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COOLING MODES INFLUENCE ON QUALITY OF HOT-ROLLED METAL AT TRANSPORTATION OF SHEETS ON THE NEW COLLECTING ROLE TABLE

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ABSTRACT

The effect of cooling modes on quality of hot-rolled metal was observed heating at different temperature, the degree of deformation was observed after cooling by water-air mixture. It was observed that the microhardness of the samples decreases and the amount of structurally free ferrite increases by decreasing the cooling time and increasing the temperature.

Key words: Cooling modes, Hot-rolled metal, Microhardness, Ferrite, Pearlite.

INTRODUCTION

Within a market economy, upgrading of the quality of production output, in the case of the research is a sheet metal, to the level of international standards, especially using newer machines and advanced technology, is one of the most important scientific and practical problems.

Nowadays, there are several ways of improving mechanical and operational properties. It includes alloying, heat treatment, controlled rolling and accelerated cooling[1]. The most perspective way in the development of production technology of high-strength steels is controlled rolling followed by accelerated controlled cooling (ACC). The cooling is carried out from the rolling heating by providing the heat by the cool condition (water) supplied on the hot surface of roll. Moreover, the way and the speed of providing water on the metal influences on the final rolls significantly. In order to make the competitive products, most modern sheet mills (SM) are set up with the installations of controlled cooling, which is located in the mill line over the rolling stand[2,3].

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Technical and economic validity of using ACC on SM is given by the following achievable advantages[1]:

- Improving the quality and consumer properties of the product;
- Reducing production costs by reducing the contents of expensive alloying elements and also by eliminating the need for further heat treatment;
- Increasing productivity of the mill;
- Expansion of assortment.

The existing installations of controlled cooling can be classified by several features[4].

By the scheme of transferring the cooling sheet[4]:

- Simultaneous cooling in which water is supplied to the entire surface of the roll. This causes the problem of limiting the length of roll due to the limited length of the cooling zone setting;
- Sequential cooling in which the strip is uniformly and consistently moves through a cooling zone.

As a method of supplying water to the surface of an accelerated cooling of the existing installation can be divided into the cooling devices[2-4]: laminar jets; water jets from nozzles; water pad; air-water mixture; water curtain.

The implemented modes can be divided into 3 main types:

- Accelerated Controlled Cooling (ACC)
- Direct Quench (DQ)
- Direct Quench and Self Tempering (DQST)

The ACC mode can be divided into soft and hard (HACC) accelerated cooling[1,5]. Soft accelerated cooling is carried out at a rate from 10-20°C/s to 450-550°C (above the temperature of martensitic transformation). Rigid accelerated cooling occurs at a rate from 20-50°C/s to 200-450°C. In these modes, the milling grains of ferrite, pearlite, bainite and acicular ferrite occurs, which in turn, provides a set of properties of strength class of X80.

Direct quenching DQ performed with the high cooling rates (above 50°C/s) and the subsequent tempering to a room temperature[1,5], followed by quenching mode autotempered

DQST performed with a high intensity heat removal from the surface of the sheet. This cooling rate exceeds 50°C/s. The water is supplied till the moment, when the surface temperature will not fall below the martensitic transformation temperature, whereupon autotempering occurs due to the inner layers in heat of the metal in order to relieve internal strain. Obtained with the martensitic or bainitic-martensitic structure provides a range of mechanical properties of the corresponding strength class X100-X120.

It should be noted that the most significant development of ACC was received in Japan[1,6]. NKK Corporation, a Japanese steel manufacture, has developed and put into operation a system of OLAC (On-Line Acceterated Cooling) for the production of ship building steel. Most of the mills in Japan, the US and Europe were equipped with such attitudes, which in turn influenced the creation of a variety of new systems and structures. At this point, these are the most common systems[1,6]:

- ADCO (Adjust Cooling);
- ACP (Accelerated Cooling Process);
- CWC (Curtain Water Cooling);
- DAC (Dynamic Accelerated Cooling);
- ICS (Intense Cooling System);
- OLAC (On-Line Accelerated Cooling) – accelerated cooling in the flow of mill (further development of the system – Super OLAC);
- KLC (Kobe steel's Accelerated Cooling)
- MACS (Multipurpose Accelerated Cooling System)
- MACOS (Mannesmann Accelerated Cooling System)
- HDTLFS (High Density Tube Laminar Flow Cooling)
- WPC (Water Pillow Cooling).

