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STRUCTURE FORMATION IN STRIP STEEL BY THERMAL STRENGTHENING

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The results of research of microstructure of the strips from low carbon steel 45x6 and 30x8 mm in hot-rolling condition and after accelerated cooling of different intensity and schemes of the coolers movement in the cooling chambers are shown. A defind a temperature interval of phase transformations is in the cross-sections area of strips starting from axis of symmetry towards the edges.

Key words: *thermal strengthening, steel, martensite, bainite*

Stvaranje struktura u čeličnoj traci toplinskim očvršćivanjem. Prikazani su rezultati istraživanja mikrostrukture traka niskougljičnog čelika 45x6 i 30x8 mm u toplom stanju i nakon ubrzanog hlađenja različitog intenziteta i različitih shema kretanja rashladnog sredstva u rashladnoj komori. U točkama presjeka trake definiran je interval faze transformacija počevši od osi simetrije do rubova.

Ključne riječi: *toplinsko očvršćivanje, čelik, martenzit, bainit*

INTRODUCTION

The properties of rolled steel after the thermal strengthening are defined by the condition of its structure. It has been shown in many researches that at rolled wire and reinforced steel cooling a heterogeneous structure with martensite tempering on the surface and perlite-ferrite core is formed [1-5]. With the rectangular cross-section of rolled steel the unevenness of the distribution of structural components must appear not only to the center of the section but also along its perimeter because its quite clear that the flank cooling goes quicker than that of the central part. For identifying the character of a temperature change in cross-section of the strip rolled steel a cooling kinetics for rolled steel of rectangular cross-section has been calculated.

RESULTS AND DISCUSSION

The amount of heat, the metal emissions into the environment, is defined by the equation:

$$dQ = \alpha \cdot F \cdot \Delta t \cdot d\tau$$

where:

α - heat irradiation ratio,
Δt - temperature gradient, i.e. exceeding of the surface temperature above cooling medium temperature,
F - the area of the surface of the body,
τ - time.

We can see from the equation above that under other equal conditions the cooling intensity is defined by heat irradiation ratio α.

It is not physical constant, typical for particular substance and depends on a large number of factors such as geometrical form and rises from the body, physical conditions of washing medium, its direction, velocity and temperature. Since its heat irradiation ratio changes along the length of cooling chamber and is defined by the character of the liquid motion, its temperature, velocity and pressure in the chamber as well, different values of α have been set: from 5 000 to 20 000 $Wm^{-2}K^{-1}$, taking it as average, which corresponds to real cooling velocities of the strip rolled steel in continuous water flow in the closed chamber.

Temperature distribution along the cross-section of the strip and its change with the time have been obtained from the heat conductivity equation:

$$\frac{\partial t}{\partial \tau} = \alpha\left(\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2}\right)$$

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with the starting conditions t_0 = 1100 °C with $\tau = 0$ and boundary conditions $\frac{\partial t}{\partial x} = -\frac{1}{\lambda/\alpha}$.

The research was conducted with the strip rolled low-carbon steel, cros-section 45x6 mm (0.29 - 0.30 % C; 0.69 - 0.74 % Mn; 0.09 - 0.15 % Si) and 30x8 mm (0.27 % C;

