to determine the metal's ability to be drawn during cold stamping of parts (Table 2).

The data in Table 2 and Fig. 4 show that high-speed two-stage heat treatment of sheet steel 0.8 kp with a thickness of 0.6 mm ensures high-quality formation of a hole with a depth of 10.1 mm, which corresponds to the OSV category - the ability of steel to particularly difficult drawing, and is usually guaranteed for higher-quality steel of the 08Yu brand (S235JR according to EN 10025-2).

Table 2.

Eriksen test results

| Annealing temperature, °C, holding time 15 s, over-aging | Hole depth without cracks, mm |
|---|---|
| 680 | 9,3 |
| **700** | **10,1** |

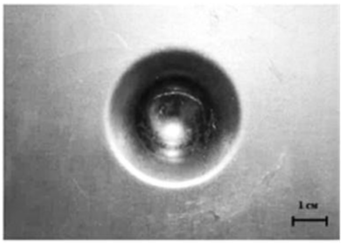


*Figure 4 – Eriksen test result of a sheet that underwent two heat treatments (annealing at 700 °C, 15 s and over-aging at 400 °C, 2 min)*

**Conclusions.**

High-speed (V = 100 °C /s) recrystallization annealing at 700 °C with a holding time of 15 s provides cold-rolled sheet steel 08 kp with a thickness of 0.6 mm with the best set of properties corresponding to the VG category, i.e. the ability of steel to cold deformation with very deep drawing.

Further natural deformation aging for a month of high-speed annealed steel 08 kp leads to a sharp drop in plasticity (δ almost 2 times) and an increase in strength

Two-stage high-speed heat treatment, consisting of recrystallization annealing in the optimal mode and subsequent aging at 400 °C for 2 minutes, provides cold-rolled steel 08kp with the OSV category - the ability to particularly difficult drawing and eliminates its deformation aging over time.

Continuous high-speed two-stage heat treatment with contact heating and cooling should be effectively used to increase technological plasticity without loss of strength of blanks from an already finished sheet and to reduce defects when forming products by cold deformation methods. To improve the deformation of blanks, bell furnaces and continuous annealing installations for rolled sheet are not suitable.

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