Every performed system has its own unique construction and series of technological characteristics as the method of providing water on the surface, the operating pressure and flow rate, the geometrical dimensions of the cooling zone, the distance from the cage, the equipment for screening the presence of the strip edges, etc.[1] For instance, the velocity of cooling realized by the system MULPIC for the sheet thickness of 10 mm is about 80°C/s, while the OLAC system has only 8-25°C/s. The speed range cooling for a KLC system at the strip thickness of 20 mm is 3-25°C/s and the system MACOS at the same thickness can be realized in a narrower range – 8-20°C/s. This kind of characteristics influence on the technological parameters of the realized processes as the velocity. The choice of an ACC system, first of all, must be produced by taking into account the range of products required mechanical and performance properties. It is also possible to combine multiple systems in a single line mill to increase production efficiency[4,5].

The evaluation of the producing ways of the hot rolled strip and sheet shows, that in producing of the sheet- shops commonly used methods of controlled cooling of moving hot-rolled steel strip, which are based on the water supply nozzle to the upper and lower surfaces of the strip[7,8]. It can be noted that the area of the torch nozzle, through which the refrigerant (water) is fed on the surface of the ingot, depends on the pressure or flow rate of refrigerant. It is a reason of instability of mechanical properties of finished steel strips because of low managing process of heat removal from the cooled object. Moreover, the usage of traditional method leads to significant pollution of agent (water), labour zone with steam, dust and scale, which causes unsteady performance of the managed object and control of automation. In the system of forcing cooling can be several hundreds of nozzles, some of which are periodically crashes. So, the system itself is the main reason of violation of the uniformity of metal cooling.

Mentioned flaws of forcing cooling of metal do not lead to the high quality of roll needed for using the production, for example, for production of large diameter pipes.

So, increasing market competitiveness of rolled metal makes manufacturers to increase the quality and consumer properties of its production, preventing the growth of prices. Increasing quality and consumer properties of production can be achieved by development of manufacturing equipment and experiencing new technologies[5,6]. The development of the system of accelerated controlled cooling is a perspective way in development of technical and economic indexes of the sheet mills. The main problems of ACC systems are:

- Ensuring uniform cooling of the plate thickness by selecting an optimum relationship between flow rate and volume of water from the top and bottom of the sheet;
- Providing the possibility of differentiated cooling of different parts of the sheet (head and the end portion edge) by use of screens and nozzles individually controlled reservoir volume and the rate of supply water;
- Expansion of product mix by increasing the range of cooling rates;
- Improving the accuracy of temperature control in the cooling process through the use of advanced automated systems;

- Reduction of energy and material costs of equipment to reduce production costs;
- Ensuring flatness under intensive cooling;
- Development of a consensus makes the new design ensures collecting roller table reduce wear collecting roller table.

The analysis of the numerous literatures[9] shows that the approaches to the development of collecting roller tables have no opportunities for a sharp increase in its efficiency. In our opinion, improving of the movement of hot-rolled strip can be achieved with using the roller tables with new design, using the principle of air cushion in the rolling mill.

The aim of the study is the influence of austenitizing mode, hot deformation and subsequent water-air cooling at a new collecting roller table on the structure and properties of carbon steel sheets.

Equipment, materials and experimental procedure

In order to increase the quality of the sheet metal and reduce wear rollers of collecting roller table, we have produced the collecting roller table with the new construction[10]. This collecting roller table of a broad band mill contains a continuous series of sections with hollow rollers and individual drives. Each roller is provided with a pinion cage, individual fan, wherein the fan case is made with a blade angle of attack of 35-40 degrees, and blades - with varying cross-section and angle of attack of 10-12 degrees (Fig. 1, where *1*-motor; *2*-cage; *3*-high pressure fan, *4*-hollow roller; *5*-spindle; *6*-bearing assembly).