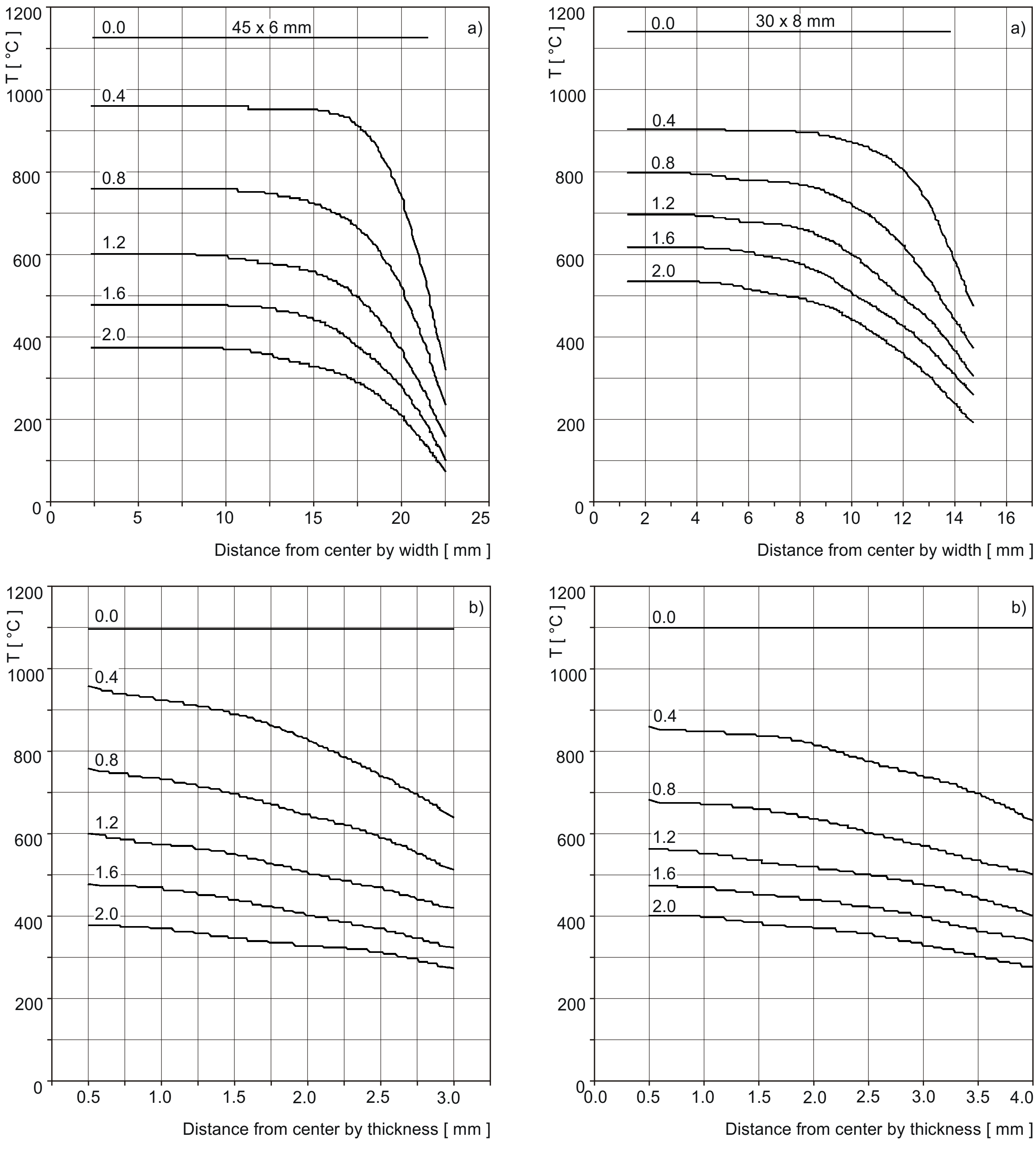

Figure 1. **Temperature distribution along the width (a) and thickness (b) of stripe rolled steel (cross-section 45x6 and 30x8 mm) under accelerated cooling (α = 10 kWm^{-2}K^{-1}); figures near the curves - time since the beginning of the transformation, s; a - distance from the center considering the width; b - distance from the center considering the thickness**

Slika 1. **Razdioba temperature po širini (a) i debljini (b) valjane čelične trake (presjek 45x6 i 30x8 mm) pri ubrzanom hlađenju (α= 10 kWm^{-2}K^{-1}); obilježja uz krivulje - vrijeme od početka transformacije, s; a - razmak od centra gledano po širini; b - razmak od centra gledano po debljini**

0.73 % Mn; 0.27 % Si). The stripe were cooled in the continuous water flow in the wire-type chambers after rolling in the rolling-mill.

From the curves of temperature distribution and their change with time in points, which are located on the axes of cross-section of the strips, (cross-section 45x6 and 30x8 mm) on Figure1., it can be seen that the flanks of strips with the width of about 3 - 5 mm are cooled much quicker than the central parts, but the most intensively it takes place only in the first moment.

The same picture can be seen also along the thickness of the strip. With the maximum possible on the rollong-mill length of track of active cooling, time of cooling process mustn't exceed 1.5 - 1.6 s. During this time the surface layers of the strips with cross-section 30x8 and 45x6 mm under all set values of α are cooled down to the temperature below the temperature of the start of martensite transformations and the central parts - down to ~ 650 - 450 °C.