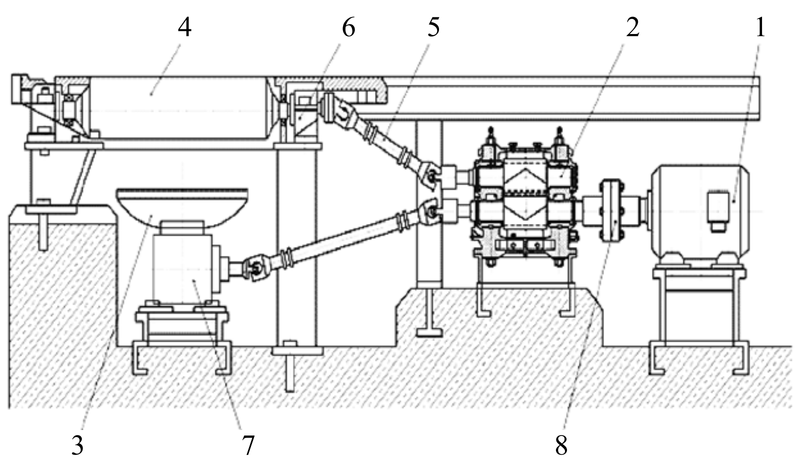

Fig. 1: The collecting roller table with the new construction

The transportation of hot-rolled strips is carried out in the following way – The transformer provides a continuous or variable current to an electric motor (i). Electric motor rotates shafts of pinion stand (ii), whereas shafts of pinion stand rotate hollow cage rollers 5, as well as fan blades (iii). Rotating fan blades suck up the air and direct the air with a lot of pressure on the transported strip.

All of it leads to:

(i) Up the sheet metal in the vertical direction;

(ii) Decreasing of friction between the strips and the rollers,

(iii) The movement of the strip from the last mill stand to coiler.

Under the condition, that fan housing attack is at the angle of 35-40° and blades are at the angle of 10-12°, it provides the greatest lift forces on the band, so that the air resistance will be minimal. With less than 35° angle of fan case attack and less than 10° angle of blades, the lifting forces, acting on the band, will be the smallest. Whereas at 40° angle of fan case attack and more than 12° angle of blades, the air resistance forces increase and therefore lifting force, acting on the strip, decreases. Cooling of the hot rolled strips is done by heat elimination of the cooling means (water-air mixture), supplied to the surface of the hot peal, from the rolling heat in the outlet table.

Here, the effect of air-water mixture cooling was investigated on the structure and properties of rolled sheets of steel 60S2HA having the following chemical composition, %: C 0.64; Si 1,6; Mn 0,6; Ni 0,23; S 0,21; P 0,025; Cu 0,2; Cr 0,8.

To investigate the austenitizing, the samples of 25 ± 2 *mm* were taken and subjected to a heating temperature of 800-1050^{o}C in increments of 50°C and exposure of 1 min/mm of cross section followed by quenching gradient (the method is normalized by GOST 5639). The experiment was conducted using the laboratory oven SNOL-1,6.2,5.1/11. To identify the size of the austenite grin, a special reagent was used. The special reagent comprises: 1-4 g of picric acid, 3-5 mL of hydrochloric acid, and 95-100 mL of ethyl alcohol. Austenite grain size was calculated using an eye piece with a ruler on the microscope MIM-7 with an increase of 100.

To determine the effect of the deformation degree and subsequent water-air cooling at a new collecting roller table on the structure of the steel 60S2HA, the samples of the size Ø10,0 × 15,0 mm were experienced by compression on the test complex Gleeble-3800. Complex features Gleeble presented on sites www.gleeble.com and http://tmslab.spbstu.ru.

The plastic deformation of the steel samples 60S2HA was performed on the module "tension-compression". Heating of the samples was conducted at 100°C/s to a temperature of 850, 1050°C and held at this temperature for 1 hr. Next, each heated sample after heating or cooling to the temperature of 700, 800, 900 and 1000°C was deformed with compression and cooled within 3 and 6 *s* with blowing air and water wrapping. Subsequently, the samples were cooled naturally to a room temperature.

Thin sections were prepared for metallographic examination by the traditional method of grinding and polishing on the circles. Etching of the samples was done by using a solution of nitric acid in ethanol. After physical modeling, cooling on a new construction of collecting roller table on the processed samples was performed quantitative analysis of the final microstructures with a universal microscope NEOPHOT 32 (Karl Zeiss, Jena) (Germany).

On the deformed and by the water-air mixture cooled samples, the microhardness was measured on the PMT-3 with a load of 1N.

RESULTS AND DISCUSSION

The dependence of the grain size on the austenitizing temperature is shown in Fig. 2. By increasing austenitizing temperature, the average grain size of austenite increases as well. Till the temperature of 850°C, austenite grain size increases in the small sizes, and equals to 12,95 μm.

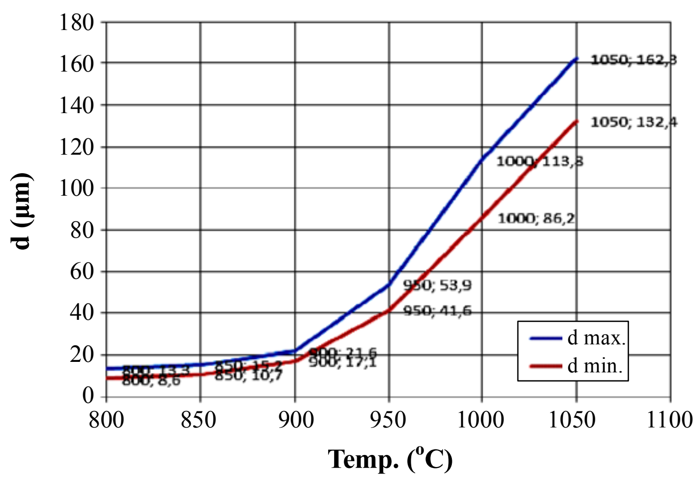

Fig. 2: The dependence of the grain size d (*mm*) from the austenitizing temperature (°C) at a specific shutter speed 1 *min*/*mm* of cross section

Figure 3 shows changes in the laws of deformation resistance of σ depending on the compression unit ε. From the analysis and comparison of curves hardening of steel 60S2HA, shown in this figure, it implies that the deformation resistance of steel 60S2HA at temperatures of 700, 800, 900 and 1000°C for all the tested deformation degree values increases at the initial moment of deformation and then deforms at a constant voltage. It occurs due to the fact that during the hot plastic deformation in the metal sample, there are two processes-hardening and softening passing through the dynamic processes of polygonization and recrystallization. The ratio between them as a formation of the structure depends on such parameters as temperature, degree and rate of deformation. In our opinion, a significant influence on the received curves of deformation resistance causes the dynamic softening processes and thermal deformation effect mentioned above.