After leaving the cooling plant the rolled steel keeps on cooling in fresh air; heat irradiation ratio drops very quickly.

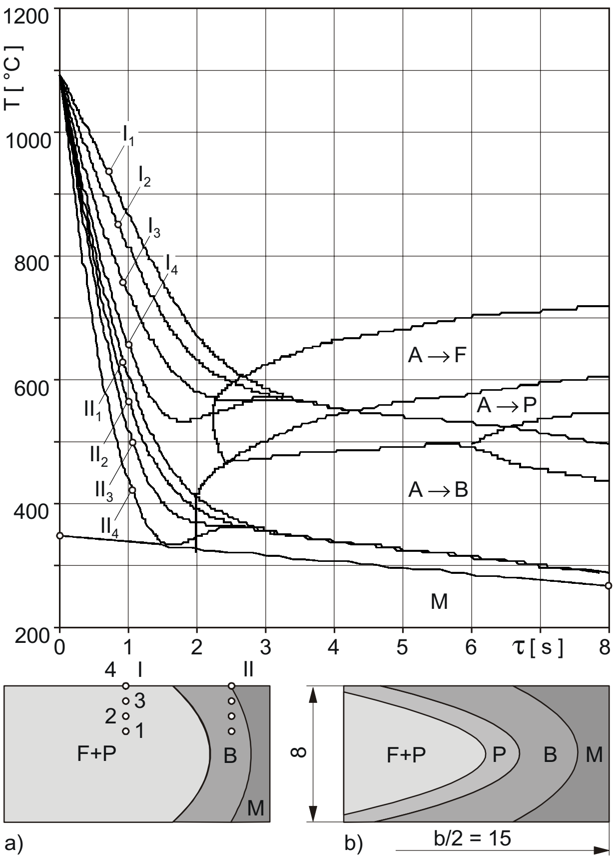

Figure 2. **The scheme of strip rolled steel structure forming with the cross-section 30x8 mm with different cooling inten-sities (according to the results of the calculation): a) - heat irradiations ratio (α = 7 kWm^{-2}K^{-1}); b) - α = 10 kWm^{-2}K^{-1}**

Slika 2. **Shema valjane čelične trake - presjek 30x8 mm s različitim intenzitetom hlađenja (prema rezultatima proračuna): a) - omjer isijavanja topline (α = 7 kWm^{-2}K^{-1}); b) - α = 10 kWm^{-2}K^{-1}**

Thanks to the high temperature of the central parts and low temperature of the surface, the heat from the core spreads to surface layers very quickly and heats them. With the same duration of the process, the more intensive water cooling, the lower heating temperature of the surface, and this, in its turn, is defined by the heat irradiation ratio.

In order to show the influence of the cooling intensity on structure-forming, the curves describe the cooling velocity under a different diagram of low-carbon steel. It gave a chance of defining a temperature interval of phase transformations in the points of cross-sections of strips starting from axis of symmetry and going to the edges with the step of 1.5 mm. Central parts of the strip are cooled evently: at the velocity of ~ 250 K/s. On the surface and the areas, adjoining to flanks, the cooling velocity is very high in the first moment (~ 1 200 K/s), but it goes down gradually and by the end of the cooling it is ~ 50 K/s.

Analysis of distribution of the structural components along the cross-section of the strip with cross-section 30x8 mm, found out that with the heat irradiation ratio of 7 kW m^{-2}K^{-1}, the strengthening phases martensite and bainite can be obtained only in the thin layer next to the surface with width of 3.0 - 3.5 mm in the flanks (Figure 2.a), which is not enough for the considerable strengthening of the rolled steel.

The required strengthening effect can be achieved only with increasing the time of cooling up to 2 s, which is possible under decreasing the velocity of roling down to 5 m/s. Under the lower cooling intensity (α = 5 kWm^{-2}K^{-1}) the perlite-ferrite structure is formed around the entire section, i.e. the hot-rolled condition remains.

With the increasing of cooling intensity up to α = 10 kWm^{-2}K^{-1}, the share of high-durable phase in the structure of the cooled metal is going up. In the surfase layers with a width of about 1 mm along the entire perimeter there is a probable formation of bainite and martensite. The width of the flanks with the structures of martensite and beinite can reach ~ 5 mm. A higher level of durability characteristics of rolled steel must correspond to such a distribution of structural components.