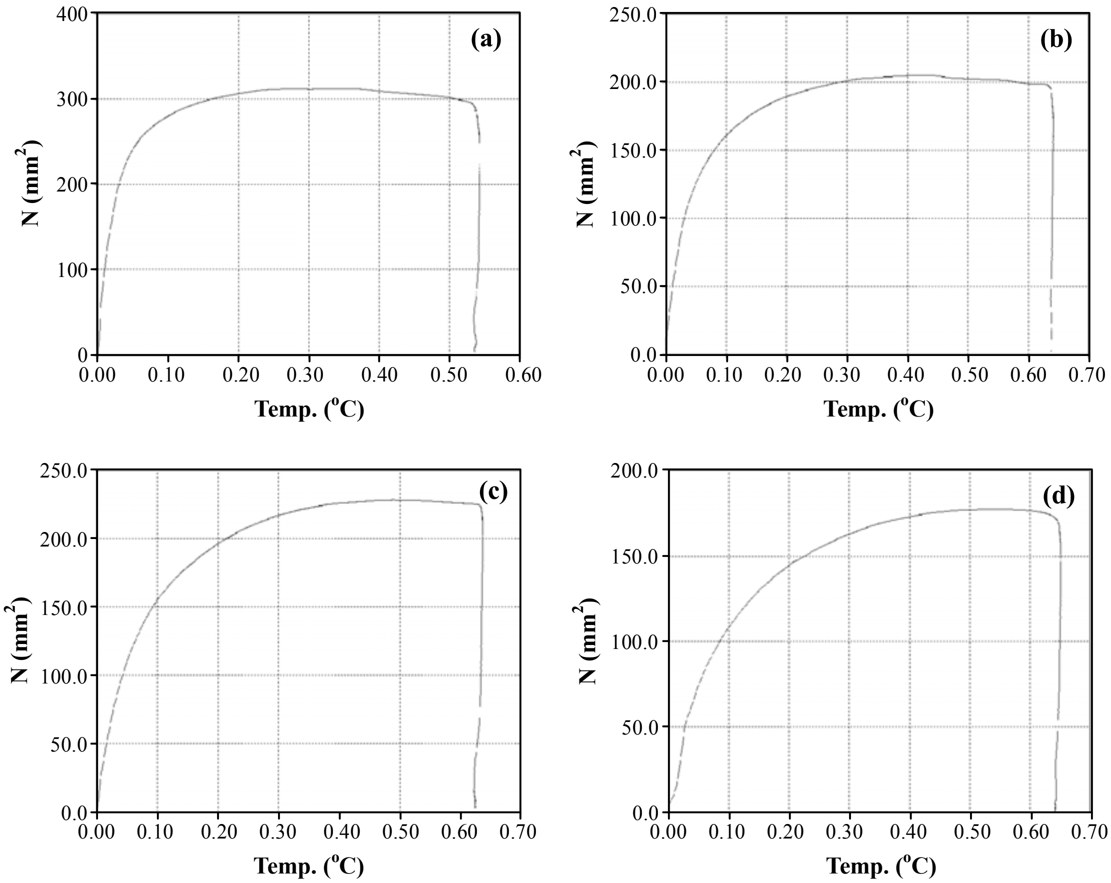

Fig. 3: The resistance of deformation change of steel 60S2HA at charging temperature of 700°C (*a*), 800°C (*b*), 900°C (*c*) and 1000°C (*d*)

The results showed that the deformation at a temperature of 1000°C and cooling water-air mixture for 3 and 6 *s* causes fully recrystallized ferrite-sorbitol structures in a fine grain austenitic structure. (Fig. 4*a* and 4*b*). The deformation at a temperature of 900°C and during cooling at 3 and 6 *s*, reduces the degree of recrystallization, respectively till 15% and 30% (Fig. 4*c* and 4*d*). In this case, the consertal structure is formed in the blank, which is associated with the advent of large recrystallized grains in the fine structure. In case of precipitation at temperatures of 700 and 800°C and cooling for 3 and 6 *s*, structure of the metal is not recrystallized (Fig. 5 *a, b, c, d*). The structure of the metal consists of blanks of ferrite-sorbitol colonies in a distorted radially stretched form.

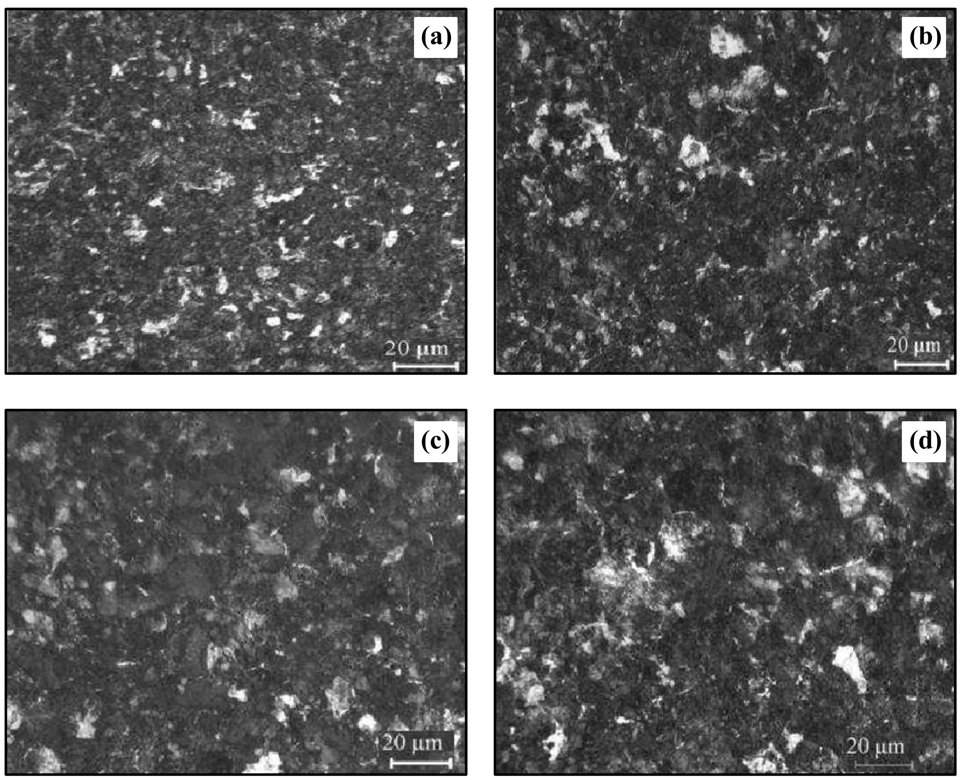

Fig. 4: Microstructure of steel 60S2HA after austenitizing at a temperature of 850°C with an exposure of 1 hour and a subsequent hot deformation at temperatures of 900 to 1000°C and cooling during 3 and 6 s

(a) The precipitate at a temperature of 900°C and cooling 3 s; (b) The precipitate at a temperature of 900°C and cooling 6 s; (c) The precipitate at a temperature of 1000°C and cooling 3s; (d) The precipitate at a temperature of 1000°C and cooling 6 s.

The study shows that the hot deformation at different temperatures during subsequent cooling leads to a change of dispersion of perlite. The increase of degree of deformation in the range of 60-65% leads to a decrease in the values of interlamellar distance by forming finer ferrite grains and the austenite-sorbitol colony. The interlamellar distance measurement shows that heating the samples to a temperature of 700°C, with a degree of hot deformation of 55-65%, and cooling for 3 and 6 *s* causes the formation of thin plate pearlite in fine-grained austenitic structure with interlamellar spacing of the orders of 1.32-1.36 and 1.12-1.23 μm, respectively (Fig. 6). Thus, the degree of hot deformation of the samples of 55-65% at a temperature of 800°C and subsequent cooling for 3 and 6 *s*, leads to the formation of fine-grained austenitic structure with thin plate pearlite with interlamellar spacing of the order of 0.92-0.96 and 0.74-0.82 μm, respectively (Fig. 6).

Austenitization at a temperature of 850°C, heating to a temperature of 900 and 1000°C with subsequent deformation with a degree of 65% and cooling by water-air mixture 3 *s* results in gaining a structure with high carbon steel sorbitol with interlamellar distance on the order of 0.45-0.51 and 0 37-0.41 μm, respectively. By increasing the holding time of up to 6 *s*, the interlamellar distance decreases to 0.22-0.28 at a temperature of 900°C and 0.14-0.18 μm at a temperature of 1000°C (Fig. 6).

It can be noted that the small average size of the grain of initial austenite forms a fine-grained sorbitic ferrite structure after the behavior of ferritic transformation and leads to size reduction sorbitic colony formed because of pearlite reaction. When there is 0.64 of carbon in the steel, in most cases, the ferrite precipitates not in the form of individual grains, but beans around sorbid and observed on the thin section as ferrite grid.

The measurement of the interlamellar distance of sorbitic ferrite colony showed that heating for austenitizing at 1050^{o}C, and further sediment with the degree of 55-65% at the temperature of 700, 800^{o}C, then cooling by water-air mixture with the time of 3 *s* lead to formation of microstructure with interlamellar distance of 1,83-1,89 μm and 1,56-1,64 μm, respectively (Fig. 6*b*). So that the structure is of coarsely lamellar pearlite. By increasing of the exposure time till 6 *s* the interlamellar distance decreases till 1,36-1,44 μm and 1,24-0,31 μm, respectively (Fig. 6*b*). Whereas the size and quantity of pearlite colonies increase. The austenitization at the temperature of 1050^{o}C, by heating to the temperature of 900 and 1000^{o}C with the further degree of deformation of 55-65% and cooling by water-air mixture for 3 *s* leads to receiving in the structure of high carbon sorbitol steel with interlamellar distance of order of 0,67-0,72 μm and 0,57-0,62 μm, respectively. By increasing the time of exposure till 6 *s*, the interlamellar distance decreases till 0,57-0,61 μm at the temperature of 900^{o}C and till 0,31-0,37 μm at the temperature of 1000^{o}C (Fig. 6*b*).