The stripe with cross-section 45x6 mm can be strengthened under α = 7 kWm^{-2}K^{-1} and τ = 1.6 s (Figure 3.). Combination of martensite and bainite in surface layers and perlite-ferrite core has to provide high durability and sufficient flexibility.

A more intensive cooling (α = 10 k Wm^{-2}K^{-1}) for 1.6 s can lead to the obtaining of martensite in the surface layers and bainite in the central part of the cross-section. This kind of structure is undesirable because of bad flexibility of its components.

The required combination of structural components under α =10 kWm^{-2}K^{-1} can be obtained by decreasing the time of cooling to 1.2 - 1.3 s. With the more intensive cooling (α = 20 kWm^{-2}K^{-1}) in the strips of both sizes a martensite-bainite structure is formed (the bainite area in

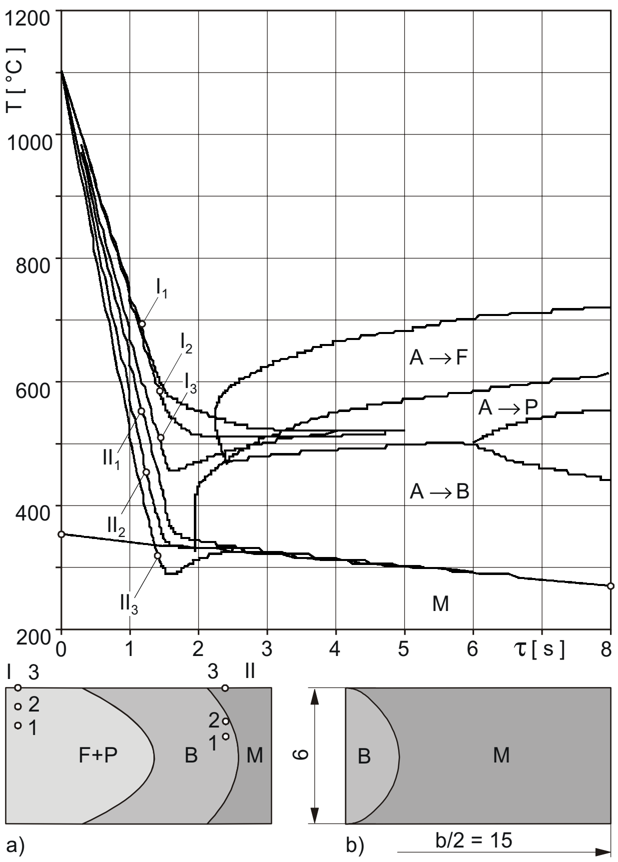

Figure 3. **The scheme of strip rolled steel structure forming with the cross-section 45x6 mm with different cooling inten-sities (according to the results of the calculation): a) - heat irradiations ratio (α= 7 kWm^{-2}K^{-1}); b) - α= 10 kWm^{-2}K^{-1}**

Slika 3. **Shema čelične valjane trake presjeka 45x6 mm s različi-tim inzenzitetom hlađenja (prema rezultatima proraču-na): a) - omjer isijavanja topline (α= 7 kWm^{-2}K^{-1}); b) - α= 10 kWm^{-2}K^{-1}**

it occupies only ~ 25 % of the total area of the cross-section of the strip).

Thus, it has been found out, that the more the ratio of the strip width to its thickness, the more degree the unevennes of the distribution of the strengthening phases is expressed and consequently the mechanical properties along the width of the strip. The required structural condition of stripe rolled steel can be achieved under α = 7 - 10 kWm^{-2}K^{-1}.

CONCLUSIONS

1. The strengthening layer is spread unevenly along the perimeter of the rolled steel. The formation character of the structure and its spreading along the cross-section depends on intensity of cooling and the ratio of the width of the strip to its thickness.
2. The study of the structure and its comparison with the calculated one with different values of heat abstraction coefficient α has shown that under contraflow cooling of the strip in the designed device the heat irradiation ratio reaches ~ 10 kWm^{-2}K^{-1} on average.
3. Under the conditions of mainly uniflow cooling the intensity goes down. The heat irradiation ratio makes 5 - 7 kWm^{-2}K^{-1}.

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