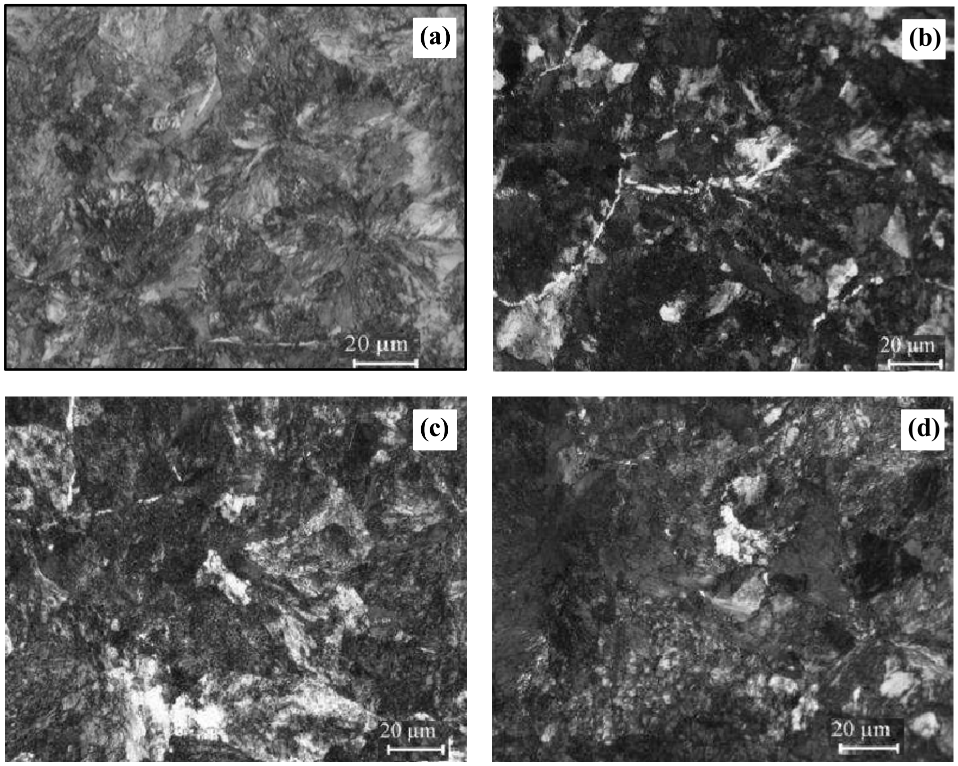

Fig. 5: Microstructure of steel 60S2HA after austenitizing at 850°C with an exposure for 1 hr and a subsequent hot deformation at the temperatures of 700 and 800°C and cooling during 3 and 6 s

(a) The precipitate at a temperature of 700°C and cooling 3 s; (b) The precipitate at a temperature of 700°C and cooling 6 s; (c) The precipitate at a temperature of 800°C and cooling 3 s; (d) The precipitate at a temperature of 800°C and cooling 6 s.

The results of hardness showed that hot deformation at the different temperatures on the condition of further cooling by water-air mixture causes the changing of microhardness of perlite. Increasing the degree of deformation in the levels of 60-65% leads to increasing the values of microhardness as a result of pulling of ferrite-sorbitol colonies or the formation of the finer grain.

The average microhardness of the fine-grained samples, precipitated at 700 and 800°C and cooled by water-air mixture during 3 *s*, is 3658 MPa (3364 MPa – in the centre and 3823 MPa – on the surface) and 3593 MPa (3294 MPa – in the centre and 3976 MPa – on the surface). Whereas the average microhardness of the fine-grained samples, precipitated at 700 and 800°C and cooled by water-air mixture during 6 *s*, is 3805 MPa (3618 MPa – in the centre and 3992 MPa – on the surface) and 3735 MPa (3417 MPa – in the centre and 3942 MPa – on the surface), respectively. By contrast microhardness of the samples, precipitated at 900 и 1000°C and cooled by water-air mixture during 3 *s*, is 3319 MPa (3246 MPa – in the centre and 3393 MPa – on the surface) and 3078 MPa (2932 MPa – in the centre and 3224 MPa – on the surface). In case of cooling samples during 6 *s* is 3416 MPa (3141 MPa – in the centre and 3691 MPa – on the surface), respectively and 3287 MPa (2958 MPa – in the centre and 3617 MPa – on the surface), respectively.

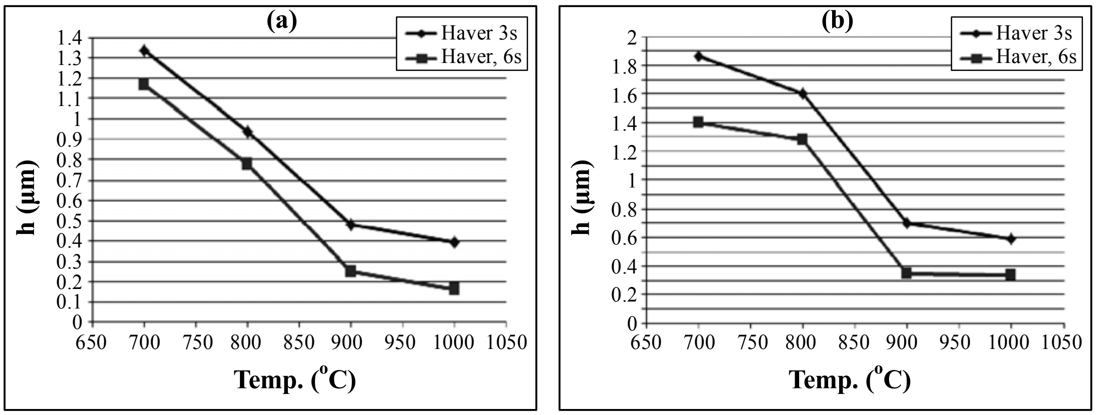

Fig. 6: Interlamellar distance variation of ferrite-sorbitic colonies at the moment of heating for austenitization at 850°C (*a*) and 1050°C (*b*) with a degree of sediment equal to 55-65% and cooled by water-air mixture

The values of microhardness confirm the fact that with decreasing sediment temperature and increasing the time of water-air cooling the microhardness increases. The data prove that there is a little difference in the hardness of the samples in the longitudinal and transverse directions, so there are no large scatter of the properties when a water-air mixture method for cooling is used.

CONCLUSION

(i) Heating until 700-800°C and deformation by the degree of deformation of 65-70%, and further cooling by water-air mixture during 3 and 6 *s* does not always form a fine-grained ferrite-sorbitol structure in the high-carbon samples.

(ii) Heating till 1000°C, the deformation with the degree of deformation of 65-70%, and cooling by water-air mixture upon 3 and 6 *s*, leads to formation of fine-grained ferrite structure in the samples of studied diameter and chemical composition.

(iii) By decreasing the cooling time and increasing the test temperature, the microhardnessof the samples decreases, and the amount of structurally free ferrite increases.

(iv) Heating of the samples to temperatures of 900 and 1000°C, with a degree of deformation of 65-70%, and cooling by water-air mixture for 3 and 6 *s,* results in the formation of sorbitol structures in the samples, made from high carbon steel with interlamellar distance of 0.23-0.62 µm. With increasing cooling time, interlamellar distance decreases, and the size of pearlite colonies increases.

(v) At high temperatures of deformation along with the dynamic recovery, the dynamic recrystallization occurs. Grains, occurred during the dynamic recrystallization, in the process of growth subjected to strain, and the substructure forms in them. The dislocation density increases to a critical value, followed by recrystallization of a new cycle. In dynamic recrystallization, the austenite grain size decreases.

(vi) Repeated recrystallization leads to an effective grain austenite refinement. Small average size of austenite grain provides formation of a fine-grained sorbitic ferrite structure after behavior of ferrite transformation and leads to a reduction of pearlite colony size, as a result of pearlite reaction.

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